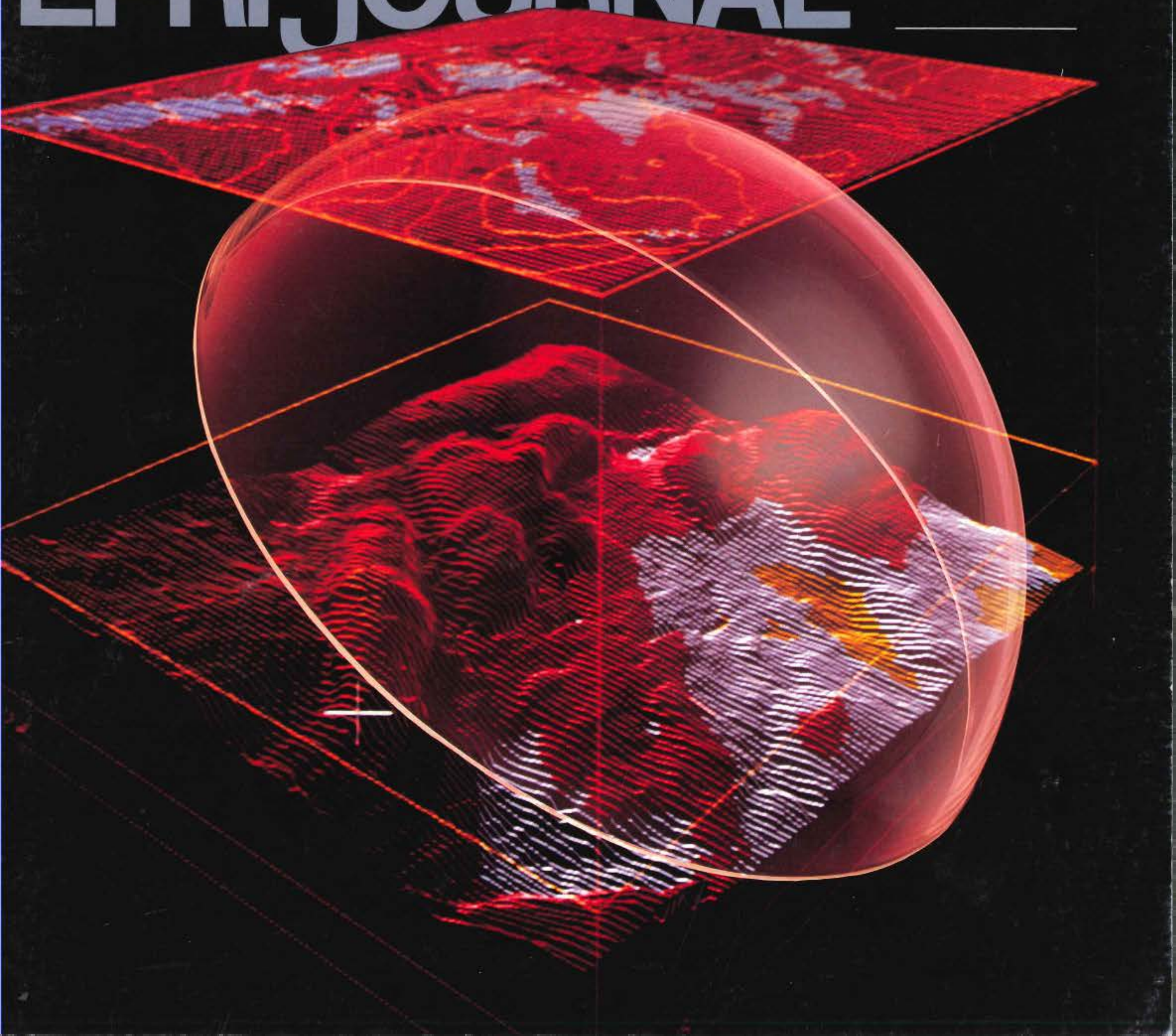
The Promise of Supercomputing

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

OCTOBER/NOVEMBER
1988



EPRI JOURNAL is published eight times each year (January/February, March, April/May, June, July/August, September, October/November, and December) by the Electric Power Research Institute.

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

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Graphics Consultant: Frank A. Rodriquez

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

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Cover: The incredible number-crunching capabilities of supercomputers have allowed scientists to mathematically model complex systems and processes that eluded them in earlier decades. Researchers hope that new supercomputing concepts will open possibilities for real-time control of the nation's highly interconnected power networks. (Photo: Topographical seismic modeling, courtesy Floating Point Systems.)

EDITORIAL

The Supercomputer Challenge

The emergence of a new generation of supercomputers is challenging some long-held beliefs in the electric power industry concerning the suitability of meeting utility needs with large number-crunching machines. Over the last decade, most attempts to use supercomputers for such numerically intense problems as modeling regional power systems have been neither satisfactory nor economically viable. As described in this month's cover story, there exists a mismatch between the design of traditional supercomputers and the requirements of utility analysis.

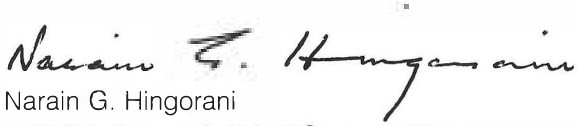
Now, a variety of new supercomputers are coming to market, offering wider choices in design and price. Of particular interest to utilities are relatively inexpensive array processors that can be attached to conventional computers, enabling them to act like supercomputers for particular kinds of massive numerical calculations. Another promising development is the use of many small concurrent processors, which employ what might be called the piranha approach to supercomputing—breaking a problem down into numerous parts that can be simultaneously attacked.

Even more startling developments in mathematical techniques lie just around the corner. Expert systems, for example, may help utilities model the problem-solving techniques of their foremost experts, while neural networks learn from experience to recognize disturbance patterns in power systems and take remedial action before they lead to catastrophic failure.

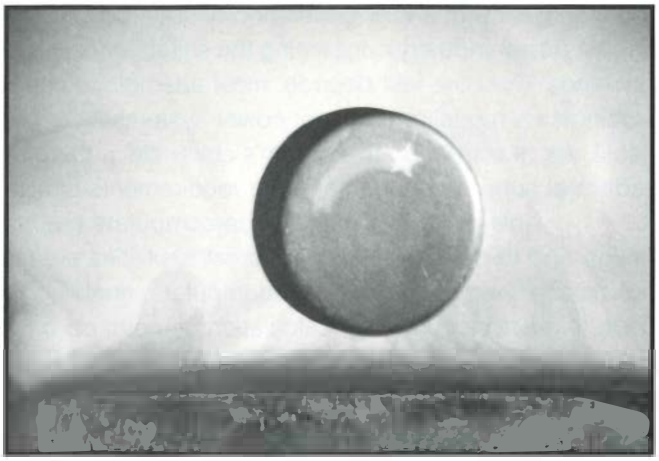
The computational complexity of controlling power systems is increasing rapidly as utility networks become more interconnected and as the wheeling of power becomes more commonplace. The need for on-line analysis of voltage and transient stabilities of future power systems has been evident for some time, but only with the advent of affordable new computer technologies can such analysis be considered feasible.

Much has already been learned about adapting system analysis codes for use on computers with innovative designs. EPRI, working through Wisconsin Electric Power Company and ESCA, Inc., has already made available for control centers the steady-state security monitoring and assessment of both thermal and voltage conditions in complex power systems. In addition, evolution of processor technology has made it possible to have real-time digital control and protection.

The formidable challenge for the next decade is to build on this framework of knowledge and new computer technologies by developing the necessary software and defining the hardware needs for control centers in order to provide on-line analysis and control of dynamic conditions for increasingly complex power systems.



Narain G. Hingorani
Vice President, Electrical Systems Division



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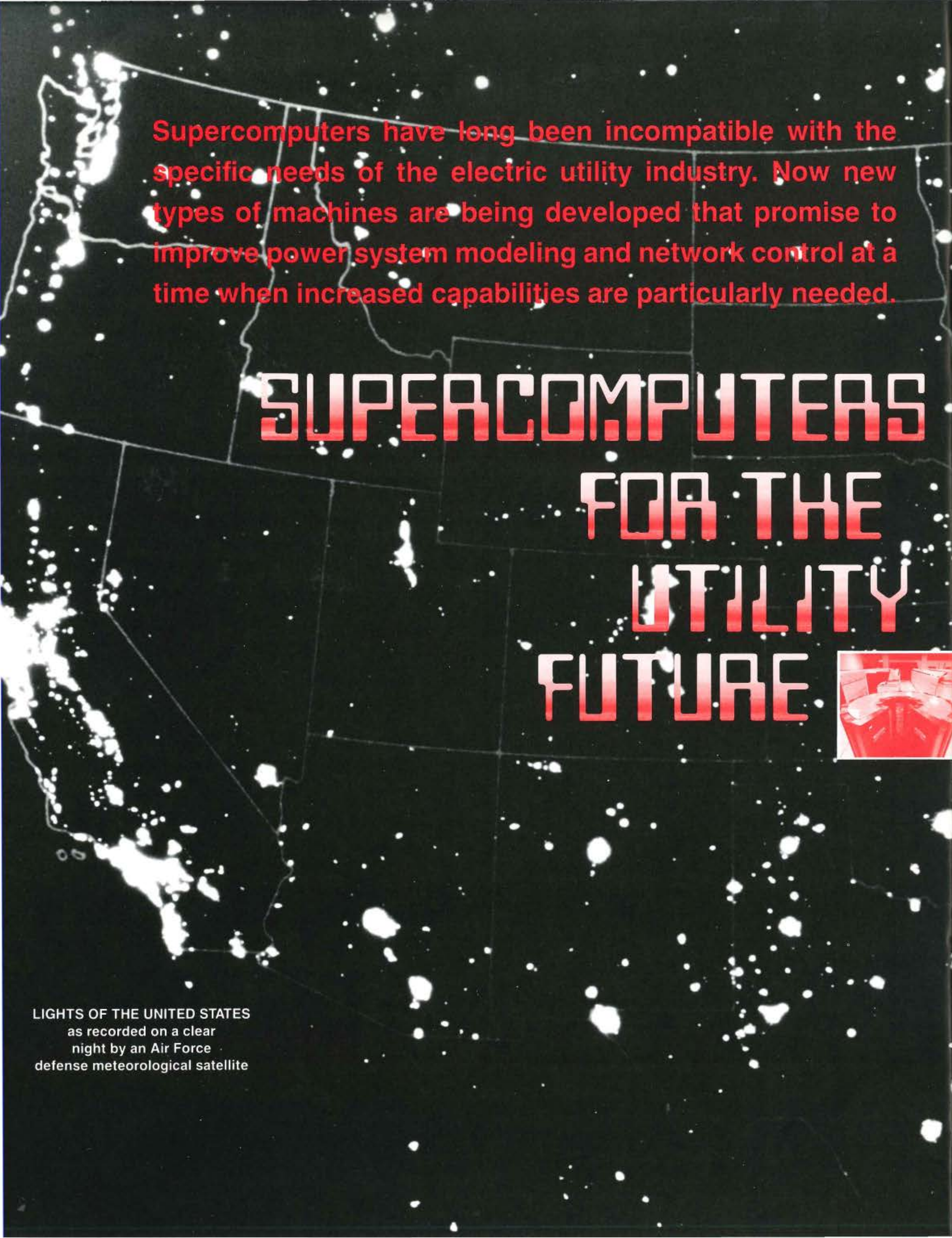


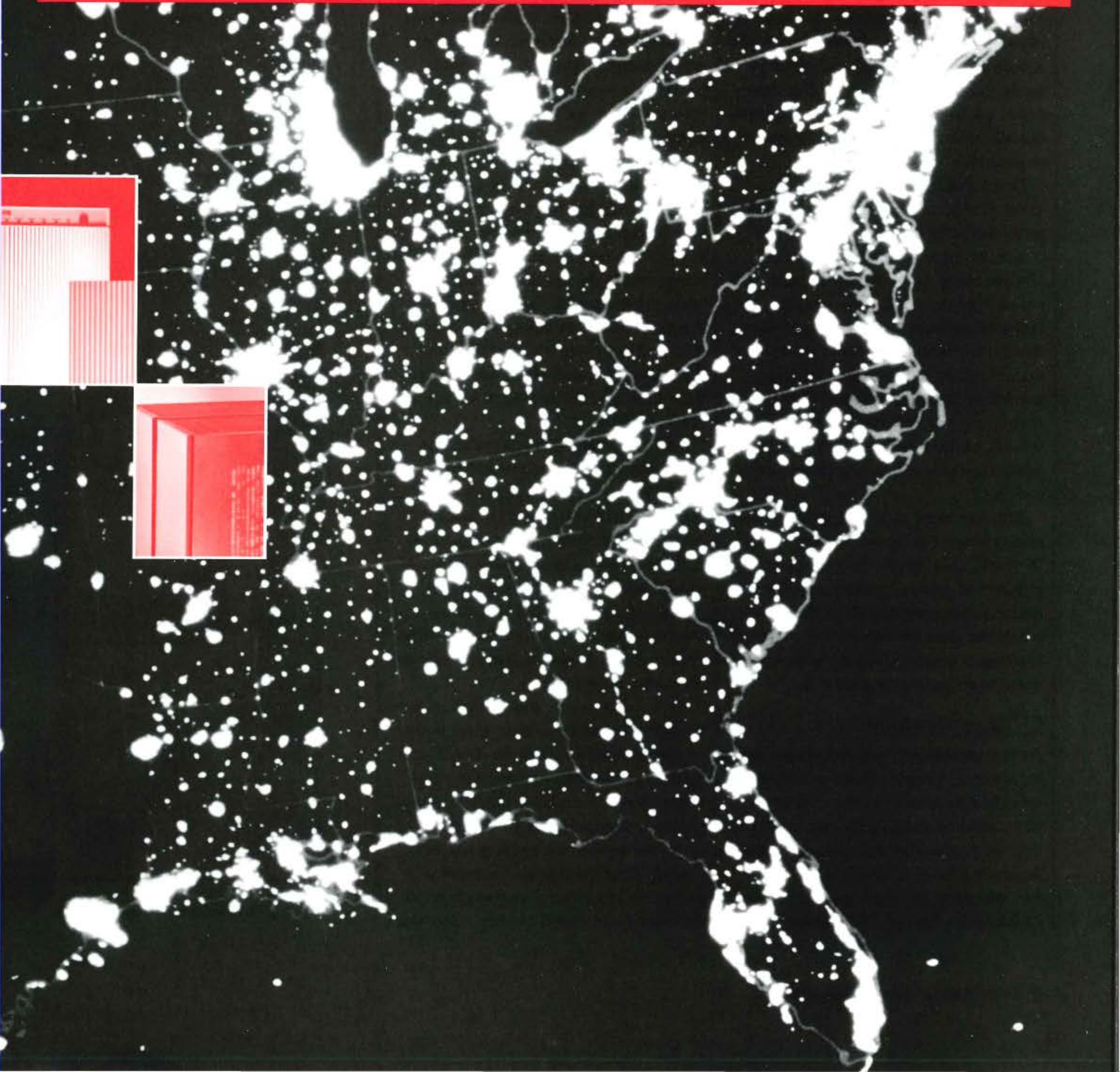
Supercomputers have long been incompatible with the specific needs of the electric utility industry. Now new types of machines are being developed that promise to improve power system modeling and network control at a time when increased capabilities are particularly needed.

SUPERCOMPUTERS FOR THE UTILITY FUTURE

LIGHTS OF THE UNITED STATES as recorded on a clear night by an Air Force defense meteorological satellite

Supercomputers—the ultrafast "number-crunching" machines used to make massive arithmetic calculations—are creating a revolution in many areas of science and engineering. Until recently most supercomputers belonged to government agencies, where their unique abilities were needed for such specialized applications as breaking secret codes and modeling nuclear explosions. Now, however, with the cost of supercomputers declining rapidly and national supercomputer networks providing wider access, these formerly esoteric instruments are being used to create special effects for movies, design new aircraft engines, predict the effects of cancer drugs, and reveal details about the early universe.

Utilities have indirectly benefited from supercomputers since the machines first achieved a distinct identity, during the mid-1960s. The development of nuclear power plants, in particular, was facilitated by the use of early supercomputers in government laboratories that designed military reactors. Similarly, utilities are today purchasing sophisticated equipment, such as advanced turbines, designed by vendors' supercomputers. Some EPRI research has also been performed with supercomputers—for example, tests of ways to calculate relay settings in a power system after the outage of particular circuits. Even the improved weather forecasts that are made possible by supercomputer modeling of the earth's



atmosphere are helping utilities provide more reliable electricity service to their customers.

Still, the direct use of supercomputers by utilities has remained limited, even though the electric power industry ranks as a major purchaser of most other kinds of computers. Part of the explanation is that most utility business operations, such as sorting through meter readings and issuing bills for service, are not arithmetically complex and can be handled adequately by conventional computers. In addition, the basic design of most early supercomputers made them inefficient at solving those utility problems that are most computationally intense, such as power system modeling.

This situation may soon change dramatically, as two trends in the computer industry begin to make supercomputing much more attractive for electric utility applications. First, a variety of fundamentally new concepts are being introduced into supercomputer design, including some that are immediately applicable to power system modeling. Second, new software techniques are providing approaches to solving utility problems that take better advantage of the new supercomputer designs.

EPRI has been monitoring and influencing these two trends for more than 10 years. As a result, the electric utility industry is gaining greater ability to utilize supercomputers just at a time when the growing complexity of power systems is outstripping the computational tools currently available.

Utility applications

As transmission networks become more highly interconnected and as massive wheeling of power becomes more common, utilities need faster and more precise ways to model system operations. According to an EPRI study, for example, wheeling transactions increased 12-fold from 1961 to 1983. So far, however, supercomputers have not provided utilities with sufficient computational power to analyze highly interconnected power systems in real time (i.e., on-line, as events occur).

At present, only an analysis of the thermal limitations on power systems is routinely conducted in real time at regional control centers. As power system operations become more complex, regional control centers also need to do on-line analyses of voltage conditions and system stability. Such calculations are so complex, however, that today's utility computers may take minutes to simulate events that can occur in seconds—thus precluding real-time analysis.

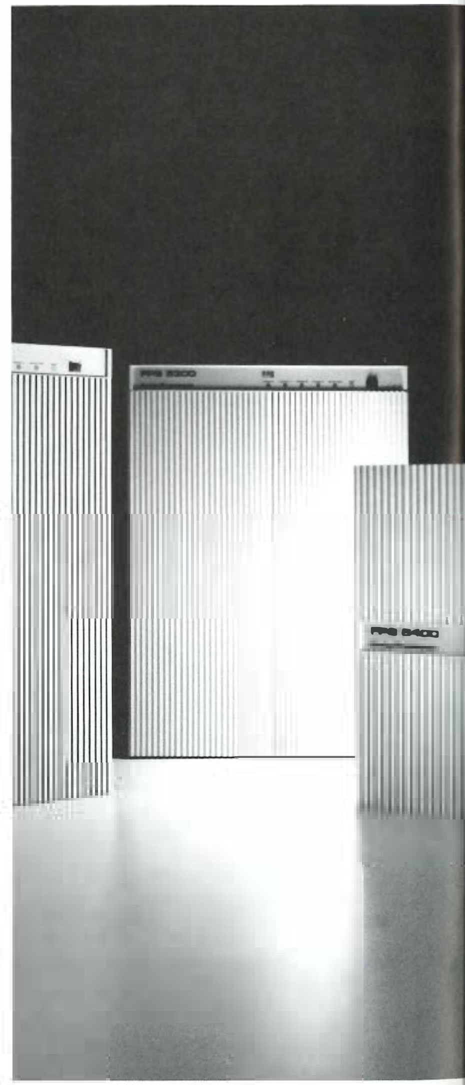
"Maintaining proper voltage conditions and transient stability has become a serious concern for many utilities," says Robert Iveson, technical adviser in EPRI's Electrical Systems Division. "Not being able to do the calculations on these parameters in real time introduces unnecessary conservatism in design and increases margins of safety. For today's requirements, we need to have both calculations done on-line at control centers."

EPRI began exploring ways to improve the use of supercomputers to model power system operations at a workshop held in 1977. The general consensus of opinion to emerge from the meeting was that conventional serial computers—which can solve a problem only one step at a time—would remain inadequate for real-time system control, even if their speed was increased manyfold.

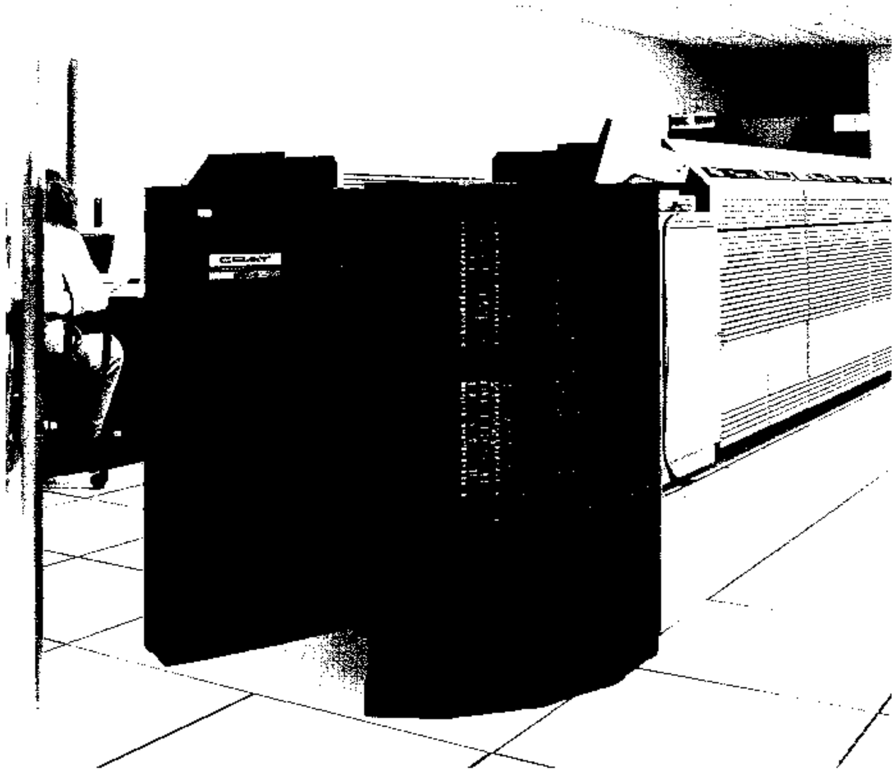
As an alternative, the workshop attendees identified various ways power system equations could be solved on parallel processors—supercomputers that can attack multiple parts of a huge problem simultaneously. "Progress in power system computing has been unduly slow because of limitations of computer hardware," one engineer at the workshop stated bluntly. "The one

A Multiplicity of Machines

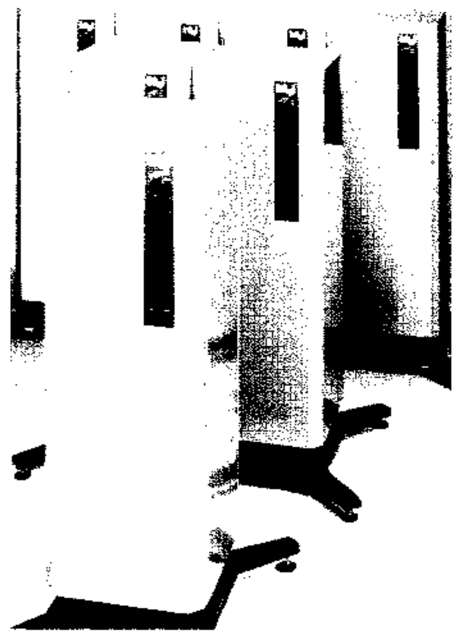
Once a rare and monolithic tool for only the highest-priority projects, the supercomputer has now evolved into a whole family of powerful but less expensive machines created in a variety of shapes and sizes. The addition of parallel processing options to the standard serial computer architecture has opened up the world of applications and drawn in many new manufacturers, who are now competing feverishly for pieces of a growing global market.



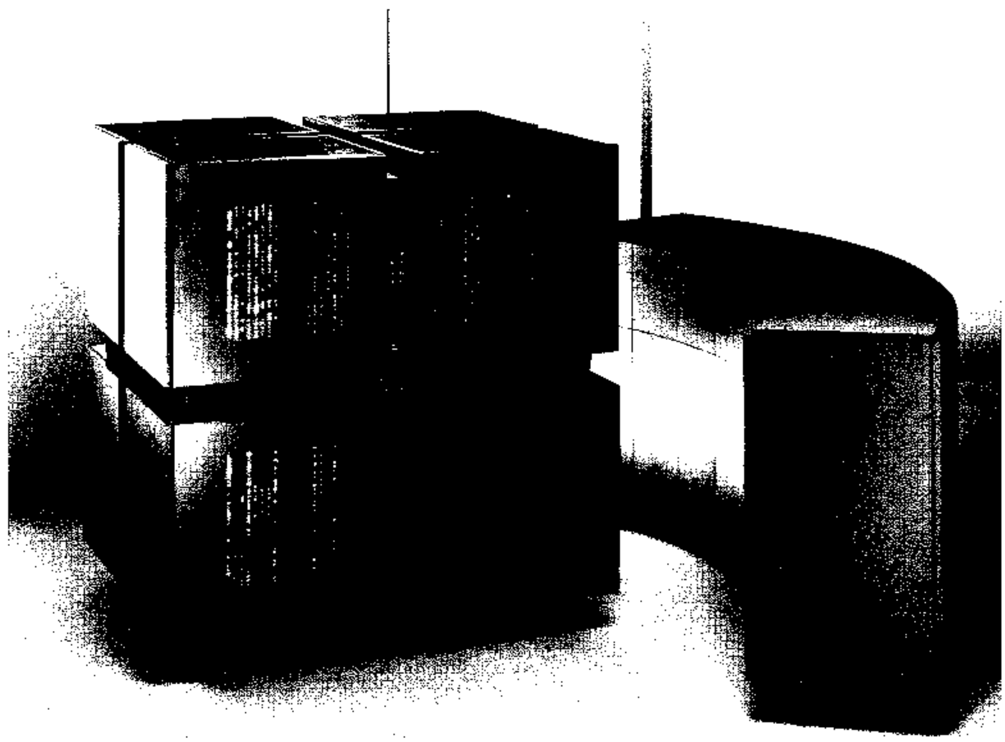
Floating Point Systems array processors



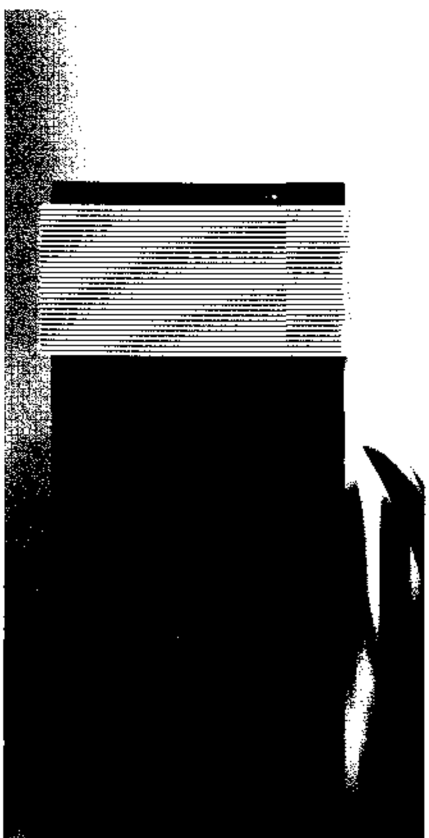
Cray-2 supercomputer



Intel iPSC/2 personal supercomputer



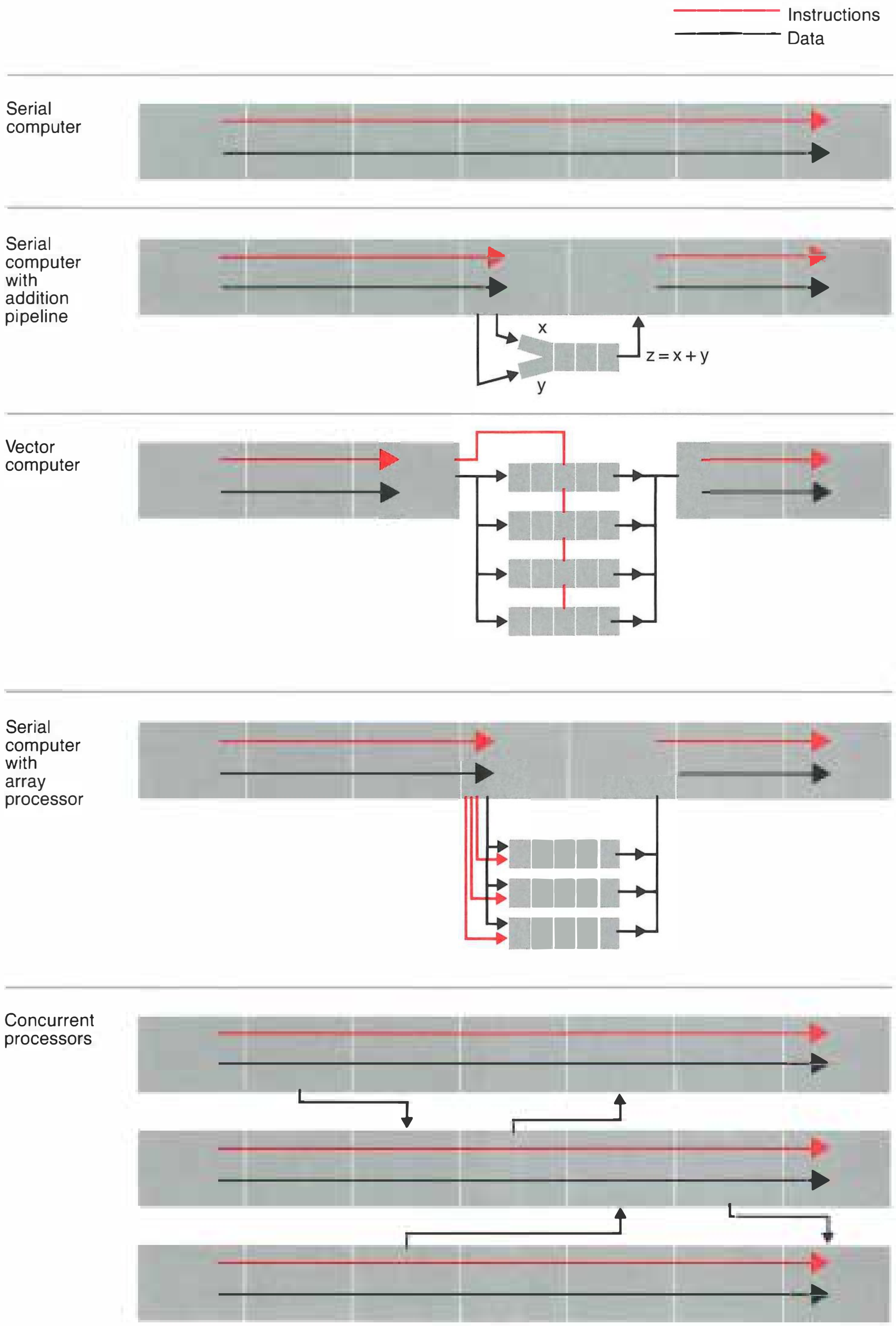
Thinking Machines Corp. Connection Machine



Ardent personal supercomputer

Innovative Concepts in Supercomputing

Traditionally, supercomputers have been designed to perform individual arithmetic operations on data one step at a time. Such serial computers are now being replaced by machines that can attack several parts of a large problem simultaneously—an approach called parallel processing. The simplest example is the addition to the serial computer of "arithmetic pipelines," which shunt a continuous stream of data to a separate track for quick performance of a particular operation. Another approach, vector computing, breaks a data stream into smaller groups and performs one function on all the streams simultaneously. An array processor attached to a serial computer can also operate on multiple data streams, but can accommodate separate instructions for each stream. Concurrent processors are even more independent, dividing up the problem efficiently for speed of solution and sharing data when needed.



bright prospect in an otherwise gloomy outlook is parallel processing."

A matter of mismatch

Responding to the challenge issued by the workshop participants, EPRI sponsored a series of research projects to see how well various new kinds of supercomputers, each with its own special parallel-processing architecture, could be used to solve power system equations. One of the early conclusions to emerge from this research was that the most popular type of supercomputer design is not compatible with the special needs of power system modelers. There was also concern about reliability and cost-effectiveness.

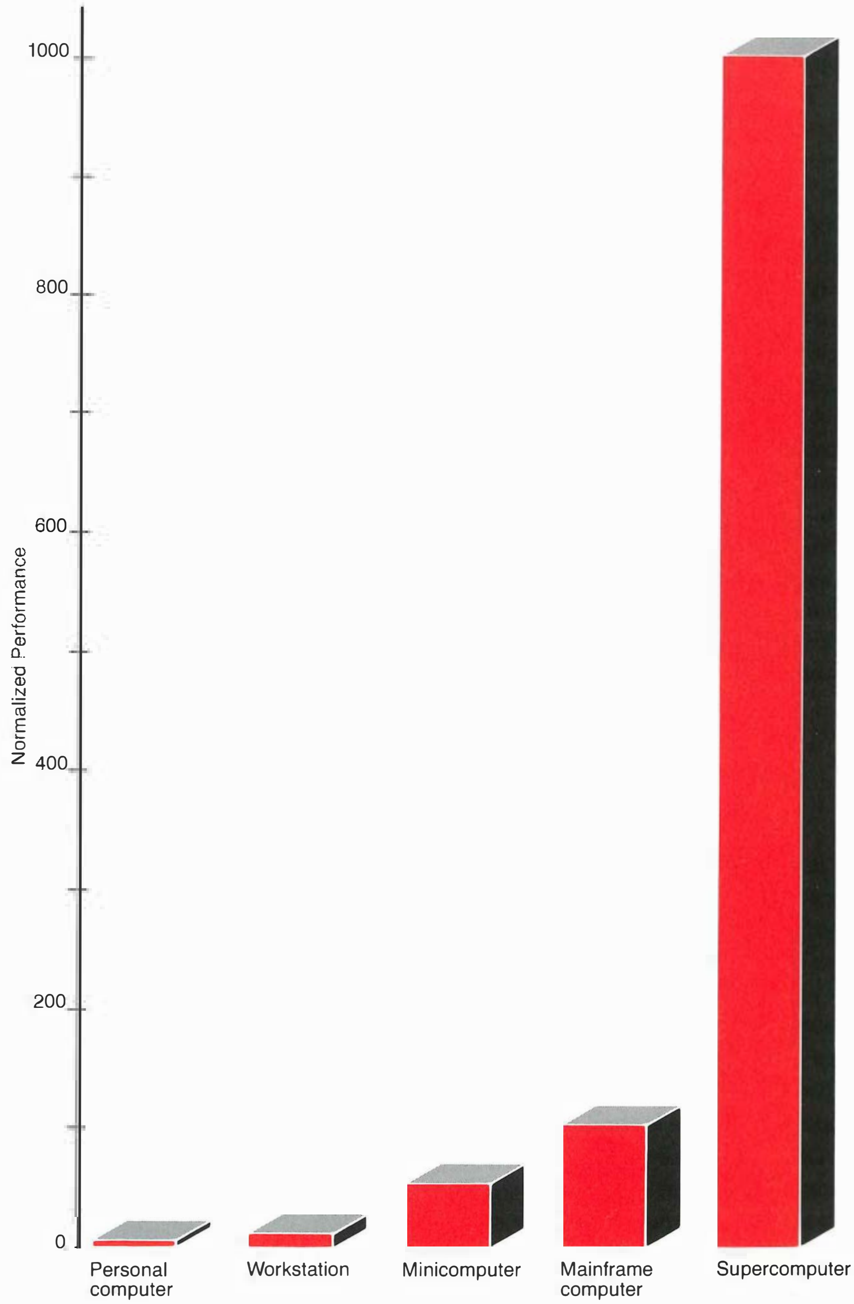
Consider the problem of calculating power flows in a 1000-bus utility network—about the size of the combined Ontario–New England–New York system. From a computer's point of view, the most computationally intense part of solving this problem involves multiplying elements of a 1000-number array by elements of a million-number array and summing the products. The 1000-number array represents initial voltages at the buses, but since these are only a first approximation, 5 to 10 rounds of iterative calculations must be performed to reach an acceptably accurate, or "converged," solution. One specific goal of EPRI's research has been to find a computer that can converge on an acceptable base-case solution within half a second. Then the whole iterative procedure may have to be repeated for each of 300 or so contingencies, one at a time, such as loss of generators, faulted lines, or open circuit breakers.

The scientific world abounds with problems involving this sort of repetitious multiplication and addition of huge quantities of numbers. Most of today's supercomputers were designed to speed up such calculations through two relatively simple means of parallel processing.

The first, called *pipelining,* breaks up

How Computers Stack Up

Relative capabilities of different types of computers are difficult to capture in one discrete unit, but general comparisons of overall performance can be made by normalization to an arbitrary base—in this case a value of 1 for the capabilities of a standard personal computer. Supercomputers clearly overshadow other machines presently in broad use, including large mainframes. However, recent introduction of small, "personal" supercomputers and specialized add-ons such as array processors are quickly narrowing the gap, offering much improved capability at a relatively modest cost.

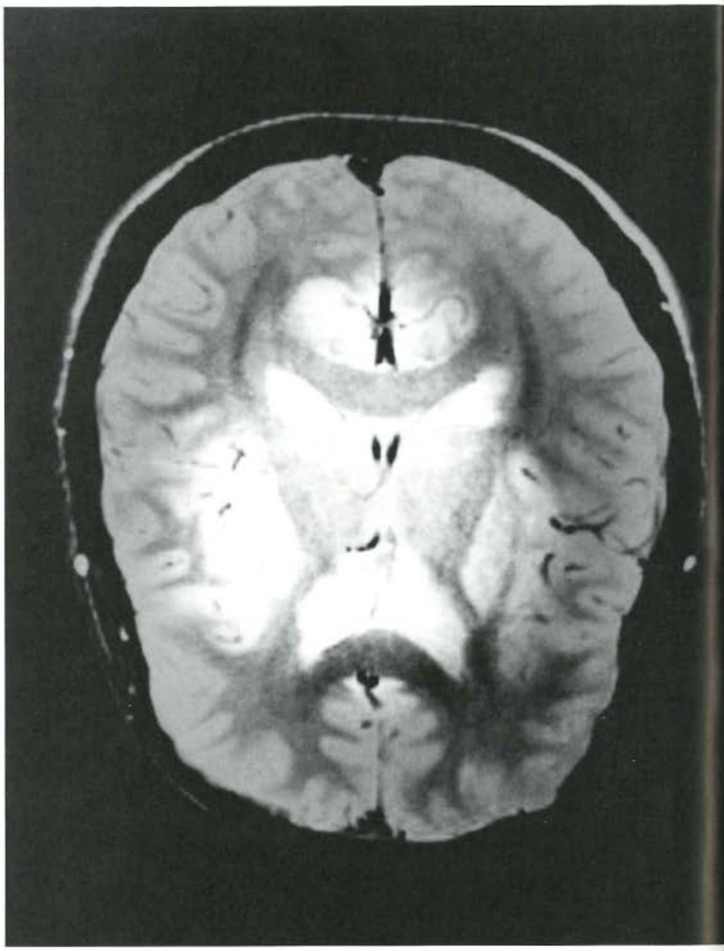


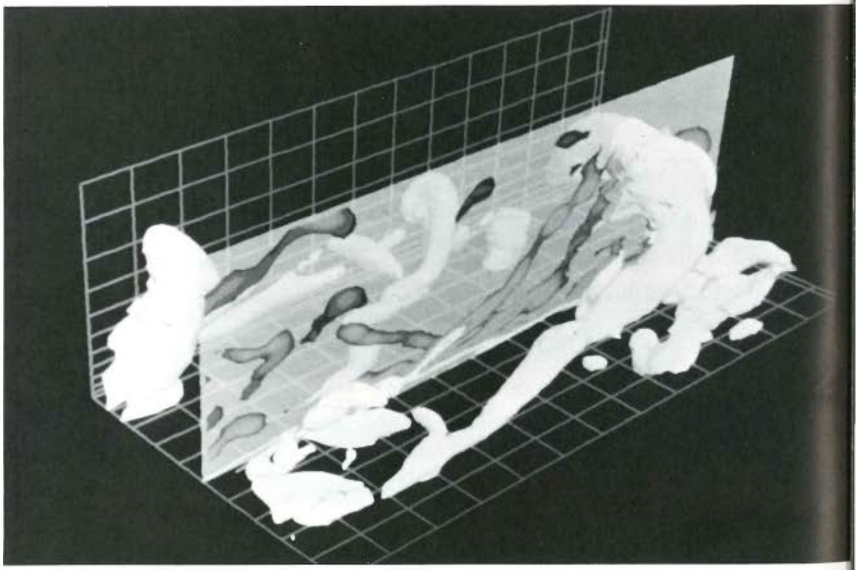
each arithmetic operation into sequential steps that can be handled by different circuits of the computer. Pairs of numbers to be added, for example, are pushed rapidly into these circuits like a stream of water being poured into a pipe. Although the total amount of time required to add any pair is not affected, the time to add numerous pairs is decreased because all the little steps involved in the addition processes occur continuously, and many pairs of numbers are being handled at once.

The second design feature that provides parallelism to most of today's supercomputers is called *vector processing*. In this scheme multiple pipelines are used to perform arithmetic operations on different pieces of data simultaneously. All the pipelines operate in lockstep fashion, in response to a single series of instructions. Closely related data must be grouped into arrays (vectors) that can be fed continuously and synchronously into the pipelines, thus keeping all the units working at full speed. Supercomputers with vector processing have proved particularly useful in solving problems based on fluid flow equations, such as the air flow over an airplane wing and weather system modeling.

Neither pipelining nor vector processing, however, works very efficiently in solving utility power system problems. The reason is that many of the arithmetic calculations involve multiplying by zero, which forces the computer to waste time on numerous trivial steps in a problem. In the power flow example just discussed, the million-element array of numbers may have only a few thousand nonzero elements, corresponding to the limited number of paths (transmission lines) over which current can actually flow from one bus to another. In one large power system analysis performed on a CRAY-1 (vector-type) supercomputer, only about 1.5%

Medical imaging *(Floating Point Systems)*





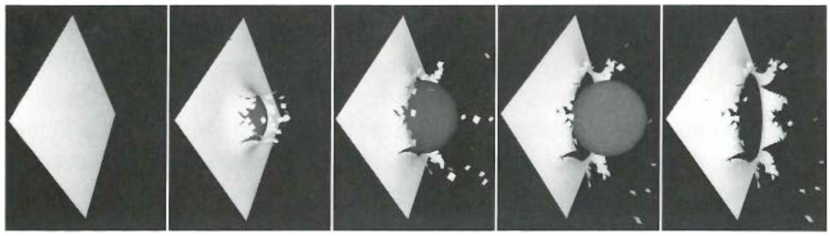
Turbulent-flow analysis *(NASA/Ames, Stanford University)*

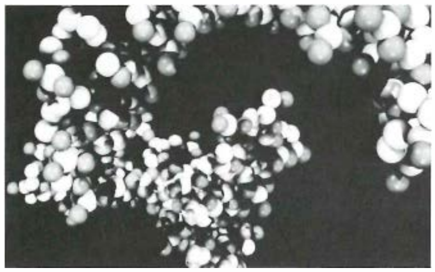
A World of Applications

In addition to finding an increasing number of uses in the electric power industry, supercomputers are opening up advanced capabilities in a wide variety of other fields. Typically they prove most useful where repetitive, massive calculations are needed, as in aerodynamic modeling, interactive training simulation, and 3-D graphics.

Aircraft simulator training *(Floating Point Systems)*

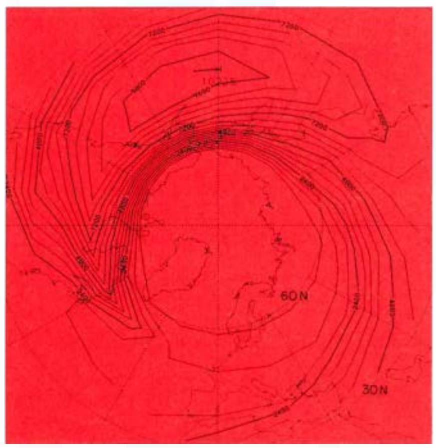
Structural dynamics *(David J. Benson, John Hallquist)*



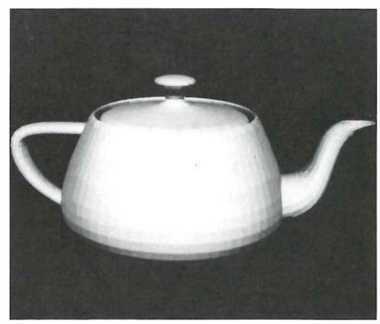


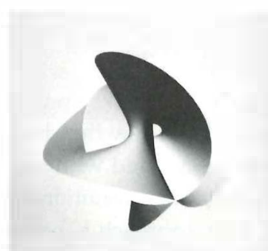
Three-dimensional modeling *(Ardent Computer Corp.)*

Atmospheric modeling *(NCAR, Rolando Garcia)*

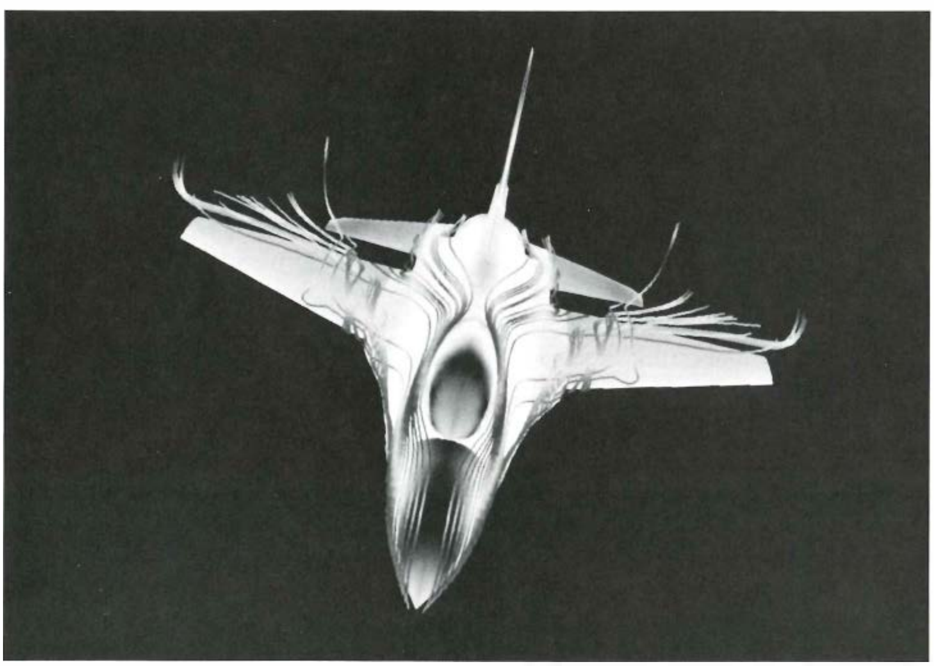


Product design *(Ardent Computer Corp.)*





Mathematical visualization *(Ardent Computer Corp.)*



Aerodynamic flow simulation *(NASA/Ames)* of the computer's ultimate power was actually utilized!

"EPRI research has shown convincingly that vector processing does little to speed up the solution of that type of computationally intense utility problem," says Iveson. "Therefore, utilities still routinely use the largest and fastest serial computers available. Our research has shown, however, that two new types of supercomputers—array processors and concurrent processors—offer much greater advantages for solving power system problems."

Array processors

Strictly speaking, an array processor is a number-crunching add-on that enables an existing serial computer to act like a supercomputer for certain types of parallel calculations. Developed for signal processing (radar signal discrimination and picture enhancement), early array processors were unsuitable for utility use because they could not accommodate enough digits (32 bits) for the precision needed in power system calculations. By the early 1980s, however, array processors with greater precision had become commercially available, and an EPRI study, performed by Cornell University and published in 1982, concluded that they appeared to offer a cost-effective way to achieve the goal of solving a 1000-bus power flow problem in half a second.

The great advantage of array processors is their price—a few hundred thousand dollars, compared with several million dollars for traditional supercomputers. This approach is particularly cost-effective if the buyer already has a mainframe or minicomputer to which the array processor can be attached, although the entire capital cost of a small serial machine and an array processor would still be several times less than that of a supercomputer. Such a front-end serial computer handles the input and output of data, performs the step-by-step parts of a calculation, and then passes off the parallel portions to the array processor. Unlike the components of vector processors, each of the arithmetic units of an array processor acts independently, in response to multiple instructions from the front-end computer.

Providing such instructions to make the most efficient use of an array processor presents an enormous challenge to programmers. A typical power system program contains over 60,000 lines of computer code. Rewriting such a program to separate those portions that should be handed off to an array processor can require the better part of a year for a skilled programmer, if done manually. Fortunately, new compilers (software that translates a program into specific instructions for a computer) have been developed that can automatically determine which parts of a calculation can be treated in parallel.

To explore the potential of array processors for power system modeling, EPRI sponsored the manual reprogramming of a Bonneville Power Administration power flow code. The code was then used in tests with different hardware configurations. One configuration, in which an FPS-264 array processor from Floating Point Systems was attached to a VAX 11/780 super-minicomputer, solved a 1454-bus problem more than six times faster than was possible on the VAX alone. The final report for this project (EL-4642), published in 1986, concluded that the FPS-264 "does appear attractive for installations where large numbers of power flow calculations are performed daily;" however, it cautioned that "utility personnel would have to become familiar with two operating systems—one for the host computer and one for the attached array processor."

One of the first actual utility applications of array processors came in 1984 in a dispatcher training simulator at the world's largest private electric utility, located in Japan. In this system, an array processor calculates system power flow every three seconds to represent real-time changes caused by system faults, switching operations, and demand-supply regulation. The Japanese utility reports that use of the array processor with a minicomputer has increased calculation speed 10-fold.

More recently, a large energy management system vendor has added array processors from Floating Point Systems to its line of energy management systems for utility control centers. According to this vendor, the addition of an array processor increases computational speed by an order of magnitude at one-quarter to one-third the cost of expanding mainframe capacity. The first of these enhanced energy management systems will enter service late next year. Early utility customers include Carolina Power & Light, Potomac Electric Power, and New York State Electric & Gas (NYSEG).

"We see the use of an array processor as a logical extension of our supplier's philosophy of distributed processing," says Eric McClelland, a project manager for energy control systems at NYSEG. "It allows us to put the computer power where it's needed, when it's needed."

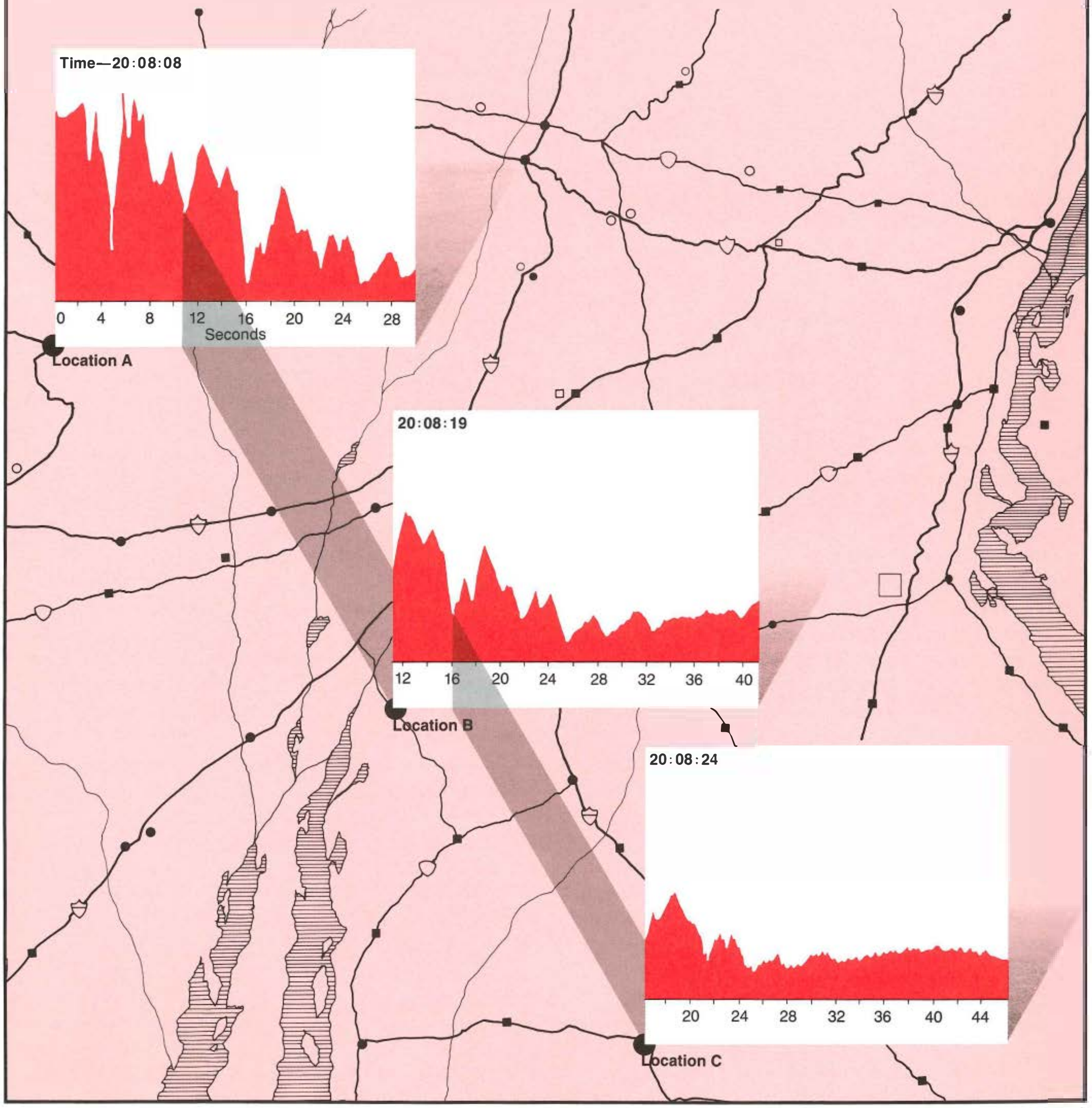
Concurrent processors

Both vector and array processors employ a small number of powerful processors whose operations are closely coordinated by instructions from a master processor. An alternative approach involves dividing up parts of a problem among a large number of less powerful processors, which may work either in close coordination or independently. With the recent development of inexpensive, high-speed, high-capacity microprocessors with 32-bit precision, it is now possible to consider solving power system problems by using dozens—and potentially thousands—of processors.

This possibility was explored in a recently completed EPRI project that used

Real-Time System Monitoring

One of the functions supercomputers may some day perform for utilities is to recognize specific patterns of frequency disturbance in a power system quickly enough to take corrective action before protective relays begin disconnecting lines. Such action might, for example, involve pulsing the system with additional capacitance. By collating data from three different points in a system, as shown here, the computers may also be able to locate the source of the disturbance as it cascades through a network.



Computers in the Control Center

Control centers act as the brain and central nervous system of utility networks—directing the flow of power, monitoring equipment functions, and maintaining stable operation. There are about 150 such control centers in the United States, managing power systems that range in size from individual municipal utilities with a few dozen megawatts peak capacity to regional power pools with more than 40,000 MW peak capacity. In each of these centers, human expert operators must work closely with computers to ensure smooth operation of the power system.

The combination of computer hardware and software that performs most of the technical functions of a control center is called the energy management system (EMS). This system collects and processes information coming to the center from tens of thousands of remote data collection points. Under the guidance of the expert operator, the EMS also sends signals to equipment throughout a power system to control its operation. By continually measuring changes in load and determining the most economic means of providing power, the EMS automatically dispatches generating units and controls the output of individual generators.

During emergencies, computers and operators in control centers must work even more closely together. Hundreds of alarm signals may be received virtually at once, and a vital function of the EMS is to prioritize them so that the human operator can deal with the most important first. Anticipating problems before they become critical is also an important function of the EMS, which repeatedly analyzes hypothetical failures and checks for resulting overloads.

In addition, the EMS performs many "housekeeping" duties, such as managing a huge data base, keeping track of sales and purchases with other power systems, and providing system simulation for operator training.

Several different kinds of computers may be used in a control center, performing separate EMS functions. Usually one or more large mainframe computers provide the raw computing power needed for such applications as power flow analysis and economic dispatch. Other, smaller computers may be dedicated to single operations such as operator interface and data management. Dedicated minicomputers that are used to generate graphic displays for operators have become particularly popular as the size and complexity of control centers require new ways of helping humans and machines work together more efficiently.

So far, supercomputers have played a relatively minor role in control centers. Although the current generation of supercomputers could, in theory, enhance the ability of an EMS to perform computationally intense functions, their basic design is not optimum for the sort of analyses often required for simulating a power system. In addition, utilities have been concerned about the reliability of supercomputers, availability of service and spare parts, maintenance problems, and the need for more intensive training of personnel. With prices of $10 million and up, supercomputers have not yet been able to compete with teams of smaller computers that have a substantially lower total cost.

"The time you need a supercomputer is when you are going to do complex calculations and massive processing, such as large matrix manipulations and screening and selection of tens of thousands of contingent events for further detailed analysis," says Neal Balu, program manager for power system planning and operation in the Electrical Systems Division. "It's a computation box that's not particularly good for user interaction—an especially important point in the control center environment. As new types of supercomputers become available at lower prices, I believe we will see them used increasingly to do real-time analysis of dynamic system conditions, which must now be done off-line. But the need for other types of computers will remain, particularly in the area of man-machine interface and up-front data collection and processing." □

an Intel personal supercomputer containing 16 microprocessors. The EPRI power system stability code SYREL was modified to run on the Intel machine in three ways, each with a different amount of coordination among the various processors. This experiment showed that the greatest speedup in calculations resulted when the microprocessors acted independently—in which case they are called concurrent processors.

Specifically, for a 140-bus reliability problem, when the 16 processors worked in close coordination, they were able to evaluate contingencies only 3.5 times faster than a single processor; when they worked independently, however, they increased the overall computation speed by a factor of 10.8. The key to the speed difference was found to be the time wasted in communicating interim results among the processors when their activity was tightly coordinated.

Another important milestone in the use of concurrent processors was reached recently at Sandia National Laboratories. Although not related directly to utility applications, this experiment has done much to dispel earlier doubts about the practical feasibility of using very large numbers of concurrent processors—a result that could have significant advantages for power system modeling. In the experiment a computer with 1024 processors was able to achieve speedups ranging from 1011-fold to 1020-fold for problems related to wave propagation, mechanics, and fluid flow. This achievement contradicts a long-standing belief in the cybernetics community that speedup factors of more than about 100 would not be possible in practice, no matter how many processors were linked in parallel.

"Concurrent processors now clearly look like the way to go in seeking a better way to solve power system problems," says Iveson. "Both our research and research conducted elsewhere have indicated that the speed of solution can rise proportionately with the number of processors you are using. As electronics prices continue to fall, I foresee a time when we could model a power system by assigning one concurrent processor to each bus in the system. Such an approach not only would give us the speed we need for on-line voltage and stability analysis but could also ease the task of reprogramming."

Thinking computers

Further in the future lies the possibility that computers would not so much solve specific utility problems as "think" about system operation—in the sense of learning from experience to recognize and control broad patterns of network behavior. Progress toward this goal is now being made in two converging fields of computer science: artificial intelligence and neural networks.

Artificial intelligence is basically a software approach to teaching computers how to learn from experience. In so-called expert systems, for example, a team of "knowledge engineers" quizzes an expert in some field and then tries to model the responses on a computer, in an attempt to solve problems the same way the expert does. Already some experimental use of expert systems has been made by utilities anxious to automate certain operation and maintenance procedures on the basis of the insights of experienced personnel. Puget Sound Power & Light, for example, is installing an on-line expert system developed for EPRI at the University of Washington to diagnose system outages, while Southern California Edison has developed an expert system to analyze problems at earthen dams.

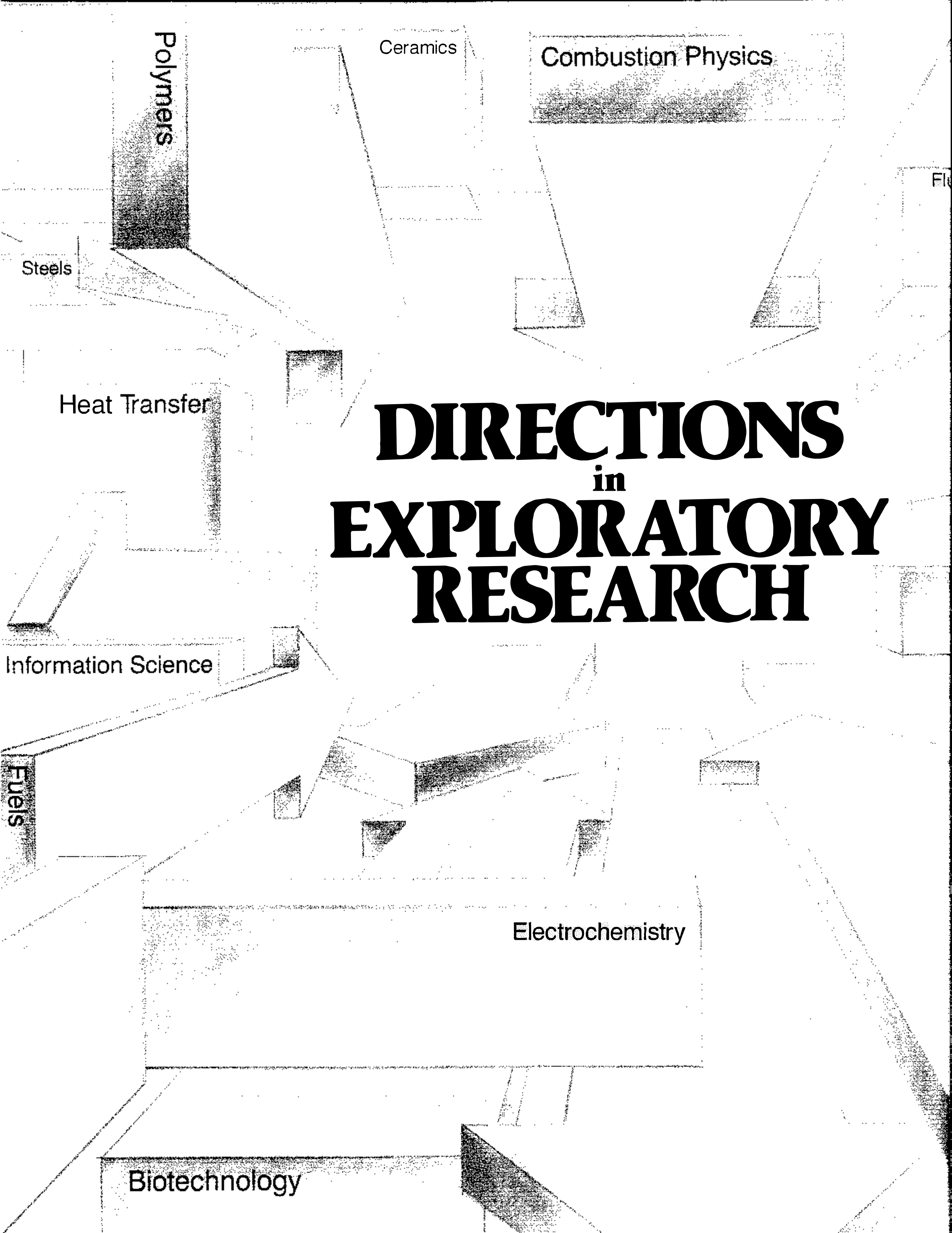
By contrast, a new kind of hardware called the neurocomputer or neural network is literally trying to mimic the way human brains process information. Unlike circuits in ordinary computers, those in a neural network can change their interconnections in response to incoming data. Repeated patterns in the data reinforce certain connections at the expense of others. Eventually the neurocomputer begins to recognize these patterns and respond to them. Although neurocomputers are still in their infancy, existing models have been taught to read aloud from printed material and to analyze the bill-paying habits of loan applicants.

"It's still too early to estimate the impact of artificial intelligence and neural networks on the utility industry, but my guess is that eventually it will be profound," states Iveson. "The possibilities for predictive analysis inherent in these techniques fall into one of the problem categories defined as a 'grand challenge' in the Office of Science and Technology Policy's recent report *A Research and Development Strategy for High-Performance Computing*.

"I can foresee all sorts of applications," Iveson concludes. "Computers connected by high-capacity fiber-optic links to solid-state power control devices throughout a network could watch for voltage or frequency changes that signal impending problems and could initiate corrective action. Advanced computational methods based on random variations in system conditions could be used for the first time in the analysis of large power systems. And, in case of system blackout, both artificial intelligence and neural networks could be used to guide operators through the restoration process. We're on the threshold of tremendous improvements in system monitoring and control, which can lead to highly automated, more efficient, more competitive operation." ■

This article was written by John Douglas, science writer. Technical background information was provided by Robert Iveson, Electrical Systems Division.

DIRECTIONS in EXPLORATORY RESEARCH



Businesses must continuously push the boundaries of scientific inquiry to move forward in today's competitive environment. EPRI's growing exploratory research program is searching out and developing new areas of science that can make a difference for the future of the utility industry.

Thomas Edison experimented endlessly with the materials and gases—and the vacuum—that finally became the electric lamp. One by-product of his continued work was the discovery in 1883 that electric current will flow in a wire placed near the hot filament in its vacuum envelope, a phenomenon that came to be known as the Edison effect.

Genius though he was, Edison had no idea what this laboratory curiosity was good for, and nothing was done with it, even experimentally, for more than 20 years. Owen Richardson then picked up the subject, demonstrating the phenomenon to be electron flow between electrodes in a vacuum, the underlying mechanism of the vacuum tube. John Fleming created a two-electrode tube that could convert ac to dc, and Lee De Forest added a third electrode to create the vacuum-tube amplifier. The incidental discovery of the Edison effect thus made possible the world of electronics that is now epitomized by solid-state devices, telecommunications, and computers.

The annals of science and technology are filled with such chains of ideas, many of them forged piecemeal, by chance and curiosity, over a period of many years. We all too often fail to appreciate this process. For most of us, the last link alone—the end product of applied research—epitomizes the notion and wonder of invention in our minds. But long before a manufacturer can develop a *product*, someone—maybe many people and organizations—must seize a *discovery*, nurture it, elaborate it, explain it, and thus fit it securely into the mesh of science. Only then can it be exploited and its potential realized.

Technology development has always been a deliberate process, but for most of history it was usually founded on strata of science randomly uncovered around an outcropping—an earlier chance discovery. The circumstance draws comment from Fritz Kalhammer, an EPRI vice president and division director. Reflecting on such prototypical innovators as Edison, he remarks, "We're less likely to run across scientific nuggets accidentally today. They aren't on the surface—certainly not in significant numbers. It takes more thought and resources now, often the systematic cross-disciplinary effort of entire groups, both to find the lode and then to map the geology of the region—develop the scientific basis that enables us to use what we've found."

Selecting with a purpose

Even as discovery and innovation are becoming more difficult and expensive, their importance is growing. Individuals, companies, and entire nations are competing in a time of ever more rapid institutional and economic change. Technology is simultaneously a cause and an effect in all this. Therefore, all of science is being probed more insistently and systematically than ever—not just for basic answers to practical problems but also for new knowledge from which further discoveries can flow and, even beyond that, for the truly conceptual leaps that put us into altogether new territory. For many people in the scientific and technical community, such inquiry calls for a special name: exploratory research.

Exploratory research opportunities for EPRI are vast. Technology for the generation, delivery, and use of electricity has its roots in nearly every area of science—for example, such broad categories as materials, electrochemistry, fluid mechanics, combustion, heat transfer, superconductivity, and many of the earth and life sciences. And EPRI's intellectual resources are nearly as extensive as the potential topics for exploration. As a result, the selection of research to be funded is an immediate and continuing challenge for Kalhammer and his colleagues. "We must have a strategic perspective," he says, "in allocating our resources to the areas of greatest potential impact. But at the same time, we must retain the intellectual and operating flexibility to recognize the potential in unconventional ideas and find ways of supporting long shots.

"Putting it another way," Kalhammer concludes, "scientific expertise and rational analysis aren't enough; we also have to bring instinct to bear, and a willingness to take greater risks than we have been used to." He characterizes EPRI's two broad purposes in its conduct of exploratory research as building knowledge and fostering innovation.

The systematic elaboration of knowledge is a more established objective, having been pursued at EPRI even before the formal inception of exploratory research in 1985 under John Stringer, a metallurgist and the director of materials research, and Walter Esselman, recently retired as the director of technical assessment and evaluation. Two examples of knowledge building—cases where there had been significant limitations in the underlying science and, at the same time, clear opportunities for major advance—are the development of so-called clean steels, which have exceptional resistance to temper embrittlement in a steam environment, and the discovery of biological organisms and processes that can liquefy coal.

Such efforts as these, whether successful or not, are only part of exploratory research, however. Fostering innovation in science is equally important. While that's just as easy to contemplate, it's much more difficult to implement as a research program. Recognizing the potential of an obscure invention almost implies selecting it in advance. And after that comes the judgment of how much research funding is warranted: what will it take to prove the concept or justify dropping it?

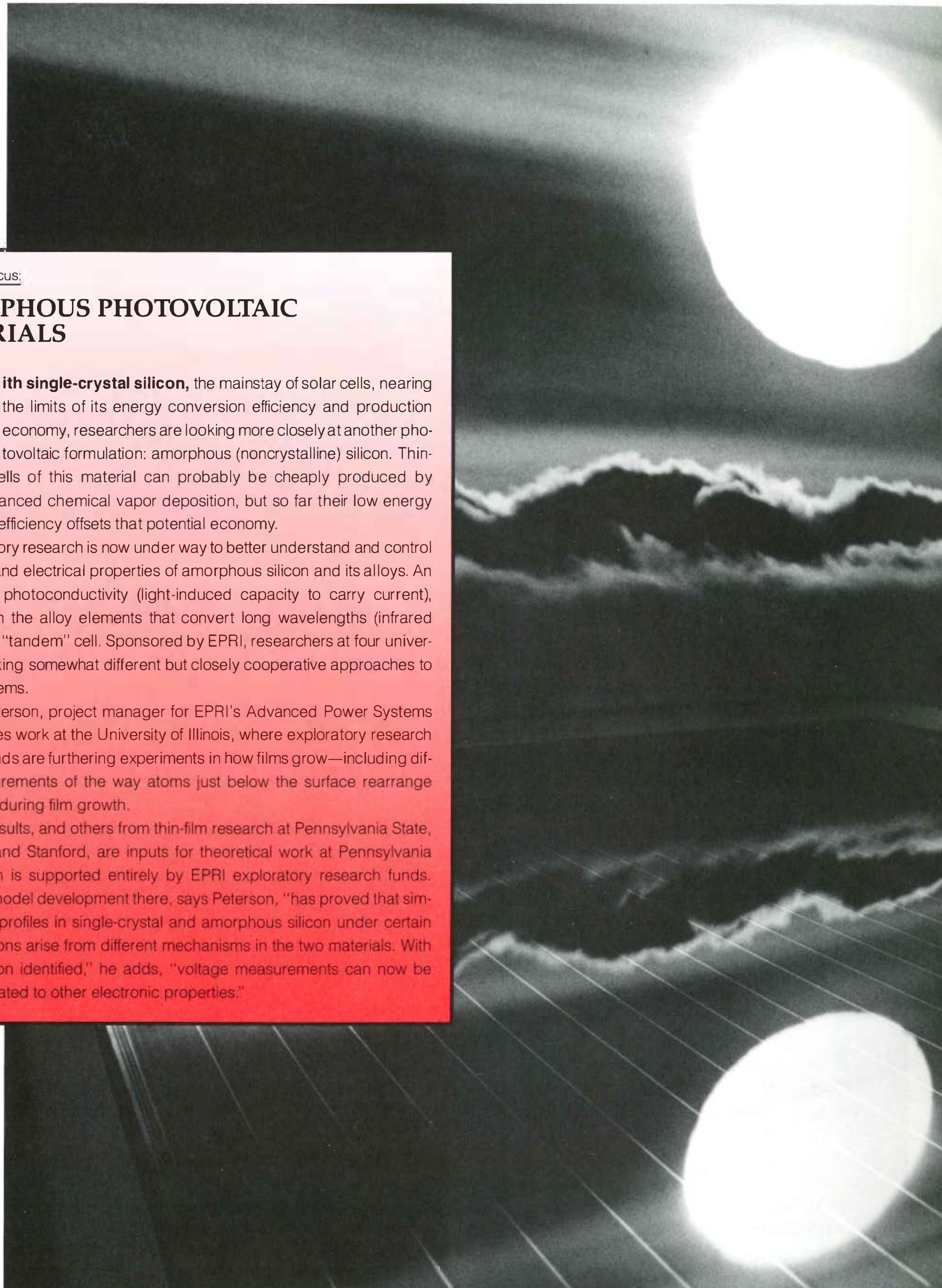
Organizing the search

The organization of EPRI's exploratory research reflects its strategic purposes and needs. The program is directed by Kalhammer himself with the aid of two senior science advisers, mechanical engineer John Maulbetsch and physicist Tom Schneider, longtime EPRI staff members with complementary academic backgrounds and areas of research experience. John Stringer, although mainly responsible for materials research, is still closely associated with the exploratory research group after serving as its technical director during several formative years.

What do they do? Maulbetsch cites two responsibilities of the advisers. One is to learn enough about several scientific fields to recognize good work and to sense whether EPRI might benefit from supporting it. The other is to look around EPRI's programs, helping to evaluate instances where technology seems to have run up against limits and could benefit from greater understanding of the underlying science. In both cases, he says, "We're looking for things we don't understand or can't compute, trying to focus the best minds in a field on work that will elucidate fundamental principles."

At the same time, the exploratory research science advisers look for the unexpected. Schneider explains why EPRI must work to be receptive to ideas from outside the scientific mainstream. "Our usual selection criteria mostly favor deliberate research, over considerable time, by well-known and established investigators, in areas we already know something about, and probably aimed toward publication in refereed journals. All well and good, but this tends to shut out the occasional radical proposal from an unconventional source—the inventive loner at work in a garage somewhere."

Schneider goes on to describe a philosophy of fairly modest (up to $75,000),



Research Focus:

AMORPHOUS PHOTOVOLTAIC MATERIALS

With single-crystal silicon, the mainstay of solar cells, nearing the limits of its energy conversion efficiency and production economy, researchers are looking more closely at another photovoltaic formulation: amorphous (noncrystalline) silicon. Thin-film solar cells of this material can probably be cheaply produced by plasma-enhanced chemical vapor deposition, but so far their low energy conversion efficiency offsets that potential economy.

Exploratory research is now under way to better understand and control the optical and electrical properties of amorphous silicon and its alloys. An example is photoconductivity (light-induced capacity to carry current), especially in the alloy elements that convert long wavelengths (infrared energy) in a "tandem" cell. Sponsored by EPRI, researchers at four universities are taking somewhat different but closely cooperative approaches to these problems.

Terry Peterson, project manager for EPRI's Advanced Power Systems Division, cites work at the University of Illinois, where exploratory research program funds are furthering experiments in how films grow—including difficult measurements of the way atoms just below the surface rearrange themselves during film growth.

These results, and others from thin-film research at Pennsylvania State, Princeton, and Stanford, are inputs for theoretical work at Pennsylvania State, which is supported entirely by EPRI exploratory research funds. Computer model development there, says Peterson, "has proved that similar voltage profiles in single-crystal and amorphous silicon under certain light conditions arise from different mechanisms in the two materials. With the distinction identified," he adds, "voltage measurements can now be correctly related to other electronic properties."

short-term (up to 18 months) funding to prove innovative concepts or assess their feasibility. "We're trying to cover some of the opportunities that are generally too risky for any single EPRI division to take on—but which would fit there if successful and seen to justify follow-on development."

Searching for subjects to explore, like carrying out the research that follows, is beyond the capability of any three or four individuals. Staff members of EPRI's technical divisions are the first-line resources for exploratory research projects, whether with their own initiative and funding or with an assist from the exploratory research team and its budget.

EPRI staff are encouraged to submit their own ideas for projects, which may be funded from a technical division budget or by the exploratory research program, as seems appropriate. This initiative gets a nod from Fritz Kalhammer. "All of us need to become better fishermen if EPRI is to contribute significantly to innovation," he says. "We must encourage ideas to surface. As one member of our Science Advisory Committee tells me, we've got to reward innovators even when they fail."

John Stringer emphasizes the importance of "looking for somebody who wants to pick up the ball and is available—who can spare some time from his or her other duties." Stringer's people-oriented style shows here. "My own reaction is, the project management champion really has to be here, at EPRI, or we won't get a decent piece of work."

There are other views on potential staff limitations and how to deal with them. Stringer's colleagues argue that a topic could be too important to neglect. Kalhammer plans to borrow experts from elsewhere—universities, private research organizations, and national laboratories—if need be. Alternatively, he proposes to use the new concept of EPRI Fellows to support individuals in devel-

Renewed Commitment

Relatively high-risk, future-oriented research isn't completely new to EPRI. In the Institute's earliest days it was called long-term research, it was part of the responsibility of each division, and it amounted to as much as 10% of the overall R&D budget.

But such work took a back seat for some years. Demonstrating the commercial readiness of newly developed technologies commanded as much as 20% of the budget well into the 1980s. Also, utilities had institutional economic problems—the costs of fuel, capital, and long construction intervals, as well as lower revenues due to slow demand growth. These called for a focus on technical fixes that would add to the life, efficiency, and reliability of existing plants.

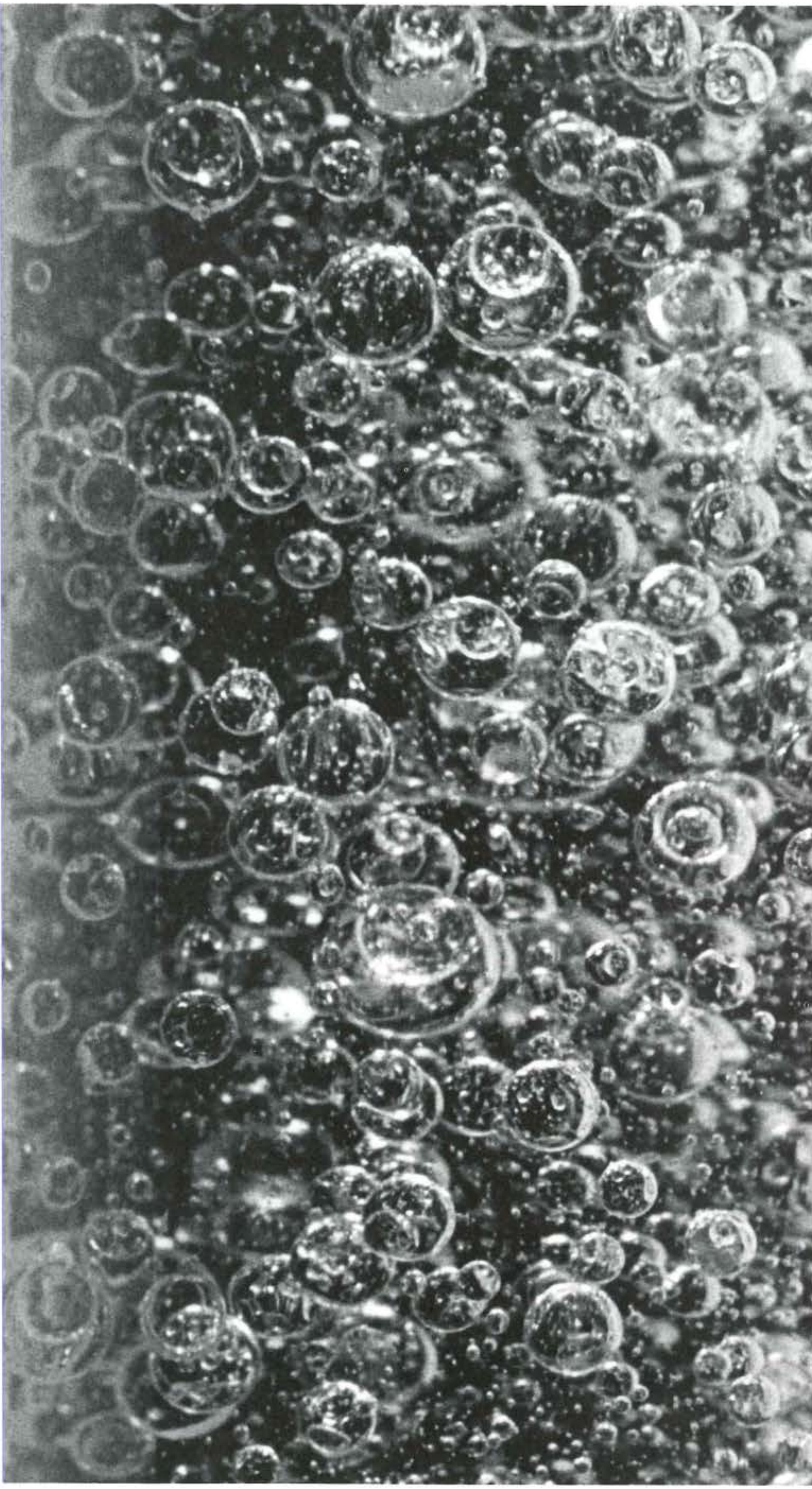
Slow growth for utilities has also meant severe cuts in the sales and revenues of their suppliers. The result? "Manufacturers' research for the U.S. power industry has been drying up across the board," says EPRI Fellow Sy Alpert, pointing to R&D consolidations, mergers, cutbacks, and the outright market withdrawal of several companies. "This also means fewer organizations for EPRI to contract with as we try to fill in."

The need for EPRI's renewed attention to exploratory research was expressed by Floyd Culler before he retired last winter, ending 10 years as EPRI's president. On several occasions he put forth the provocative image of the Institute's gradually diminishing scientific base for new electricity technologies. "We're finishing off the science of the 1930s and 1940s," he insisted, "even a little bit from the 1950s. What will be the scientific base for EPRI's program 15 years from now?"

One of the answers is the exploratory research program. It has come into its own under the guidance of Richard Balzhiser, beginning when he was R&D vice president. This year, his first as EPRI's president, the program commands its own budget of nearly $7 million. EPRI's six technical divisions fund a comparable amount on their own. The approximately $14 million total represents about 5% of the Institute's current R&D budget of $274 million.

And the commitment is growing. Central exploratory research funding alone is to be 5% by 1991–92, according to a management proposal recently approved by EPRI's Board of Directors. Further, the technical divisions are being asked to strengthen the exploratory probes that support their individual research missions. Sy Alpert welcomes these actions. "If exploratory research is to have any chance of success, it must be protected over the long term by executive commitment. In an ordinary management sense, you can never justify spending money this way. You've got to *want* exploratory research."

EPRI Vice President Fritz Kalhammer has executive responsibility for the new program, but his Energy Management and Utilization Division is only an administrative home for its budget and small senior staff. Technical management of nearly all projects is decentralized among EPRI's research divisions. This decision was made early on, and it applies both to research of cross-divisional interest and to projects that amplify just one division's efforts. The idea is not only to take advantage of the Institute's wide range of talent, but also to ensure interaction among all EPRI groups and facilitate the transfer of exploratory results into one or more programs of applied R&D. □



Research Focus:

BINARY FLUID MIXTURES

The thermodynamic properties of such working fluids as water and Freon are essentially fixed factors in the performance of power plants and heat pumps. But there is reason to believe that system efficiencies can be improved by using what are called binary mixtures—combinations of two working fluids that have different properties. Water and ammonia have been proposed for steam power plant use. R22 and R114 refrigerants are suggested as a mixture that might lift the performance coefficient of heat pumps as much as 32% above the best obtainable with R22 alone.

Jong Kim, a project manager in EPRI's Nuclear Power Division and head of the Institute's exploratory research in heat transfer, explains that the cooler fluid in a conventional heat exchanger can be heated only to its saturation temperature (at a given system pressure). A binary mixture, however, might be designed so that, in effect, its saturation temperature rises, potentially affording much greater latitude in heat exchanger operation.

But binary mixtures are not well understood. To illustrate how they can contradict expectations, Kim describes a single finding by the National Bureau of Standards (NBS), which is performing exploratory research under EPRI's sponsorship and sharing heavily in the cost. "In a horizontal pipe or tube containing a single fluid under annular flow conditions," Kim says, "heat transfer is greater at the top, the result of gravity and a thinner annular film of liquid there.

"But with a binary mixture, the annular composition varies around the periphery and there's greater heat transfer at the bottom of the tube." Seeing the implications of this qualitative difference for future equipment design, Kim counts it as an early success for exploratory research.

Research Focus:

HOT SUPERCONDUCTIVITY

Copper and iron are still the materials that superconductors must outperform in electric utility service. The figure of merit is a current density of 1000–2000 A/cm^2, and in very thin films today's "hot" superconductors of synthetic ceramic oxides beat that by more than 1,000,000 A/cm^2.

But in wire-like cross sections big enough to carry real-world electric currents, the new superconductors fall short, according to Tom Schneider, one of EPRI's senior science advisers for exploratory research. "If utilities are to exploit them at high currents and in high magnetic fields," he says, "we've got to understand and control such characteristics as critical current level, weak links, and flux pinning."

That is the aim of multiyear projects just begun by University of Wisconsin and Stanford researchers, who will study the "1-2-3" superconductive oxides—so-called because of the approximate ratio of their yttrium, barium, and copper constituents.

Flux pinning, for example, is critical to the practical use of the new superconductors because they are penetrated by flux lines. "When flux lines move under magnetic field influence," Schneider explains, "current carrying capacity is seriously reduced. So they've got to be stabilized—pinned.

"We know all these characteristics are affected by techniques used in material fabrication and processing. The work at Wisconsin and Stanford should improve our understanding of what takes place, at an intimate, submicroscopic level."

oping their own expertise and, with it, important new exploratory research directions.

Sy Alpert, named EPRI's first Fellow just last year, is closely involved with exploratory research. An inquisitive EPRI research strategist and planner since 1973, mostly in fossil fuels and their conversion processes, he now pilots an exploratory research associates program. Through this program 15 leading Midwestern university faculty members provide state-of-the-art assessments of candidate exploratory research topics.

Initially Alpert's guidance of the research associates will add ideas more than manpower to the effort, but it will constitute an important link between EPRI and the scientific community and is likely to stimulate worthwhile exploratory research at the associates' institutions.

Assigning the tasks

All things considered, much of EPRI's exploratory research guidance consists of catalyzing the efforts of others, both inside EPRI and elsewhere: searching for needs, defining topics, screening them, matching them up with investigators and funds—*networking* in every current sense of the word.

With the sensing mechanisms in place, the concern is how to make sure that they stay open and receptive. Strategic planning and rigorous evaluation of proposals have their place in the decision process of exploratory research management. But there's another side: rigor can be carried to the point where it stifles innovation.

Speaking generally of EPRI's research managers, including himself, Kalhammer acknowledges, "We're trained and conditioned to be analytical. It's an attribute we especially need in EPRI's applied R&D. But when we work with new concepts and fragments of ideas, it's easy for all of us to think of reasons why they won't work." His point is that exploratory research must operate differently

Larger Role for Universities

Like other R&D at EPRI, exploratory research is contracted out. But the distribution of contracts among research organizations is quite different. Industrial firms, consultants, national laboratories, and other R&D organizations predominate for most EPRI work, together holding 91% of all Institute research contracts. Universities account for only 9%. The figures for contracts funded solely under the exploratory research program tell a different story: 61% held by commercial and government organizations, 39% by universities. Clearly, the new program is bringing more opportunities for university participation.

Governed by the need for specific technology development, EPRI's contracting practices have in the past been somewhat at odds with the major traditions of university research—which include open-ended work statements, freedom from milestone schedules, minimal reporting requirements, the rights to patentable results, and the certainty of research funding over a reasonable term, notably the three-year "lifetime" of a graduate student.

More flexibility in these areas is one of the prerequisites for doing substantially more exploratory research, and EPRI's contracting office has therefore introduced a new form of work statement for university research agreements.

Institute funds are still subject to annual budget approval by EPRI's Board of Directors, but for all practical purposes, research projects that rely on graduate students have the needed longer-term commitment. "In effect," says John Stringer, "we front the whole three years of a university project right at the start. We tell them they've got the money; they can count on it." □

Horizons of Exploratory Research

The scope of nearly 130 separate EPRI exploratory research contracts—including evaluations of new prospects—is represented by the following examples:

Biotechnology

- Genetic ecology and bacterial communities
- Microbial coal desulfurization and identification
- Microbial coal processing

Ceramics

- Ceramic electrolyte for fuel cell applications
- Ceramic materials for molten carbonate fuel cells
- Wire-reinforced ceramic composites

Steels

- Enhanced sulfidation resistance of iron, nickel, and cobalt alloys
- Evaluation of electron beam Czochralski superalloy crystals
- Multielement diffusion coatings
- NiAl alloys for elevated temperature shape memory applications
- Nondestructive evaluation of grain boundary segregation

Superconductivity

- High-temperature oxide superconducting materials
- Critical current density in high-T_c metal oxide superconductors
- Superconducting magnetic energy storage

Prospective Exploratory Research Areas

- Accelerated life testing
- Advanced thermodynamic cycles and processes
- Artificial intelligence and expert systems
- Chaotic processes
- Conductive plastics
- Diamond films
- Electrokinetic effects in power transformers
- Fate of redox-sensitive elements in groundwater
- Global CO_2 sources and sinks
- Hormetic and harmful effects of radiation on immunity
- Nonequilibrium plasmas
- Reactions of compressed air with common minerals

Instrumentation

- Differential optical absorption spectroscopic studies of N_xO_y cycle
- Fiber optic sensors

Mathematics

- Global nonparametric estimation of spatial covariance patterns

Polymers

- Monomers that expand on polymerization
- Oxidation phenomena in water treeing
- Prediction of deterioration rate of utility cable insulation

Semiconductors

- Advanced silicon materials for photovoltaic and power devices
- Electron beam skull melt silicon crystals
- Modeling of amorphous silicon photovoltaic device structures

Chemical and Physical Nature of Coal

- Depolymerization mechanism of coal
- Homogeneous catalysts for methanol synthesis
- Methanol synthesis research
- Selective oxidation of pyrite in a fluidized bed

Combustion Physics and Chemistry

- Coke particulate formation and destruction during combustion
- Interaction of chemistry and fluid mechanics in NO_x formation
- N_2O formation in combustion systems

Electrochemistry

- Corrosion of ceramics and refractories
- Electrocatalytic gas reactions on the surface of solid-state electrolytes
- Electrochemical detection of the initiation of stress corrosion cracking
- Fluoropolymer sulfonic acids for phosphoric acid fuel cell cathodes
- Mechanisms of ultracapacitors
- Photoelectrochemical devices for solar hydrogen generation

Fluid Mechanics and Heat Transfer

- Boiling heat transfer degradation in binary mixtures
- Fluid-elastic excitation in tube bundles
- Natural convection melting and solidification
- Two-phase flow fundamentals
- Vortex breakdown and turbulent mixing

in important ways: the definition of tasks, the selection of researchers, the awarding of contracts, and especially the daily management of the work—all must be done with a studiously open mind and a light hand.

Sy Alpert agrees, and he injects a warning. "The first thing you learn is that if you overmanage this kind of research, you'll screw it up. There's no way of pacing it or accelerating it. All you can do is give it the right support, the right people, and stand back."

To a great extent, an exploratory research sponsor's mission and purpose are reflected in the choice of investigators. But how to decide? What gives EPRI confidence that an area of science warrants support? How do you know? Often you don't, Alpert says, especially in ill-explored areas or when face-to-face with a totally unfamiliar hypothesis: "You go by feel, you go by intuition."

Stringer particularly likes what EPRI calls a specialists' workshop, an occasion for targeting a topic, elaborating its research needs and possibilities, and thus documenting the criteria for reasonable, practical exploratory projects. "We'll pick the best 10 or 20 people in the world," he says, "and invite them to come together and discuss the topic. We get at least 85% attendance. Then we listen."

As Stringer describes it, the process can be almost circular; that is, EPRI's collective sense of potential researchers to some extent determines the exact topic to be explored. "As we listen, two things gradually happen. First, it begins to clarify in our minds that there is something here. And second, among all these bright people, we discover—it's a feeling—that there's one or more of them that we can work with. It's intuitive; it isn't quantifiable."

Topics and talent

Despite the range of technology employed by electric utilities, it isn't instantly obvious why some potential topics would be important to a mission-oriented R&D organization like EPRI. Topics of past EPRI exploratory research workshops suggest the "soft focus" that is possible: amorphous materials, water treeing in polymers, methods for accelerated testing, plasma processing.

Amorphous materials were the first exploratory research workshop topic addressed, in 1985. These materials yield improved electrical or material efficiencies (or both) in two important technologies, voltage transformers and solar cells. But they bring unique problems as well. Amorphous metals, for example, are embrittled by the annealing needed to improve their magnetic properties; this is a limiting factor in making transformer cores.

Workshop organizer Robert Jaffee and 3 other EPRI researchers were among 12 members of a committee that convened 39 world-class participants for a week-long series of sessions on the topics of amorphous material structure, glass formation, magnetic glasses, semiconductors, and mechanical and chemical properties. EPRI's objective was to reach some conclusion about what research avenues particularly warranted support. The problem of temperature embrittlement was indeed judged to be one such topic; and a workshop participant, Peter Haasen of West Germany's University of Gottingen, is now embarked on exploratory research for EPRI.

Glamour doesn't always go along with exploratory research, but frontiers have their fascination, appealing in different ways to investigators and prospective users of new science. Bacterial processing of coal is one example, offering the tantalizing prospect of using living organisms in controlled fashion to upgrade coal into a cleaner fuel or to transmute coal tar wastes. "We've reported on several occasions about bacteria, fungi, and enzymes that act on coal," says John Stringer. "They liquefy it, they remove sulfur or other ash constituents. There's come to be a whole list of which coals, which organisms, and how fast.

"And that can be a trap," he goes on. "There's an easy fascination in empirical work, cataloging what happens without finding out how or why. Actually, the how and why have deeper, longer-lasting appeal for a scientific investigator." EPRI is therefore moving into more methodical conceptual work, zeroing in on how the enzyme action occurs and then aiming for molecular biological techniques—synthesis or perhaps genetic splicing—to mimic the bugs with simpler, man-made materials.

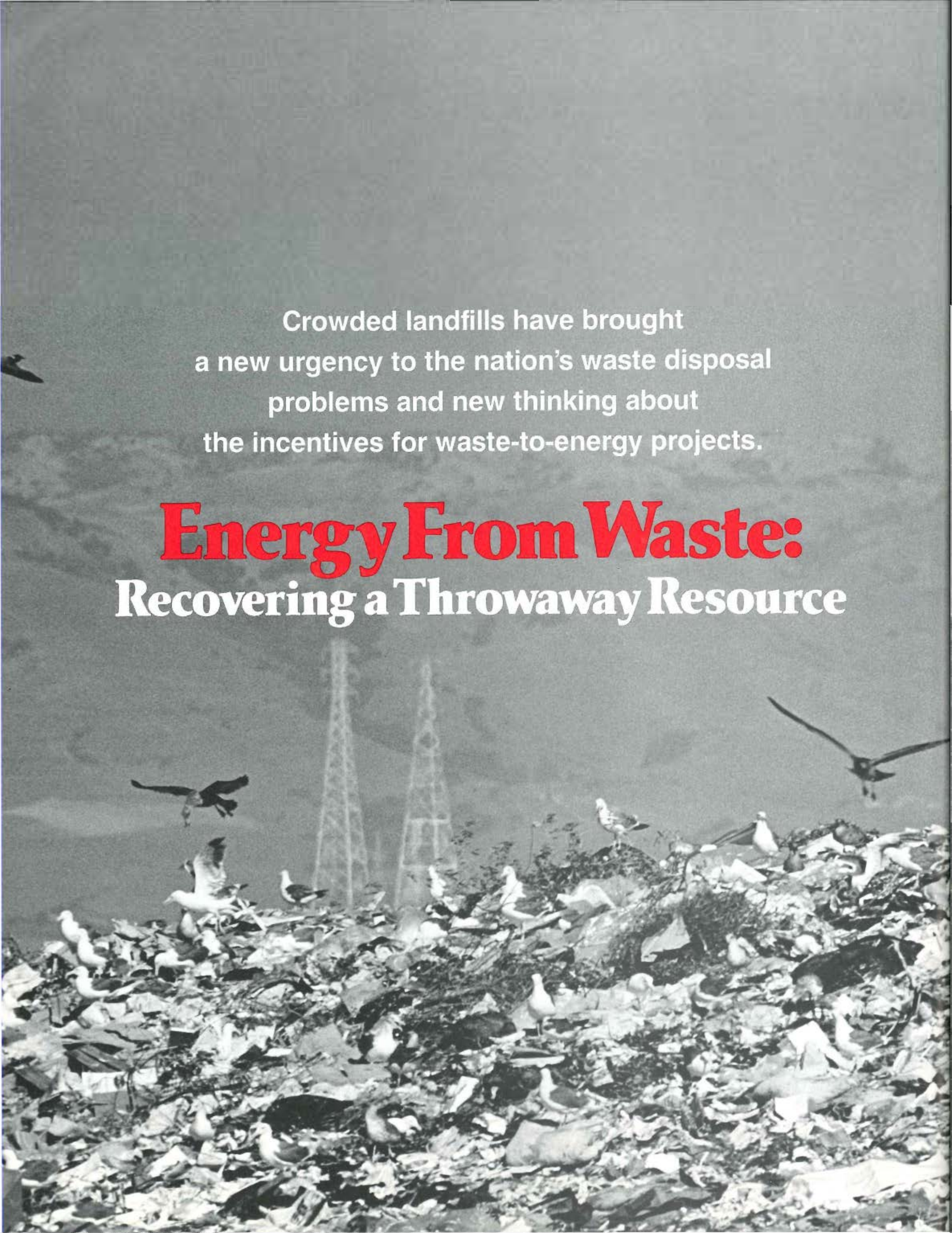
Richard Balzhiser, EPRI's president, believes that science is at a comparable point with the recent discovery of high-temperature superconductivity. "We know the phenomenon is real, and materials have been fabricated that superconduct at higher temperatures than ever before. But the experimental work is well ahead of our theoretical understanding."

The fundamental promise of these new materials governs EPRI's research in the area, Balzhiser says. "Hot superconductors could comprehensively transform many technologies and the ways they're used. The excitement is justified." But, he cautions, "the whole field of inquiry is still very much at the level of basic science. The payoff will come when we develop a sufficient body of knowledge to understand the phenomenon and its mechanisms. Then we can engineer materials for real products and applications. *That* will be the time when exploratory research has done its job; and helping us get there is what excites me." ■

This article was written by Ralph Whitaker, feature editor. Background information was provided by Fritz Kalhammer, Energy Management and Utilization Division; John Stringer, Materials Support; John Maulbetsch and Tom Schneider, Exploratory Research; and Sy Alpert, EPRI Fellow.

Crowded landfills have brought a new urgency to the nation's waste disposal problems and new thinking about the incentives for waste-to-energy projects.

Energy From Waste:
Recovering a Throwaway Resource



Garbage is finally getting some respect, or at least some serious attention. U.S. municipalities and industries generate more than 200 million tons of it a year. Managing municipal solid waste (MSW) usually accounts for the fastest-growing segment of a municipality's budget.

And more than money is at stake. In addition to finding an affordable way of managing garbage disposal, communities are concerned that it be an approach they can live with. Space is simply getting tight. In many areas landfill is rapidly reaching capacity, and in cases where land is still available, public opposition has hindered the opening of new fills. Even where the option is allowed, piling up trash has its limits: New York City's Fresh Kills landfill on Staten Island, already nearly 200 feet high, is projected to peak at 500 feet; it won't be able to go any higher because it would interfere with Newark International Airport's flight path!

Communities that can't stack garbage up, ship it out. Some Long Island towns transport it as far away as Michigan. The Long Island garbage barge that was compelled to complete a 162-day odyssey before finding a port for its cargo is legendary.

The burden of municipal waste represents opportunity for anyone willing to carry it—for a price. As communities look for ways to get rid of their garbage, investment firms and entrepreneurs scrutinize MSW to see how to wrest profits from it. One way of turning trash into cash is to remove and sell what can be recycled. Another kind of resource recovery involves converting MSW into energy, a process utility companies find increasingly intriguing.

According to EPRI's Charles McGowin, a 10-year veteran researcher in this field, today only about 5% of the nation's waste stream is treated by about 100 resource recovery plants; however, nearly 200 more plants are expected to come online in the next five years, and by the turn of the century as much as 40% of the waste will be processed by 400 resource and energy recovery facilities. Electric utilities are likely to participate in most of them, either as customers for steam or electricity or as facility owners and operators.

Options for energy

Of a number of resource recovery technologies in various stages of development and use, two options are currently favored for converting waste into energy: mass burning, and processing MSW into refuse-derived fuel (RDF).

Mass-burn technology possesses a key virtue in that it permits all kinds of refuse to be burned quickly and evenly. A crane plucks garbage from a pit and dumps it into a hopper, which funnels it to a traveling pitched grate. As it descends through a furnace 8 feet tall, the garbage burns at a high temperature (about 2500°F), producing superheated steam that can be sold to customers, including utilities. In the process a gallon of garbage becomes about a pint of landfill, and one ton of garbage produces about 525 kWh of electricity.

RDF technology is chiefly distinguished from mass-burn technology by far more front-end processing. First, the refuse is sorted; if recyclable items have not already been removed, they are recovered from the waste stream, along with nonburnable items. The remaining refuse is then shredded and weight-classified. Finally, it is burned to generate electricity, leaving an ash residue for disposal. The amount of electric power generated per ton of MSW is comparable for RDF and mass-burned MSW. Although mass burning currently accounts for about three-quarters of the projects in the United States, many experts believe RDF will expand its one-quarter share significantly in the future.

"Electric utilities have a unique opportunity to apply their expertise in the design and operation of large generation facilities to help their communities address the waste disposal problem," believes McGowin. Two means of active participation have emerged. One is the conversion of existing plant boilers to burn RDF, either alone or in conjunction with coal or fuel oil. The other is the construction of new, dedicated refuse-fired boilers to supply steam to turbine generators through mass burning. Because utilities must, above all, be reliable power suppliers, they should not place at risk their regular boilers but instead reserve, or dedicate, boilers for processing MSW—either by retrofitting unused existing boilers or by acquiring new ones designed for that purpose.

More than one-third of the nation's MSW plants are sited in the Northeast, where the landfill crisis is most acute, but facilities in all stages of development are found in 41 states plus Puerto Rico. Minnesota has the most existing plants (12), followed by New York (11), Florida (10), Virginia (9), and Texas (6). Pennsylvania has the most plants in an advanced planning stage (12), followed by New Jersey (10), New York (8), and Massachusetts and Michigan (5 apiece).

The leading operators of mass-burn facilities are Ogden Martin and Wheelabrator Technologies; other major players in the waste-to-energy sweepstakes are Westinghouse Electric, Browning-Ferris, Air Products, and Combustion Engineering.

Making it work at TVA

Many utilities have already become involved with MSW projects. EPRI collaborated with the Tennessee Valley Authority in documenting the four years from planning to operation of a refuse-fired mass-burn facility in Gallatin, Tennessee, that cogenerates steam for industrial customers and electricity for sale to TVA. The resulting two-volume report (CS-4164) is a useful resource for those interested in getting into the business.

Close cooperation among all participants was very important in expediting startup, as was vendor experience in selecting process components. Difficulties were encountered with refuse combustion and particulate emission control systems during the first year of operation; these are documented in the report, along with their largely successful solutions.

The facility proved able to process refuse at its rated capacity of 200 tons a day, and refuse volume and weight were both reduced to close to the estimated 90%. The project was not without its problems, however. Boiler efficiency was only about 60–70%, rather than the 80% specified by the manufacturer, although it has improved since the initial evaluation. And the estimated $5.2 million cost escalated to a final cost of more than $13 million. As a result of these factors, the net revenues covered only operating and maintenance costs, not deferred bond interest and depreciation charges. Nevertheless, the initial operation was deemed satisfactory and the outlook is optimistic. Justifiably so, as it turns out, for "everyone sees things as fine at the plant," said its manager, Bill Garland, last summer.

TVA has also been looking at RDF options. "The mass-burn approach was far out front for a time," says Carroll Duggan, director of the Waste Management Institute at TVA, "but now it seems to me that RDF is coming to the forefront. When people look at the investment of $50,000–$120,000 per ton of installed capacity needed for a new mass-burn facility, they ask themselves, 'Why can't I burn my waste in the existing power plant, in which I've already invested? Might the local utility be interested in burning RDF in conjunction with coal? Can it, with some modifications, work more cheaply and without jeopardizing the power plant?' Often, the answer is yes."

Duggan points out that in treating MSW, communities face the largest capital investment they will ever make, and if less capital is tied up, greater flexibility remains. This line of reasoning favors the retrofitting of boilers for RDF when the potential exists for doing so. Also, the RDF option, which requires separating out certain materials from the waste stream, appeals strongly to those committed to recycling.

Since the late 1970s, TVA has provided guidance on political, technical, environmental, and financial aspects of resource recovery to more than 25 communities. The OPEC-sparked energy crisis created considerable interest in cultivating alternative domestic energy sources, including converting garbage into electric power. But even with high energy prices, the economics were not that good. "Probably RDF should never have been looked at as a source of energy," believes Duggan, "but simply as a way of getting rid of garbage."

In 1976, when TVA evaluated RDF for its coal-fired units, it found the option to be economically unattractive. At that time transportation and landfill were relatively cheap, and landfill was still available and provoked little public opposition. Moreover, there were too many unsettling unknowns in the technologies required.

TVA's reevaluation of the situation, completed last summer, shows RDF to be technically feasible, thanks to a decade of continued development and experience. "Obviously, the front runner's bound to hit the briers first," says Duggan. "His cries warn those behind from hitting them, too." This increased technological expertise, changes in economic climate and risk assessment, and the decreasing availability of landfill sites have all stimulated utility interest in exploring RDF.

Considering the diverse and unpredictable factors in managing MSW—public policy, legislation, technology, and human behavior—Duggan points to a need for legislation that's realistic. "If

Garbage: Everybody's Problem

Generation of solid waste is a fact of life in modern society. Many groups have a stake in the problem, but most have specific interests and concerns in how to approach it. Reconciling these special interests can make development of an effective waste management strategy an institutional nightmare.

Residents, as consumers of packaged goods, represent the first "consolidation point" for waste but often take the next steps—garbage collection and disposal—for granted. Consumers are interested in low costs for collection service and minimal local environmental impact in disposal strategy. This group can help solve the problem most effectively by participating in sorting and recycling programs, which lower both the volume of waste and the cost of getting rid of it.

Public interest advocates can have all sorts of effects on garbage disposal—from lobbying for stricter hazardous substance legislation to encouraging citizens to recycle to pressuring manufacturers for less-wasteful product packaging. Such groups are generally interested in doing the "right thing." However, the specific interests of different groups can sometimes conflict—for example, advocates of lower cost for public services and those that would have zero environmental impact in waste disposal at any cost.

Waste handlers, such as trash haulers or landfill operators, may want to participate in recycling or innovative resource recovery projects if these activities fit in with overall business goals. But questions concerning cost, public liability, worker safety, and lack of experience with energy recovery technology make this group cautious. Waste handlers are becoming more open to resource recovery options as landfill areas become scarcer and more expensive.

Equipment manufacturers may either sell resource recovery hardware or offer a packaged garbage management service based on their equipment—and they want to make a profit. Technical problems that plagued the relatively young MSW technologies a decade ago have been essentially solved, and a number of large manufacturing concerns now do a thriving business in this field. With the landfill squeeze, the future market for MSW processing equipment should continue to burgeon.

Electric utilities have traditionally prided themselves on public service, and their background in combustion and generation makes them well suited as partners in energy recovery programs. However, utilities' primary concern must be providing reliable, affordable electric service for the public at large. When utilities agree to participate, specially modified boilers are generally dedicated for burning the garbage, and financial arrangements may specify that the cost of MSW combustion will not exceed that for burning conventional fuels.

Government at the city or county levels generally has the final responsibility for managing garbage in an efficient, economical, and environmentally acceptable manner. Local governments sometimes take a hands-on role, owning their own facilities and employing their own workers, but they often rely on private contractors for collection and processing. While local recycling programs are often sponsored as an effective approach for reducing waste volume, more involved and innovative approaches to MSW can be financially risky for municipalities. If land disposal area is scarce, they may have little choice.

The Solution: Recycling What's Recyclable . . .

Over the years, recycling has progressed from customer returns of soda bottles to highly integrated curbside programs that deal with a broad range of materials—cardboard, aluminum cans, plastic bottles, glass containers of all colors, and even used motor oil. Recycling is practiced by individuals, businesses, and industries, and collection receptacles are becoming familiar features of urban and suburban landscapes.

. . . And Burning What Isn't

Once mattresses, inflammables, toxics, and "white goods" such as stoves and refrigerators are removed from the waste stream, almost everything else can be burned safely, effectively, and productively. Emissions from both mass-burn and RDF combustion facilities are low, the process reduces the volume of material to be buried by as much as 90%, and electric power can be generated as a combustion by-product.

it's unrealistic, the technology can't handle it. What's needed is a strong interface between the players on the field and the spectators in the stands. We must bring the players to the table, give them information, and be willing to make compromises."

The "spectators" are nearly everyone. Certainly they include both taxpayers and ratepayers. And while a few people eschew electricity for an oil lamp and some people don't pay taxes, just about everyone generates waste. The United States, with 5% of the world's population, consumes 40% of its resources; much material is used only once and then discarded.

Reducing waste is seen by TVA as one key to managing it. Thus, in conjunction with Tennessee Valley universities, the agency has designed an educational program to promote "waste consciousness" in children in secondary grades throughout the valley. The program, called "Waste: A Hidden Resource," involves workbooks, videotapes, and teacher training. This fall it is being incorporated into curricula in various ways aimed at promoting awareness among our future citizen-consumers and modifying their behavior. For example, students are shown how big boxes for small items may be good at catching a customer's eye but are a bad use of precious resources.

"An integrated effort is what's needed," believes Duggan. This would include waste reduction, source separation, recycling what can be recycled, treating what can be treated, and ending up with as little residue as possible that's as innocuous as possible.

Nimby-proofing RDF

This is precisely the aim of Northern States Power (NSP) at an MSW facility in Newport, Minnesota, designed to treat waste from two counties. In fact, it is the avowed aim of virtually every resource recovery operation, and it is one that unanimously wins public approval.

In 1982 Minnesota passed a solid-waste management act that required each county to come up with a master plan for MSW disposal. In response, densely populated Ramsay County and sparsely populated Washington County formed a joint powers board to investigate options. In the early 1980s the board solicited bids for a mass-burn facility. However, elected officials, eager to promote recycling, favored RDF (which requires it); they also wanted a customer that would accept 100% of the product.

NSP already possessed facilities that could be modified to burn the fuel; when it proposed a plan for retrofitting existing boilers to burn RDF, the bid was accepted. There was a strong incentive for such an arrangement: nearly 40% of Minnesota's 110 landfills had less than five years' capacity left, and RDF placed a far lighter burden on county credit than funding a new mass-burn plant.

The plant seemed to have everything going for it. There was just one problem for the public: concern about where the recycling, separation, and especially the incineration and residue disposal would occur.

Such concern is often expressed by the term *Nimby:* not in my backyard. Proponents of this philosophy, "Nimbys," are gaining and exerting strength in many environmentally sensitive areas. They may be mellowing when it comes to garbage, however, perhaps recognizing that if they're not part of the solution, they're part of the problem.

NSP has been strikingly successful in neutralizing Nimbys. It helped that the Newport waste treatment plant didn't need a new site but could be built adjacent to an existing facility. Also, before NSP announced its intentions, it had carefully considered possible objections and proceeded to meet them. For example, it hoped to promote an amiable relationship with the neighborhood by pointing out that the facility would be in an industrial area away from residences; that its design would be pleasing and its landscaping appropriate; that processing would occur indoors to control noise, rodents, odors, and dust; that enclosed trucks would be used to transport trash to the facility and from it to the burning facilities (in Red Wing and Mankato, 50 and 90 miles away, respectively); that traffic would be carefully monitored to minimize impact; and that elaborate strategies had been devised to prevent explosions and to control hazardous waste (which NSP does not knowingly accept but assumes responsibility for if identified).

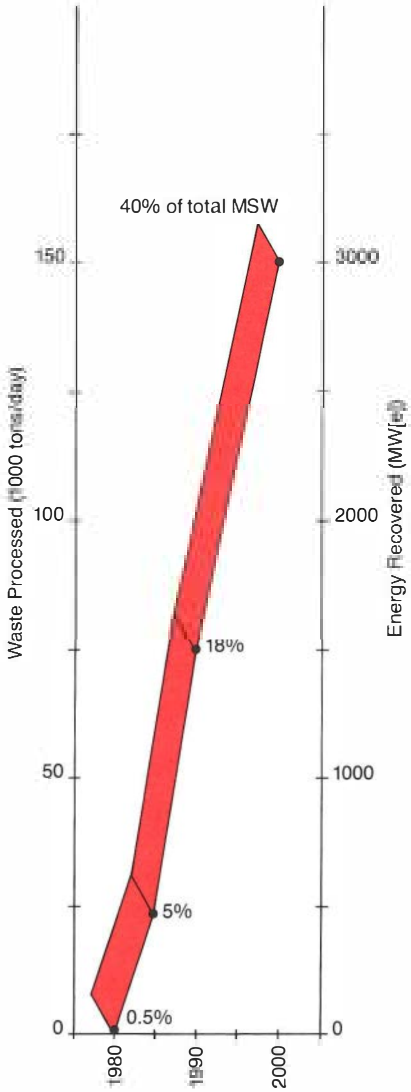
NSP appealed to ecological and environmental concerns, comparing RDF technology favorably with mass-burn technology and noting the necessity for removing recyclable and noncombustible materials from the waste stream. And the utility defused its detractors by identifying potential problems itself and then ensuring that precautions had been taken to avoid them. NSP showed, point by point, how its facility was similar to successful ones in Baltimore and Ames, Iowa, and how it differed from other, unsuccessful ones elsewhere.

The effort paid off. There has been little public opposition to the RDF plant since it became operational in July 1987. The plant effectively reduces MSW: up to 70% by weight is converted to RDF (90% by volume), and only 20% by weight is left for landfill disposal. At the generating plants, emissions are low; dioxin levels are less than one-tenth of the level allowable on newer incinerators, and sulfur dioxide emissions are less than one-fifth of those of coal-burning furnaces.

Encouraged by these results, NSP is constructing a new RDF facility in Elk River, Minnesota. United Power Association, which already has a generating plant there, has contracted to burn 70% of the RDF produced; it will also assume 15% ownership of the RDF facility. Projected to cost $24.5 million, this facility is similar to the Newport one, but its site is twice as large—35 acres—and it

Energy Recovery on the Rise

While the degree of rampup varies with the estimator, all parties see a dramatic increase in waste-to-energy conversion in the coming decades. Combustion Engineering's figures, shown here, project that as much as 40% of the nation's MSW will be burned for electricity by the turn of the century. Resource Marketing International estimates the number at 29% by 1991, led by the Northeast, which is expected to be converting about two-thirds of its garbage by that year.



Source: *World Wastes*, June 1986.

Mass-Burn Entrepreneurship

Wheelabrator Technologies, a mass-burn leader based in Danvers, Massachusetts, has eight facilities in operation, serving 5 million people; the facilities treat 4.5 million tons of refuse annually and produce 325 MW daily. With three more facilities under construction and 12 under development, the company plans to double its capacity by 1991.

Having pioneered the country's first privately funded mass-burn plant in 1975 at a landfill north of Boston, the company now has nearly 30 plant-years of experience with mass-burn technology. Some of its inventions are in their second or third generation.

What Wheelabrator has learned is reflected in its present policy: take control of the entire process "and make sure it's done right," according to Bill Keightley, managing director. This includes total design of the facilities and equipment. "We get what we want, whereas others have to go for the low bidder." Wheelabrator also prefers to control landfill for the residue produced by mass-burning MSW. Although it delivers residue to some municipalities, Wheelabrator believes that in the future it will increasingly handle the residue. The company is also becoming involved at the front end of the process: this summer, in Newton, Massachusetts, it began curbside collection of garbage, which it burns in its Millbury plant.

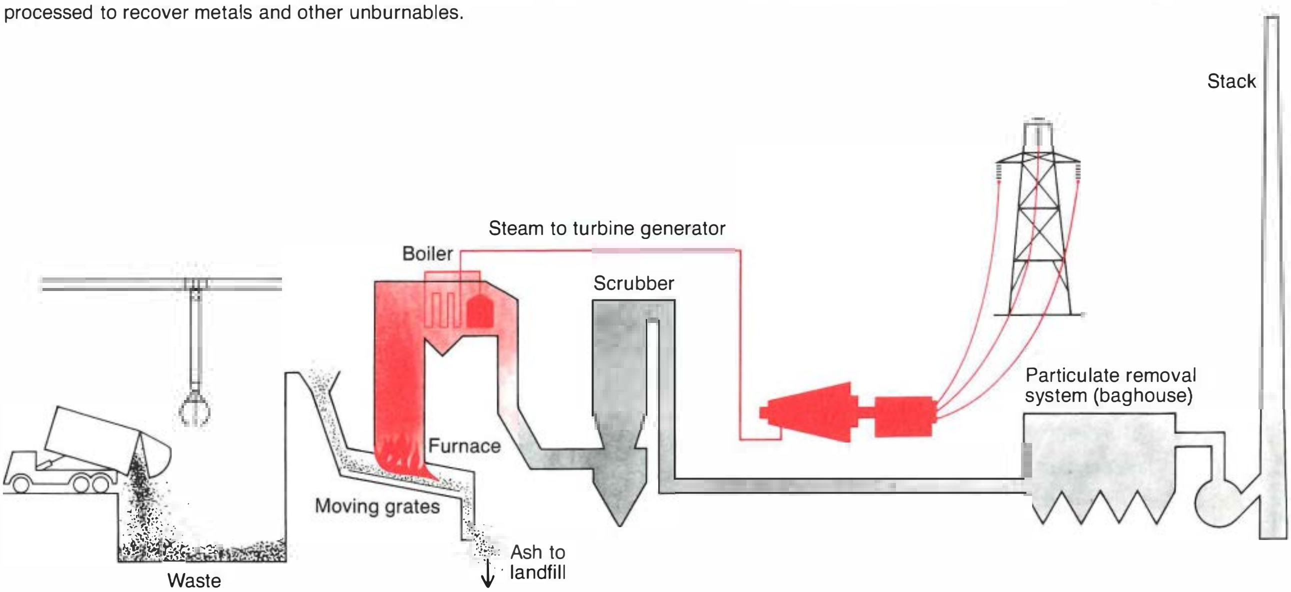
Even as Wheelabrator pursues vertical integration of its operations, it is also extending itself laterally. The company recently agreed to explore the potential for jointly developing a mass-burn facility with Kansas City Power & Light.

Although proponents of RDF technology may disagree, Wheelabrator spokesman David Tooley believes that "the most successful of the resource recovery plants are those that mass burn. RDF plants have front-end processes. There's not much gained by the shredding; and the more moving parts the more problems." Items such as nylon stockings can jam moving parts. Tooley also points to an Achilles' heel of shredding—the potential for explosion if sparks ignite dust—and notes that RDF facilities are built with blow-off roofs. Tooley emphasizes that while mass burning does not demand recycling, it's not incompatible with it, although it's usually left to municipalities to sort out recyclable and hazardous materials.

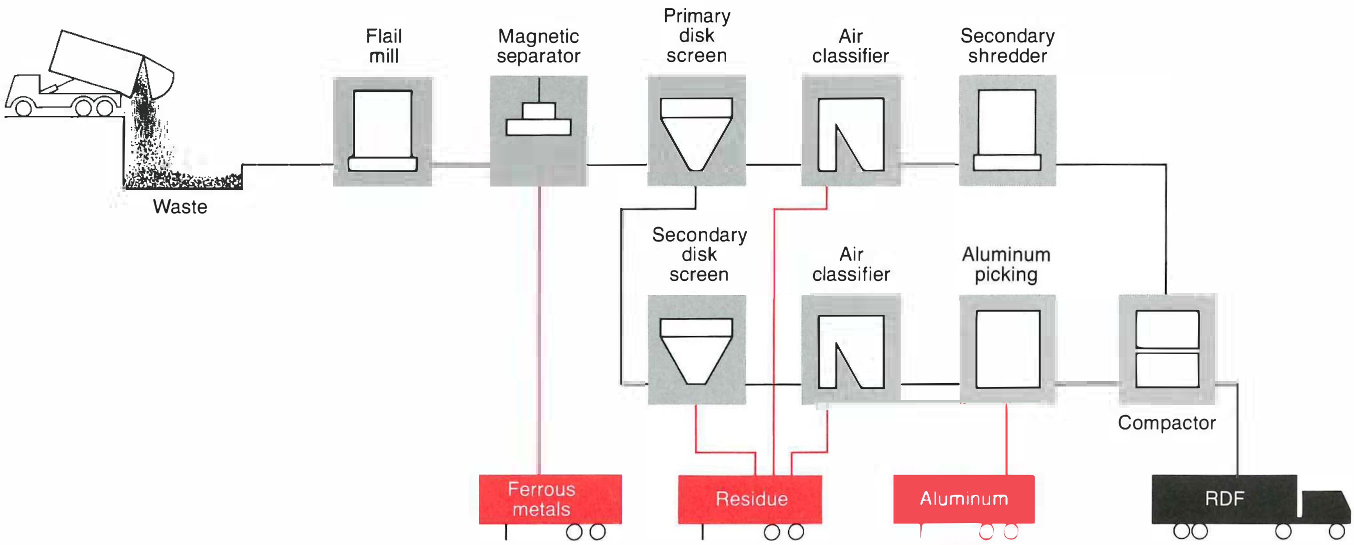
Just how successful are mass-burn facilities? All those constructed by Wheelabrator are still operating. Last year the company did a $1 billion business, earning $25 million. Most of the earnings came from getting rid of garbage, not producing power. For example, in the 45-MW Millbury plant, enough steam was produced to save about $11 million in fuel oil, but $26 million was generated by fees from processing municipalities' refuse. Despite the very high capital outlay for mass-burn facilities, this option is perceived as economically competitive in many communities, particularly where landfill is scarce or nonexistent. □

Options for Energy Recovery

Mass burning of refuse is a relatively straightforward process, but it must be done in a facility designed for the nonuniform, slow-burning material. Raw garbage is loaded from a storage pit onto moving grates that feed it slowly through a specially designed furnace. Hot gases from the burning refuse generate steam that can be passed through a standard turbine generator for electricity production. Combustion gases from mass burning continue through scrubbers and particulate removal systems to ensure environmental compliance. The furnace ash can either be buried directly in landfill or be processed to recover metals and other unburnables.



Refuse-derived fuel, or RDF, can be burned in standard utility boilers with a minimum of modification; however, turning raw refuse into RDF is an involved process in itself. The waste feed is first moved through a flail mill, where hammers break it into small pieces, and a magnetic separator removes ferrous metals for recycling. The remaining waste is separated by size and weight with disk screens and air classifiers. Much of the heavier material is aluminum, which can also be recycled, while the lighter fraction contains most of the combustible material. This light, uniform fluff—RDF—is compacted and trucked to the utility for burning. The small portion of unburnable, nonmetal waste is disposed of in landfill.



will process half again as much MSW, 1500 tons a day from five counties.

NSP's Newport operation has been a model of effective planning and cooperation. But like many facilities, both mass burn and RDF, the project has had its share of technical problems. A transfer load-out line initially moved too slowly for peak times; the operation was speeded up by transferring nonburnable items directly to a truck and taking them to landfill. Hammers in the flail mill had to be changed because the original models wore out too quickly. Another problem discoverable only in operation was that the MSW moisture content is lower than the specifications had assumed and than the equipment is designed for, a difficulty still being addressed. And for a while there were too many nonprocessible items—mattresses, rugs, "white goods" (e.g., refrigerators), and hazardous wastes—showing up at the plant. While the plant has the right to refuse them, doing so requires better sorting by both the plant and county receiving stations.

More dramatic have been two fires. One in May (unrelated to the RDF process) shut down part of the transfer system and resulted in a one-day outage. Another, two weeks later, was caused by waste processing in the presence of very high temperatures. This time the system was down for three days. It was discovered that the water deluge system had not been properly placed, and it has been adjusted. NSP and the municipality are confident that operations to date have flushed out any crucial bugs in the system. "In fact," says Patrick Story, the counties' projects manager, "the plant is beautifully designed."

Problems also provide opportunities. A number of entrepreneurs have techniques for recycling plastics into strong, low-cost material usable by the automobile industry, and they are exploring ways to contract with the counties to collect plastic bottles and carpets before they enter the waste stream.

As for profitability, there's a potential for it, but it's not yet being realized. Rate commissions place ceilings tied to the consumer price index on profits utilities may make from supplying power, but RDF generation is not regulated. "We hope ultimately to make better than a regulated rate of return," says Barb Braun Halverson, NSP media representative.

As with mass-burn plants, NSP charges tipping fees—$41.50 a ton in 1988—and charges customers for power. Although the counties issued bonds to build the plant and have guaranteed to provide it with a certain amount and quality of MSW, NSP bears the brunt of the financial risk. It backed the bonds and this December begins its payoff to retire them. But, as Story affirms, "Nobody wants NSP to fail. If it does, everybody's out." It's part of Story's job to see that it doesn't, and he is sanguine about success. "Cooperation between NSP and the counties is second to none," he explains, "and the efficiency just keeps getting better and better."

Story notes the gratifying response at various government levels to the need for boosting efficiency further and addressing the legitimate concerns of all parties. For example, the state recently passed a law mandating that beginning in 1990 all yard waste be picked up separately; a study is already under way on composting yard waste plus the 7500 tons a month of RDF residue of heavy organic matter.

Interest on the rise

Motives similar to NSP's—the desire for public service and the hope of profitability—are causing other utilities to look into the possibility of converting waste into energy. Among them is Florida's Gulf Power, which is proposing a mass-burn facility for MSW. With the state pushing hard via tax incentives and disincentives to stop landfill, Gulf's Senior Project Engineer Ralph Czepluch believes that over an eight- to 10-year period it would be cheaper for the city of Pensacola to let Gulf burn its garbage than to use any other vendor. (Under the proposal, ash disposal is left to counties.) Lacking a landfill site, Pensacola now dumps its trash in Santa Rosa County; its contract expires in 1993, however, and is unlikely to be renewed. Even though Santa Rosa is still fairly rural, landfill costs are up and there's always the Nimby factor.

Regarding the mass-burn proposal, no technical problems are anticipated, financing has been worked out, and the considerable media attention has been mostly positive. With Gulf guaranteeing to have a mass-burn plant operational 42 months after receipt of the contract (allowing 24 months for acquiring the necessary permits), the ball is now in the court of the municipal players to reach a decision by next summer.

The growing awareness of the need for an integrated approach to resource recovery has sparked a conference to be held this fall in Washington, D.C. "Waste-to-Energy '88: The Integrated Market," the fourth symposium sponsored by McGraw-Hill trade publications on resource recovery, will assemble key players to explore how various components of solid-waste management can be optimally integrated.

Equations for solving MSW disposal are complex, because the variables are interdependent and are unique to each situation. Instead of viewing alternative MSW options as competitors, resource recovery researchers and managers increasingly see the need for cooperation. The problem with garbage is not that there's too little, but too much—plenty for everyone. Everyone has a part to play, from reducing waste to disposing of it properly. For utilities, it is an opportunity fraught with challenge. ■

This article was written by Anne Knight, science writer. Technical background information was provided by Charles McGowin, Coal Combustion Systems Division.

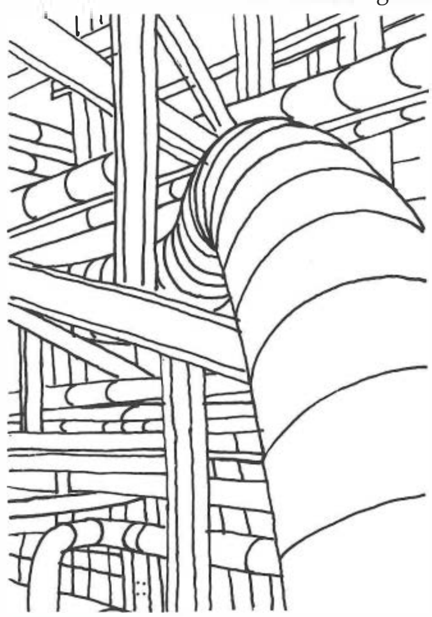
TECH TRANSFER NEWS

Degraded Piping Research Gives Utilities New Options

Nuclear utilities must periodically inspect the reactor coolant pressure boundary to determine the integrity of piping systems subject to flaws caused by such mechanisms as erosion-corrosion and thermal fatigue. Engineers have used acceptance standards in the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers (ASME) to analyze flaws in carbon steel piping and determine whether flawed pipe could be safely returned to service. In cases where flaws exceeded 10% of the wall thickness, however, no evaluation standards or procedures existed, even though many of these flawed pipes retained safety margins equal to the original design. Utilities were thus sometimes required to undertake costly pipe replacement when it was not justified by changes in safety margins. EPRI has sought to remedy this situation in an ongoing program of R&D dealing with the performance and properties of flawed piping.

Now, after more than three years of these investigations, the effort is beginning to produce new options and cost savings for utilities. After evaluating results from EPRI-sponsored research, the main committee of the ASME Boiler and Pressure Vessel Code voted this summer to accept new evaluation and acceptance criteria for flaws in carbon steel piping. This change in the ASME code, which will help utilities avoid pipe replacement in many situations, complements evaluation procedures for flawed stainless steel piping, also developed by EPRI, which were incorporated into the code in 1985. The recent work on carbon steel piping was performed by the ASME Task Group on Piping Flaw Evaluation, chaired by Douglas Norris of EPRI's Nuclear Power Division.

New acceptance criteria for piping thinned by erosion-corrosion are also now available in two new reports. These include a summary report that is generally available (NP-5911M) and a more detailed report for EPRI members (NP-5911SP). These documents update an earlier draft-for-comment version given wide distribution to EPRI member utilities. They include results that have been widely applied in both nuclear and fossil fuel plants and will form the basis for acceptance criteria now being prepared by an ASME working group.



In related work, the NRC Office of Nuclear Regulatory Research, working with EPRI, has organized an international pipe-testing program to demonstrate the margins of safety in flawed piping subject to seismic loads. Other members of the International Pipe Integrity Research Group include Canada, the United Kingdom, France, Japan, the Republic of China, Switzerland, and Sweden. In work under way, researchers are testing flawed stainless and carbon steel pipe sections and weldments under loads that simulate seismic stresses. Preliminary results indicate that many configurations of conventional piping may be more resistant to fracture than previously believed.

This three-year program of piping tests is similar in structure to work on uncracked piping that has resulted in relaxation of design requirements in Section III of the ASME Code. Two ASME code cases were passed as a result of this previous work, providing for about 20% higher allowable stresses on piping. The research has key importance for utilities because it lays the groundwork for possibly reducing the number of costly snubbers and pipe supports used to minimize stress on piping.

"Even higher allowable stresses will be pursued after the research is completed early in 1989," says Sam Tagart, technical specialist in EPRI's Component Reliability Program. "Although NRC has not yet endorsed these code cases, the research results clearly show that piping is extremely resistant to seismic loading and that eventually most piping snubbers can be eliminated." ■ *EPRI Contacts: Sam Tagart, (415) 855-2793, and Douglas Norris, (415) 855-2791*

Life Extension for Plant Electrical Equipment

By 1995 one-quarter of U.S. coal-fired plants and one-half of oil- and gas-fired plants will be more than 30 years old, creating an increased need among utilities for a systematic approach to life extension. To develop such an approach for electrical equipment used in fossil fuel power plants, utilities can turn to a new report, *Generic Guidelines for the Life Extension of Plant Electrical Equipment* (EL-5885).

The report, which complements earlier generic guidelines covering major mechanical components in power plants (CS-4778), begins by addressing such issues as scheduling and data acquisition for a life assessment and extension program. The next section introduces a procedure for assessing equipment life on the basis of historical plant data, visual inspection and examination, monitoring, and diagnostic testing. A detailed review of 11 major electrical equipment systems follows, covering generators and exciters, transformers, electric motors, switchgear, motor control centers, power and control cables, bus systems, protective and auxiliary relays, batteries, cathodic protection systems, and grounding systems. The final section outlines a plan for using life assessment data to schedule the refurbishment or replacement of equipment.

By following the general method and detailed procedures presented in this guideline, utilities with life extension programs can make cost-effective decisions about electrical equipment. ■ *EPRI Contact: Jan Stein, (415) 855-2390*

A Guide to Fabric Filters

Utilities using fabric filter baghouses on coal-fired power plants face many different decisions related to baghouse design and operations and periodic cleaning of filter bags. For guidance on making these decisions, utilities can refer to a new report, *Fabric Filters for the Electric Utility Industry*, Volumes 1 and 2 (CS-5161).

Volume 1 of the report provides an introduction and technical overview for baghouse applications in coal-fired utility boilers. This information will help utility engineers design more-effective systems, improve specifications for purchases or modifications, and develop procedures to reduce operating costs. Volume 2, a guide to sonic cleaning of filter bags, describes the cost-effectiveness of sonic horns and their potential for increasing the efficiency of reverse-gas-cleaned and shake-deflate-cleaned baghouses. This volume also provides practical guidelines on selecting, installing, testing, and operating sonic horns.

The two volumes are part of a planned multivolume series that will cover design considerations, bags and fabrics, flue gas dynamics, reverse-gas cleaning, shake-deflate cleaning, pulse-jet cleaning, combined SO_2 collection, and operation and maintenance. ■ *EPRI Contact: Walter Piulle, (415) 855-2470*

Utilities and Probabilistic Risk Assessment

Nuclear utilities are making increased use of probabilistic risk assessments (PRAs) to analyze risks and make informed decisions on plant modifications. Now utilities can turn to a new report, *The Practical Application of Probabilistic Risk Assessment* (NP-5664), to assess the factors affecting the success of these efforts.

In compiling the report, EPRI organized interviews with more than 50 individuals from 10 nuclear utilities to provide information on what was done, what benefits the utility received, and what program characteristics enhanced or inhibited success. Although all the utility participants stated that the benefits of PRAs warranted the development costs, some reported considerably larger benefits. Utilities that performed PRAs primarily to satisfy NRC requirements achieved their original objectives, but with few subsequent benefits. For others, particularly those using PRAs for purposes such as identification of more cost-effective design alternatives and procedures, benefits have continued to accrue.

The report cites tangible benefits that specific utilities have gained from their PRA programs and identifies factors that had strong impacts on program success. These factors include the experience and credibility of program personnel, the production of detailed plant-specific models, and advocacy on the part of senior management. ■ *EPRI Contact: John Gaertner, (415) 855-2933*

CHANGES AT EPRI

The following changes have been announced that will affect future contact with EPRI staff members:

- In October four groups—the Advanced Power Systems Division, Coal Combustion Systems Division, Plant Electrical Systems Rotating Machinery Program, and Materials Support Program—were merged under Vice President Kurt Yeager into a new Generation and Storage Division. The change is expected to streamline operations and improve member access to technical resources. The new divisional organization will be reflected in the next issue of the *EPRI Journal*.
- Vice President Fritz Kalhammer has announced that as of early 1989, his Energy Management and Utilization Division will be known as the Customer Systems Division. The name change has been instituted to better reflect the industry's increasing focus on its customers.

Nuclear Fuel Behavior

FREY: A Fuel Rod Evaluation Code

by Ching-lu Lin, Nuclear Power Division

ABSTRACT *Over the past several years, EPRI has been sponsoring the development of the FREY code for evaluations of LWR fuel rod behavior. The code follows a mechanistic modeling approach and utilizes up-to-date physical and material models that are well known in the technical community. The unique characteristics of FREY make it a suitable tool for transient fuel analysis in reload licensing, plant support, and diagnostic evaluations of problems related to fuel behavior. Extensive verification and validation analyses have been performed using a wide range of test reactor transient experiments, as well as power reactor fuel performance data. FREY is well documented and is now being tested by a utility working group. Its formal release is planned in the very near future.*

Nuclear fuel technology has advanced significantly in the last decade as a result of extensive R&D efforts undertaken by both industry and government. As a participant in these efforts, EPRI has contributed technical and financial support to domestic and international fuel projects. The analysis and computer modeling of fuel behavior has been an important part of EPRI activities. One result is FREY, a key to transient fuel behavior analysis.

FREY is a best-estimate code that employs two-dimensional finite-element formulation with fully coupled thermal-mechanical modeling. It can analyze fuel behavior under both steady-state and rapid-transient conditions. Utility fuel analysts can use FREY for fuel behavior evaluation, plant support, and fuel reload licensing analyses.

Under normal conditions, reactor fuel is subjected to power maneuvers dictated by many operational requirements, which include reactor control procedures, load following, and reactor shutdowns and startups. In the early years of nuclear fuel experience, such power maneuvers had caused fuel failures that were attributed mainly to a phenomenon known as pellet-clad interaction (PCI). The fission gas in fuel rods could then escape through the failed cladding, causing an increase in off-gas level, thereby impacting plant availability. During the past decade, efforts on the part of both industry and government organizations directed at the development of improved nuclear fuel utilization have resulted in an impressive record of fuel reliability.

The primary motivation for these efforts has been the significant economic incentives associated with reduced fuel cycle costs, increased reactor availability, and operational flexibility. Minimizing the economic impact of plant derating and prolonged outages, such as those caused by operational events in which fuel integrity may be affected, would be of equal or even greater benefit to nuclear power plant owners. The FREY code, with its two-dimensional mechanistic modeling for both (r,z) and (r,θ) geometries, provides the analytic means to diagnose fuel problems associated with power maneuvers and operational events to help develop operational remedies.

A complete reload licensing analysis includes the analysis of design basis events (DBEs) for which fuel limits have been specified. As an advanced and detailed fuel behavior code, FREY can help utilities meet their fuel analysis needs. FREY applies to LWR fuels and can be specialized to specific BWR or PWR fuels by means of an extensive array of user options. This flexibility will save utilities resources in code maintenance and quality assurance costs.

Plant support tool

Generic operational events that affect fuel response are generally considered in advance and accounted for either in the fuel design or in plant operating procedures. Although they do not compromise the safety of the reactor if they occur, some of the operational events, such as a sudden change of core coolant conditions or local power, could cause local excessive heat load on the fuel. Induced failure is a possible consequence of the mechanical interaction of fuel pellet and cladding.

Such events may result in derating of the reactor, followed by time-consuming inspections for possible fuel damage during plant outages. With its mechanistic modeling, the FREY code can provide realistic estimates of the fuel condition following such events. Moreover, FREY provides the analytic means to develop a fuel preconditioning procedure to avoid fuel damage on subsequent resumption of power operation. In this application, the FREY code becomes an operation support tool for diagnosing fuel problems and developing operational remedies.

FREY can also be used to diagnose the phenomenon of localized waterside cladding corrosion, which occurs in certain reactor environments. FREY's (r,θ) two-dimensional finite-element formulation allows the close simulation of such an asymmetric phenomenon. Utility engineers used FREY to analyze locally corroded rods under various operating conditions and were able to propose remedies for mitigating their effects. Figure 1 shows the results of this analysis, in which the effects on power are quantified as a function of ramp rates. With such a figure and worst-case assumptions on defect size, one can determine operating power regimes that are unaffected by this phenomenon.

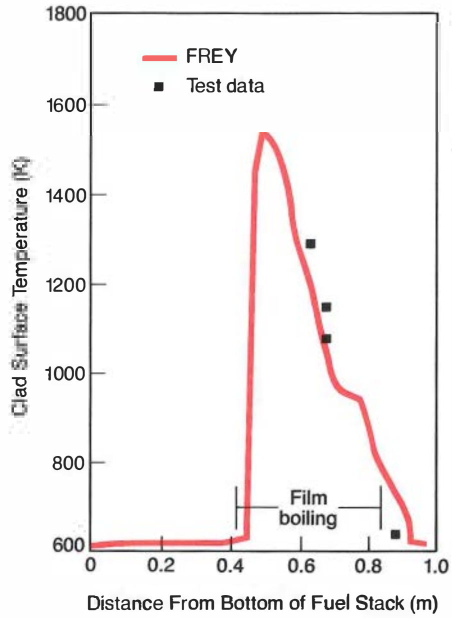
In recent years, nuclear fuel manufacturers have been seeking greater economy for nuclear fuel utilization through new fuel design, longer fuel cycles, and more convenient refueling schedules. These changes will impose new requirements on fuel performance, and the development of new, more detailed models will be needed. FREY's modular structure and the mechanistic modeling approach will provide users with an easy transition and extrapolation to new applications.

Fuel reload licensing tool

Established procedures for licensing fuel reloads require that each licensee demonstrate that the new fuel reload or proposed operating procedure will not violate previously established limits. A reload analysis includes performing and/or reviewing both steady-state,* transient, and accident analyses. The transient and accident analyses include a broad spectrum of design basis events for which acceptable fuel limits have been specified and result in operational limits for the reactor plant being analyzed. In some cases, such as plant changes that affect the fuel limits, it may be necessary to use a fuel transient code such as FREY to demonstrate the acceptability of these operational limits.

FREY's ability to analyze these DBEs is demonstrated by analysis of experiments simulating three representative events. These transients, conducted in test reactors, are frequently much more severe than those in the power reactors if they occur. Analyzing such transient experiments is thus a good test of the FREY code.

Figure 2 FREY's capability to analyze DBEs for reload licensing has been demonstrated through simulation of experiments under similar but far more severe conditions. This figure shows the cladding temperature calculated by FREY versus test data of a flow reduction experiment conducted in a test reactor.



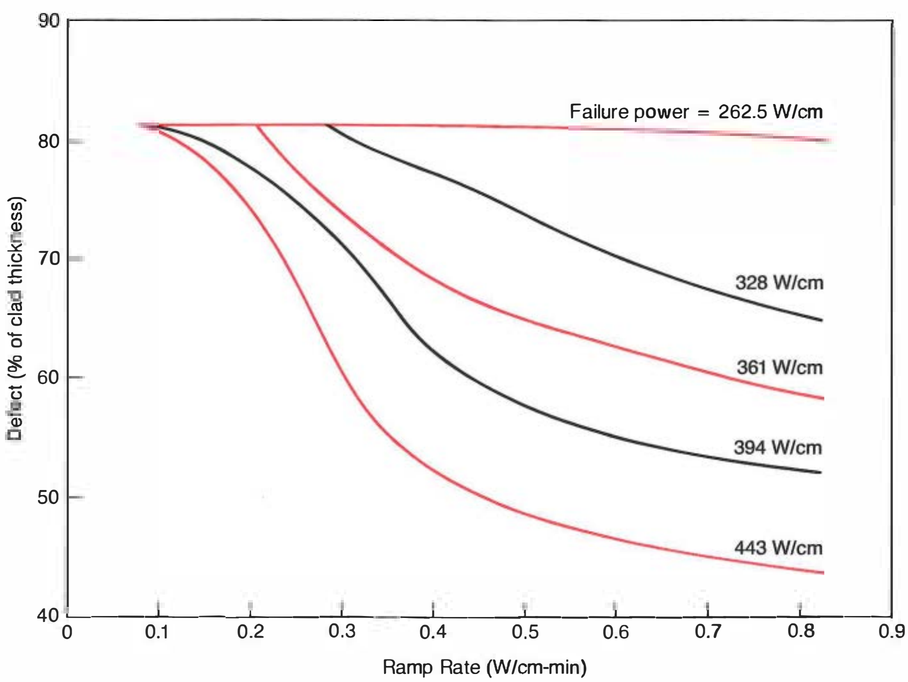


Figure 1 FREY is a tool for plant operational support. The locally corroded fuel rods were analyzed for various combinations of defect size, power, and ramp rates. The operating power regimes that are unaffected by the localized waterside corrosion phenomenon are to the left of the failure power curves.

*The ESCORE code has been developed by EPRI to perform the steady-state reload fuel analysis.

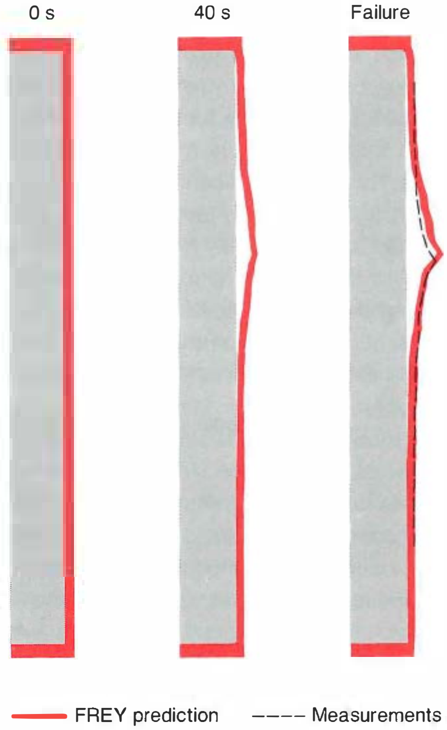
One class of DBEs is caused by a primary pump malfunction that reduces coolant flow so that the coolant does not efficiently transport the thermal energy generated by the fuel. Figure 2 presents FREY's predictions of the peak outer clad temperature and compares them with test results of such an experimental transient. Considering the complexity of the physical phenomena involved in transient fuel behavior and the many sources of uncertainties in the experimental measurements and interpretation of the data, the differences between FREY calculated and experimental values are within expectations.

Another, and a more severe, class of transients that FREY is designed to handle is the hypothetical inadvertent rod ejection (or rod drop) accident, in which local power spikes occur in fuel rods that are directly affected by displacement of the control rod. The magnitude of the power spike could reach significantly higher levels than the fuel rod's linear power rating in a fraction of a second. Because of the short duration of the power spike, the fuel thermal response lags behind and the fuel temperature remains relatively low, in most cases several hundred degrees below melting. The specified acceptable design limits for this type of transient are given in terms of the stored energy in the fuel and the peak cladding temperature. Comparison of the results of these experiments and FREY calculations shows that the calculated temperatures are higher by about 13%. The stored energy calculated by FREY is 197 cal/g, compared with the experimental value of 185 cal/g. Considering the uncertainties stated above, these results are in reasonably good agreement with the measured data.

Under current fuel reload licensing procedures, a loss-of-coolant accident (LOCA) is handled through special procedures. The three phases of a LOCA are blowdown, heatup, and reflood. During the blowdown phase, the cladding may be subjected to heating rates ranging from 5°C to 100°C per second, depending on the type of reactor and the characteristics of the accident. As a result of this rapid heating, the internal pressure induces cladding strains of the order of 30–100%. As a problem in thermomechanical analysis, this type of response requires detailed constitutive modeling and computational efficiency. FREY's simulation of this type of transient is illustrated in Figure 3, which shows close agreement with experimental measurements.

These three examples give a representative cross section of reactor transients for which FREY's capabilities have been benchmarked. FREY is capable of analyzing the entire spectrum of hypothetical transients that make up the DBEs used in reload licensing.

Figure 3 FREY's prediction of fuel clad swelling during a LOCA experiment compared with test results.



Fossil Fuel Generation Systems

Steam-Injected Gas Turbines Versus Combined Cycles

by Art Cohn, Advanced Power Systems Division

Steam-injected gas turbine (SIGT) power plants have reached the stage of commercial availability. A number of SIGT packages in the range of 1–50 MW are now being marketed, and there are at least 10 installations operated by nonutility cogenerators in the United States. These include three applications of the General Electric LM5000 gas turbine, which has the best heat rate of the offered steam-injected units and at 50 MW comes closest to the unit size of interest to utilities. The emerging SIGT technology is a potential competitor to the more established combined-cycle technology for power plant applications.

SIGT technology

Like a combined-cycle system, a steam-injected gas turbine system has a heat recovery steam generator (HRSG) downstream of the turbine exhaust. The combustion gases are passed through the HRSG to heat pressurized water to superheated steam. In the SIGT system, however, this steam is injected back into the gas turbine itself—rather than into a separate steam turbine, as in the combined-cycle system.

Most of the steam is injected into the combustor region of the gas turbine, where it is mixed with the combustor air and heated up

ABSTRACT *Steam-injected gas turbine systems are now commercially available for power plant applications. These systems, which use turbine exhaust gases to produce steam for injection back into the gas turbine, are a potential competitor to combined-cycle systems. Under EPRI sponsorship, Jersey Central Power & Light has conducted a site-specific comparative analysis of the two technologies. The study concluded that for power plants of about 150 MW or greater, combined-cycle systems are preferable, primarily because of heat rate and capital cost. Steam-injected systems appear to be a competitive option for small applications (~50 MW) and also merit consideration for energy parks that produce steam as well as electric power. The study's conclusions have been reviewed and unanimously endorsed by a panel of engineering executives from a wide range of utilities.*

to the turbine inlet temperature. Some lower-pressure steam can be injected downstream into the turbine spools. SIGT power plants do not require steam turbines, condensers, or cooling towers. However, although the injected steam is heated to the turbine inlet temperature, its expansion ratio is limited to that of the turbine section, and the quantity of steam is limited by the turbine's swallowing area.

The optimal pressure ratio for a gas turbine in a combined cycle is in the 12–15 range. For the steam-injected gas turbine, an early EPRI study showed the optimal ratio to be much higher—above 20. The General Electric LM5000, an aircraft derivative, has a pressure ratio of ~30 and a high turbine inlet temperature, features that make it excellent for conversion to steam injection. Moreover, with an output of ~50 MW, it is the most powerful of the available units and hence the most logical candidate for utility use.

Comparative analysis: cost and heat rate results

Jersey Central Power & Light, under contract to EPRI, has recently completed a technical assessment comparing LM5000 steam-injected units with combined-cycle units for specific power plant applications. The study was made for two of the utility's generating stations—the Gilbert station, located inland on the Delaware River, and the Forked River station, located on an inlet of the Atlantic Ocean. For each technology at each site, the study evaluated fixed costs and operating costs, environmental compatibility, and power plant flexibility.

The SIGT power plant was compared with standard combined cycles at a series of power levels. The base case, the one of most interest to Jersey Central, involved the 350- to 400-MW category. This pitted a plant with seven LM5000 steam-injected units against a standard combined-cycle plant with three General Electric MS7001E gas turbines. For further comparison, a combined cycle using two of the more advanced General Electric MS7001F gas turbines was also considered.

Capital cost and heat rate quotes were obtained from equipment vendors by Sargent & Lundy, the project subcontractor. Three different vendors supplied quotes for the LM5000-based plants. Sargent & Lundy also designed the plant layouts. Nonreheat combined cycles were used, as specified by Jersey Central. On the basis of the performance quotes, the overall fixed and variable costs were calculated by using the EPRI-developed GATE program.

As Table 1 indicates, in the large, 350–400-MW category, the combined cycles had considerably lower fixed costs and lower variable costs than the SIGT plant. Even though they included steam turbine, condenser, and cooling tower equipment, the combined-cycle plants had the capital cost advantage. The main factor here was the high cost of the LM5000 steam-injected unit: it cost about twice as much, on a per kW basis, as the heavy-duty units used in the combined-cycle plants. In each case the heat rate of the combined cycles was significantly better than that of the steam-injected system. The other factors evaluated—environmental compatibility (discussed below), operating flexibility, and potential availability—slightly favored the SIGT plant. However, they were overwhelmed by the large economic advantage of the combined-cycle plants.

For the 350–400-MW power plant, the combined-cycle and steam-injected options differed distinctly in terms of gas turbine capacity and the number of turbines required. Therefore, the researchers also made a comparison based on gas turbines of more nearly equal size. In this case the plants were about 150 MW. An SIGT plant

Table 1
COMPARISON OF STEAM-INJECTED GAS TURBINE POWER PLANTS AND COMBINED-CYCLE POWER PLANTS

	Large Plant			Midsize Plant		Small Plant	
	SIGT	Standard CC	Advanced CC	SIGT	CC	SIGT	CC
Output (MW)	349	363	426	149	167	49	55
Capital cost ($/kW)	817	585	536	962	875	1237	1247
Capital charge ($/kWyr)	119	85	78	139	127	179	181
Heat rate (Btu/kWh)	9115	8230	7710	9150	8430	9200	8590
Levelized fuel cost ($/kWh)	0.056	0.050	0.047	0.056	0.052	0.056	0.053
Levelized O&M cost ($/kWh)							
3500 h/yr	0.012	0.011	0.010	0.018	0.017	0.033	0.033
5000 h/yr	0.010	0.008	0.008	0.013	0.013	0.024	0.025
7000 h/yr	0.008	0.007	0.007	0.011	0.010	0.018	0.019
Levelized total cost ($/kWh)							
3500 h/yr	0.102	0.086	0.079	0.114	0.105	0.140	0.137
5000 h/yr	0.089	0.076	0.071	0.097	0.090	0.116	0.113
7000 h/yr	0.081	0.070	0.065	0.087	0.080	0.100	0.098
Nonlevelized total cost ($/kWh)							
3500 h/yr	0.064	0.051	0.047	0.073	0.067	0.094	0.093
5000 h/yr	0.053	0.042	0.039	0.058	0.054	0.073	0.072
7000 h/yr	0.045	0.037	0.034	0.049	0.046	0.060	0.059

Note: The analysis assumed a fuel cost of $2.50 per million Btu, a fuel levelizing factor of 2.45, and an O&M levelizing factor of 1.68.

with three LM5000 units was compared with a combined-cycle plant built around three General Electric MS6001 gas turbines. The combined-cycle system had three HRSGs (one for each gas turbine) and one steam turbine.

In this midsize category, the SIGT plant again had both a higher capital cost and a higher heat rate (Table 1), resulting in higher fixed and variable costs. Although the differences between the two options were smaller than in the 350–400-MW case, they were large enough to establish the combined-cycle plant as preferable. It should be noted that on a per kW basis, the combined-cycle costs were considerably greater for the 150-MW size than for the 350–400-MW size. Thus, the large combined-cycle plant offers considerable savings over the midsize one.

Even though Jersey Central was not interested in any smaller-sized power plants, the project did compare plants of about 50 MW. At this size, the SIGT plant had one LM5000 unit and the combined-cycle plant had one MS6001 unit. Since the steam plant of the combined-cycle system was only about 15 MW, its contribution in terms of efficiency and capital cost was expected to suffer. Hence it seemed possible that the steam-injected system would be competitive in this range. This was found to be the case. The combined-cycle plant had a somewhat better full-power heat rate, but the SIGT plant had a slightly lower capital cost (Table 1); as a result, the overall economics of the options were about equal.

Utility panel review

The results of the comparative assessment were reviewed by a panel of engineering executives from Florida Power Corp., Florida Power & Light, the Salt River Project, Texas Utilities, Green Mountain Power, the Southern Company, and Northeast Utilities. The panel concurred with the study's conclusions for the Jersey Central sites—that is, that the combined-cycle option would be superior at both 350–400 MW and 150 MW. More important, the panel concluded that these findings would apply throughout the industry for pure power stations larger than about 50 MW.

For plants of about 50 MW or smaller, the panel felt that the operating complexity of the combined-cycle steam turbine (and its demands on personnel time) would outweigh the fuel savings of that option; the members concluded that they would probably choose the steam-injected system for this application. However, both the SIGT and combined-cycle plants of this size would have much higher costs than the larger combined cycles, and the panel agreed that a plant of 50 MW would be an atypical generation addition.

The panel recommended that further studies be conducted to assess advanced steam-injected units not yet on the market and to examine a case study involving both steam and electricity demand.

Although the ~50-MW steam-injected unit appeared to be competitive, utility generation expansion plans typically do not call for plants this small. Thus the possibilities for utility application of SIGT technology seem limited at this time. However, utilities with total heat and power applications or with cogeneration subsidiaries would be advised to consider steam-injected units for small installations serving both steam and electricity demand.

Environmental factors

Environmental compatibility was extensively investigated, since this has been an area of uncertainty concerning the steam-injected cycle. The evaluation focused on two factors—plume incursion and water usage.

In general, the impact of the SIGT stack plume was found to be smaller than the combined impact of the two plumes connected with combined-cycle technology, the stack plume and the cooling tower plume. Because of differences in plume buoyancy, specific geographical features could in some cases be more affected by an SIGT plant plume than by combined-cycle plumes. However, the Jersey Central sites were not adversely affected by this phenomenon.

The total water use of the steam-injected units was only about 70% of the cooling tower and boiler makeup requirements of the combined-cycle units. However, since all the water for the steam-injected units had to be processed to boiler quality, they required about five times the high-quality-water and demineralization processing capacity of the combined-cycle units. The blowdown impurity and disposal requirement of the steam-injected units was also five times as high, but this was not found to cause any licensing problems.

Recovering water from the stack could help meet the requirements of steam-injected units for high-quality water. A special study in this project found that essentially complete water recovery could be accomplished with about an 11% increase in capital cost and a 1.2% increase in heat rate. The cost of removing combustion impurities from the water depends on the fuel burned; it is expected to be small for natural gas, but it could be considerable for distillate No. 2 oil. At any rate, such a water recovery feature should be considered for arid locations, where the recovered water could be put back into the water table if it was not processed for reuse. For the New Jersey plant sites, the extra costs for water recovery would not be offset by reduced water makeup costs.

Overhead Transmission

New Responses to Transmission System Challenges

by James Hall, Electrical Systems Division

Designing transmission lines to meet today's utility requirements involves a variety of criteria that generally were of little concern to design engineers 30 years ago. There are pressures to provide increased energy transfer; yet, at the same time, it is more difficult to obtain new rights-of-way because of concerns about environmental and electrical effects. Utilities need sophisticated design tools for use both in designing new transmission lines and in upgrading existing lines—an alternative that is receiving increased attention.

Improved analysis methods developed for EHV and UHV power transmission are being used to improve transmission system power transfer at lower voltage levels. This article examines issues in, and approaches to, improving transmission system design: reducing electromagnetic effects, voltage upgrading, compact line design, the use of common corridors, and increasing conductor loading up to thermal limits.

Electric and magnetic field effects

Environmental considerations are an increasingly important factor in transmission line design. Electric fields are evaluated in terms of their effect on individual safety and comfort in the vicinity of lines and their effect on radio and television reception. There is significant interest in magnetic fields because of possible health effects. A computer program has been developed to calculate electric and magnetic fields in terms of line configuration, ground resistance, voltage, and loading. The program, ENVIRO, was developed by research engineers at EPRI's High-Voltage Transmission Research Center (HVTRC) in Lenox, Massachusetts. It is one of the task modules for the TLWorkstation,* an integrated system of software for transmission line design.

Voltage upgrading

When energy transfer to a load center must be increased but corridors for new transmission lines are not available, existing tower strength is inadequate for larger diameter conductors, and the existing corridor is not wide enough to accommodate a parallel line, the only alternative may be to increase the voltage on the existing line. Research for EHV and UHV transmission lines has demonstrated that the electrical design of many older lines is conservative. When that is the case, the line voltage can be increased quite easily. Line design adequacy can be verified through the TLWorkstation task modules. For example, ENVIRO can be used to determine conductor surface gradients, electric and magnetic fields, and audible noise profiles.

Another task in voltage upgrading is to determine insulator performance and radio and television interference. A TLWorkstation task module for radio noise, RNOISE, is in the final stage of testing. Methods for determining insulator performance are described in EPRI's *Transmission Line Reference Book: 345 kV and Above*, 2d ed. (EL-2500).

If insulator contamination performance is inadequate but lightning and switching surge performance is acceptable, one solution is to use improved insulation—for example, nonceramic/composite insulators. Silicone rubber insulators have demonstrated contamination performance that is superior to that of porcelain insulators. If lightning and switching surge performance are acceptable, line compaction (discussed below) is another alternative.

If a line is undergoing voltage upgrading and the original conductor and hardware are retained, special attention is required to avoid excessive electrical effects from the higher electrical stresses. It may be neces-

*TLWorkstation is an EPRI trademark.

ABSTRACT *There are increasing pressures on utility transmission systems. Limitations on new utility generation, requirements to purchase power from cogenerators, deregulation, competition for customers, and power wheeling are placing demands on transmission systems for which they were not designed. Moreover, regulatory and environmental constraints are making it increasingly difficult and time-consuming to gain approval for and install new lines. To help utilities get the most out of their transmission systems in the face of these challenges, EPRI is developing sophisticated design and analysis tools. These include reference books and a comprehensive, integrated library of computer software. Also, EPRI operates the High-Voltage Transmission Research Center, where utilities can test proposed transmission line designs at full scale.*

sary to install larger conductors or new hardware to avoid excessive radio interference and audible noise. Calculating the conductor gradient and the potential for excessive corona is straightforward; calculating the hardware gradient is not. To ensure that hardware corona will not be excessive and that the line will perform as designed, it may be necessary to construct a short test line. The HVTRC provides this capability.

Compact line design

Line compaction, which can be used in upgrading existing lines or in designing new lines, may be an attractive option for several reasons. These include the need to minimize right-of-way requirements, the need to reduce electromagnetic field effects or impedance effects, and minimal visual and physical intrusion.

Post-type insulators, which eliminate conductor swing, are one means of reducing right-of-way requirements. However, porcelain posts have poorer contamination performance than suspension insulators. In areas where contamination is a problem, long-creepage-path nonceramic/composite post insulators can be used to provide the needed insulation strength, or porcelain posts can be coated with silicone compound or room-temperature-vulcanized silicone rubber to improve their withstand strength.

High-phase-order transmission is a line compaction technique that can be used to reduce electromagnetic effects (Figure 1). The ENVIRO program can calculate electromagnetic effects for lines with up to 12 phases. The program has a special feature to reduce data input for 3-, 6-, and 12-phase lines; when this feature is activated, user-supplied data for the first phase will automatically be entered for the other phases.

Figure 2 presents electric and magnetic field profiles from ENVIRO for a standard double-circuit 230-kV line and a compact 6-phase 230-kV line with two conductor heights and phase-to-phase spacing of 5 ft (1.5 m). The minimum conductor height above the ground is the same for both lines. As the profiles show, the 6-phase line is comparable to the standard line in terms of electric field strength and offers a significant reduction in magnetic field strength.

For 115- to 138-kV lines, phase-to-phase spacing can be reduced from a nominal value of 12 ft (3.7 m) to as little as 3 ft (0.9 m). Information on line compaction is presented in EPRI's *Transmission Line Reference Book: 115–138-kV Compact Line Design* (EL-0100-3). Much of the information can also be applied to 230-kV compact line design.

Common corridors

The prospects for obtaining approval for a new transmission line or a line upgrade may

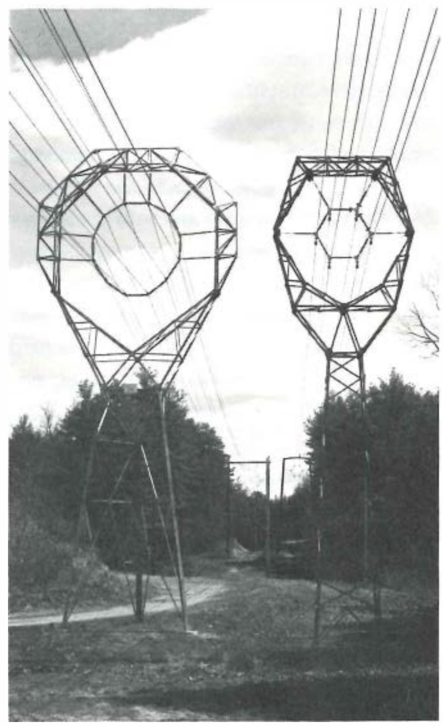


Figure 1 The 6- and 12-phase lines shown here are examples of compact line design. These lines were developed by Oak Ridge National Laboratory under the sponsorship of the Department of Energy.

be improved if the line shares a corridor with a pipeline, a railroad, or a communications conductor. Constructing new lines or upgrading existing lines along such common corridors may require the evaluation of induction effects with respect to safety issues. Two EPRI computer programs, CORRIDOR and ECCAPP, are available for making these predictions. CORRIDOR was developed for use with the IBM-AT version of the TLWorkstation. ECCAPP was developed as a stand-alone program for use with the IBM mainframe and VAX computers. CORRIDOR has been used in more than 18 transmission line–railroad site studies in the United States and has demonstrated good accuracy.

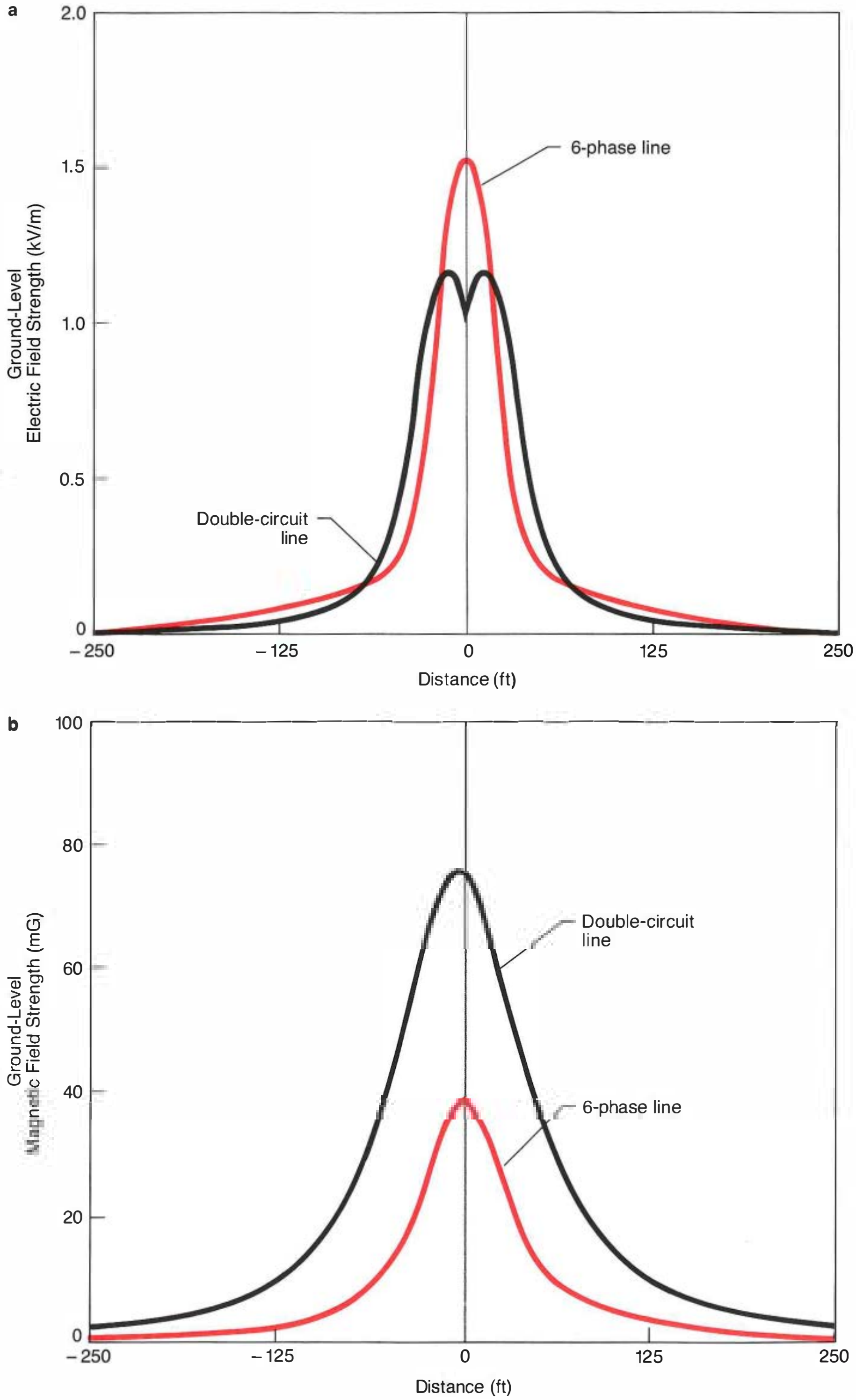
Methods for increasing conductor loading

Utility economics, together with regulatory directives (e.g., the Public Utility Regulatory Policies Act, or PURPA), environmental issues, and deregulation, are causing transmission systems to be loaded at higher levels. In many cases, these factors are causing utilities to import power from other areas. A utility may import power from distant hydroelectric generation sites, for example, or it may be required to wheel power through its transmission system to other utilities or industrial customers who are purchasing power elsewhere at a lower price.

For reasons of economic operation and reliability, long transmission lines generally are not loaded above their surge impedance loading. Historically, two parallel lines have not been loaded above 50% of their normal static rating, so that if one line tripped out, the other could safely carry the combined load. Today, however, the economic and regulatory factors cited above are exerting pressure on utilities to increase conductor loading up to thermal limits.

A major issue facing utilities is how to increase transmission line loading without exceeding the safe conductor temperature. An alternative to basing loading on a conductor's static ampacity rating is to use a method of variable thermal rating. One such method is ambient temperature adjustment.

Figure 2 The ENVIRO computer program was used to compare a standard double-circuit 230-kV line and a compact 6-phase 230-kV line in terms of (a) electric field strength and (b) magnetic field strength. The two line designs had the same minimum conductor height. The results indicate that in addition to minimizing right-of-way requirements, compact line designs can actually reduce magnetic field strength while producing comparable electric fields.



In this method, a minimal wind speed (e.g., 2 mph) and the wind direction (e.g., perpendicular to the conductor) are assumed, and the allowed current is calculated as a function of air temperature and conductor characteristics.

Another, more sophisticated method of variable thermal rating—one that is receiving significant R&D effort—is conductor dynamic thermal rating. It takes into account actual wind velocity and solar radiation as well as the ambient temperature. EPRI's DYNAMP program uses this method to predict the conductor temperature and allowed ampacity as part of an off-line dynamic rating system. Also available is an on-line system that actually monitors the conductor temperature and the meteorological conditions to predict the allowed ampacity.

One West Coast utility was required by a state public utilities commission to substitute variable thermal rating for static ampacity rating in order to accommodate cogeneration. The utility is currently using the ambient temperature adjustment method and is evaluating dynamic thermal rating as an alternative.

The HVTRC

EPRI's High-Voltage Transmission Research Center is a unique research facility. No other facility in the United States matches the HVTRC's range of transmission line research and test capabilities—a fact recognized by EPRI's member utilities when they chose to save the center by acquiring it from General Electric. The HVTRC has provided significant data to the industry on EHV and UHV line design. An important focus of research now in progress is transmission and distribution system magnetic fields.

The facility is a valuable resource where utility engineers can conceptualize and test new transmission ideas, with assistance from HVTRC engineers. The center provides the means for verifying designs with full-scale mockups or, in the case of electric fields, through small-scale modeling.

Toxics and Health

TOXRISK: Computerized Health Risk Assessment

by Abe Silvers, Environment Division

ABSTRACT *Assessing the potential human health risks of toxic substances in the environment is a demanding task and one with far-reaching consequences for utilities. EPRI has developed TOXRISK, a computer program that facilitates the risk assessment process. TOXRISK enables utility managers to communicate more effectively with regulatory agencies, to evaluate various assumptions in risk assessment, and to develop estimates of safe dose.*

Risk assessment is a methodology for inferring the risks to public health from man-made substances in the environment. Estimating the occurrence of cancer as a result of exposure to various agents has been the primary focus of risk assessments. Such estimates are usually made by exposing animals to the substances of interest and then extrapolating the results to the human population.

In these animal bioassays, rodents and other species are exposed to various doses of the substance under test. The animals are then observed until they die or are sacrificed, and extensive autopsies are performed to estimate the number of tumors. Exposed animals are compared with unexposed animals to determine if the number of tumors in the exposed group is significantly higher than that in the control group. Mathematical models are used to predict human risk at low exposure levels on the basis of results from these high-dose animal bioassays.

The predicted risk to human health from exposure to a potentially toxic chemical is determined by two equally important factors: the level of human exposure to the chemical and the potency of the chemical (i.e., its potential for producing undesirable health effects). Thus, to ensure a safe working environment and to protect the public, utility industry toxicologists and environmental managers assess both the potential for exposure and the potency of chemicals.

The risk from chemical exposure decreases as the level of exposure decreases, with the risk becoming very small at very low exposure levels. This dose-response principle is fundamental to toxicology. It implies that human health can be adequately protected by controlling the level of exposure to a toxic chemical.

To assess the potential health effects of exposure and the potential effects of regulatory proposals, utility environmental managers conduct risk assessments for substances of concern to the industry. A new EPRI computer program, TOXRISK, automates and facilitates this process.

TOXRISK methodology

A basic function of TOXRISK is to estimate safe doses of potentially toxic materials by extrapolating from animal data to predict human health effects. The user can supply estimates of exposure in order to obtain overall estimates of excess risk—that is, the incremental risk occurring as a result of exposure. Alternatively, the estimated dose-response relationship can be used to predict exposure levels consistent with predetermined low maximum levels of excess risk (e.g., 1 case in 1,000,000 exposures). To allow the assessment of risk under a range of alternative assumptions, TOXRISK implements a number of dose-response statistical procedures that estimate risks as a function of exposure. Several statistical dose-response models are included in TOXRISK, such as the linearized multistage model frequently used by regulatory agencies, K-stage models, the log-normal model, the Weibull model, and the Mantel-Bryan model.

TOXRISK also facilitates the management of toxicological data and automatically makes appropriate statistical and mathematical calculations. This enables risk managers to get the answers they need from risk assessments and ensures that appropriate mathematical and statistical procedures are being applied.

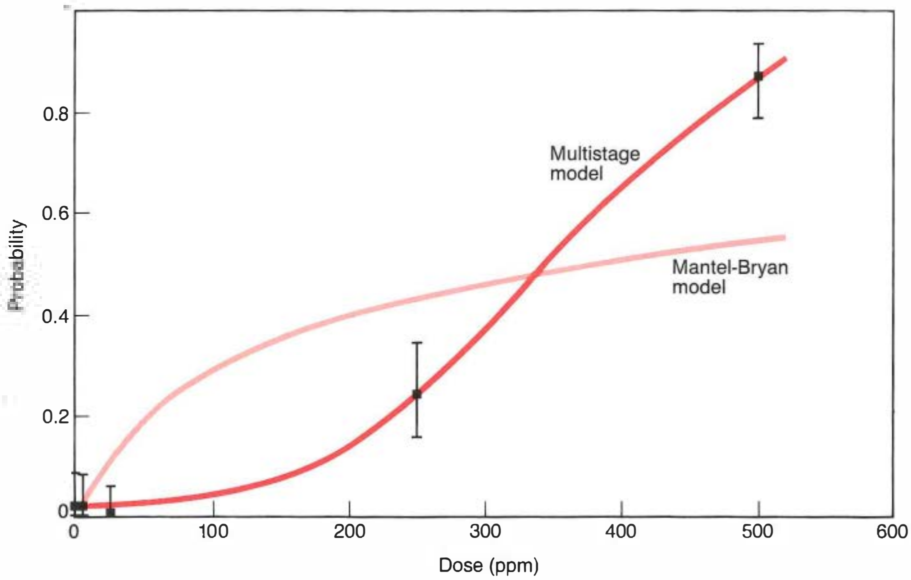
The use of TOXRISK does not replace the need for performing a careful toxicological evaluation of data and for making informed choices about the data to be used as the basis for a risk assessment. It does, however, allow the user to concentrate on those important tasks by facilitating data management and calculations.

TOXRISK features

A menu-driven interactive software package for IBM-compatible microcomputers, TOXRISK provides the user with a convenient environment in which to perform standard types of health risk assessment. The procedures implemented by TOXRISK are most frequently used in estimating carcinogenic risk. In this application, TOXRISK uses the following toxicological data: the number of animals in the various dose groups in a carcinogenesis bioassay, the experimental dose applied to each group of animals, and the number of animals in each group that acquired a tumor of the type of interest. Also used are data on body weight, breathing rate, water consumption rate, and food consumption rate both for the experimental animals and for humans.

After the toxicological data have been input, TOXRISK calculates standard statistical tests for dose-related effects. It can derive the fits of several mathematical dose-response models to the data. In each case, it gives a measure of the model's fit by providing the chi-square value and the corresponding p-value. These procedures allow the user to determine if any of TOXRISK's dose-response models adequately correspond to the data. TOXRISK can also provide graphs showing the fit of the dose-response models to the data (Figure 1).

Figure 1 **TOXRISK generates this kind of graph to show how well various dose-response models fit experimental toxicological data. Here the data points indicate, for four doses of the substance under test and for no dose, the probability that a tumor will develop in rats. The bars indicate the confidence limits for the data. TOXRISK has plotted two dose-response models (curves) against the data.**



To extrapolate from animal to human risks, TOXRISK either calculates the human risks from user-specified exposure estimates or calculates the doses that correspond to user-specified levels of risk. Users can select methods based on different routes of exposure for converting from animals to humans. The software supplies default values for animal and human parameters (e.g., body weight, breathing rate, life span) so that it is not necessary to obtain values for these from the literature before using TOXRISK. The model makes it easy to store and modify data on these parameters and facilitates their proper application in risk calculations.

The program contains many user-friendly features. Its improved algorithms permit mathematical calculations to be performed interactively in most cases. A batch feature allows several risk assessment approaches to be applied automatically to different sets of toxicological data. TOXRISK provides a summary of risk calculations performed on a group of toxicological data sets.

Data entry is accomplished by using fill-in-the-blank tables. Validation of the data takes place during data entry, which eliminates many of the common data entry mistakes. Preprogrammed selections, such as the choice of species data or dose units, are implemented through the use of pull-down windows. On-screen help appears in a special help or status window. The program can output results to a printer or to a computer screen or file. Also, the user can exit temporarily to a DOS shell to perform other DOS applications while keeping TOXRISK resident in random access memory (RAM).

TOXRISK is designed to run on IBM-compatible microcomputers with DOS 3.0 or higher. The program requires either 537K or 305K of RAM, depending on whether the graphing function is run from within TOXRISK or independently. It requires a 720K (or larger) floppy drive, or two 360K floppy drives, or one floppy drive and a hard drive (the preferred configuration). Also necessary is a numerical coprocessor chip—8087, 80287, or 80387, depending on the computer. Currently the graphing function of TOXRISK requires the use of a graphics board and Lotus 1-2-3, although a planned future modification will eliminate the need for Lotus. This and other enhancements to TOXRISK are being pursued in ongoing work. The current version is available from the Electric Power Software Center.

Radiation Control

Decontamination of BWR Fuel Bundles

by Howard Ocken, Nuclear Power Division

ABSTRACT *The first-ever decontamination of LWR fuel bundles was performed at Commonwealth Edison's Quad Cities station using the CAN-DECON and LOMI solvents. Various analyses showed substantial amounts of radioactive corrosion products were removed without inducing fuel rod damage. The intact fuel bundles were shipped to the Babcock & Wilcox hot cells for detailed examination. There was no evidence of general or localized corrosion attack by LOMI, but CAN-DECON attacked some of the small components that were fabricated with Inconel X-750.*

Decontamination of individual systems in operating reactors, such as recirculation piping in BWRs and steam generators in PWRs, is being increasingly used by nuclear utilities to reduce radiation fields and occupational radiation exposure. Because a significant inventory of radioactivity resides on the fuel rod surfaces, a longer-term goal is to decontaminate the entire plant with the fuel in place. Full plant decontamination has proved effective in CANDU and SGHWR plants, but only recently have U.S. plants seriously considered its merits. A first step is to show that highly irradiated LWR core components will not suffer any adverse effects from exposure to commercial decontamination solvents.

On-site research

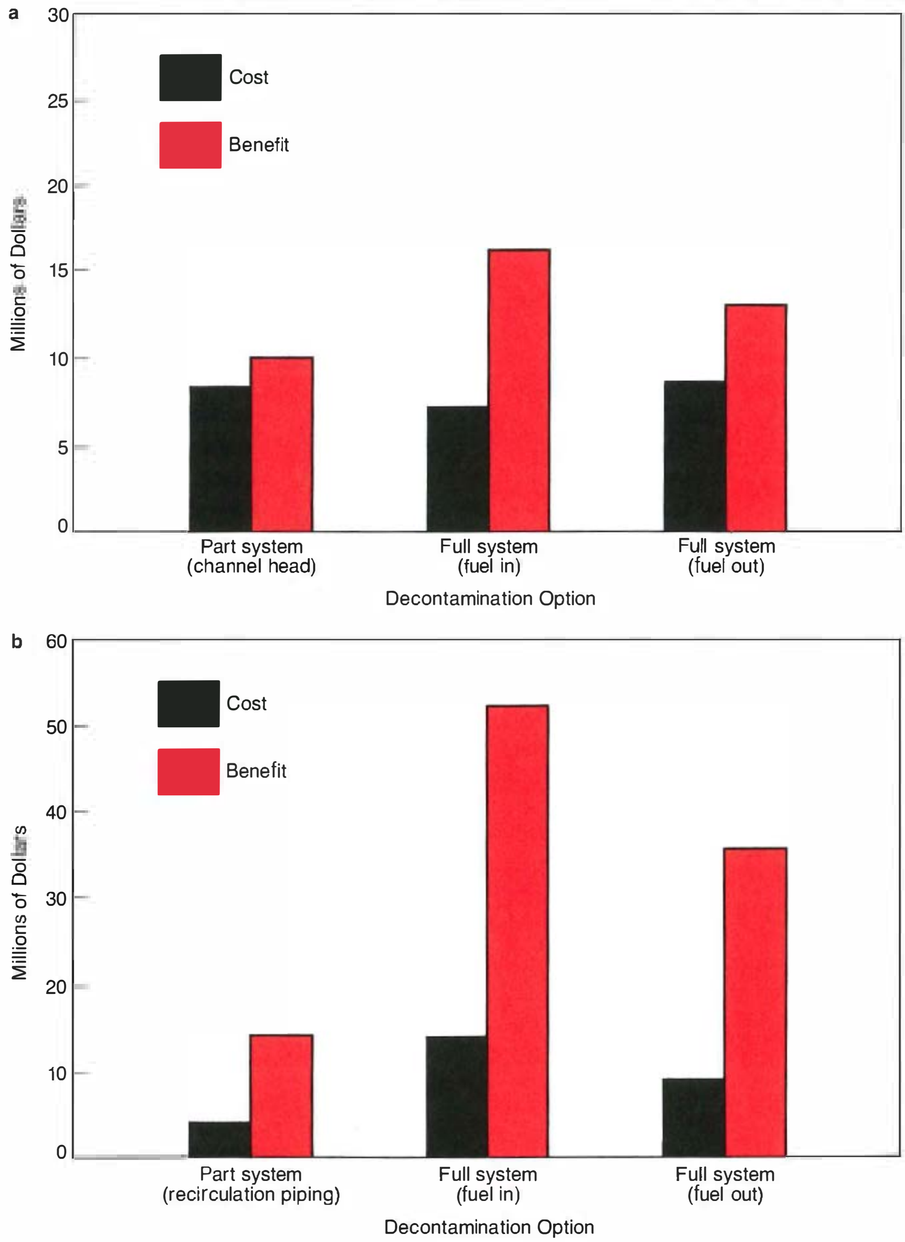
To test this idea, EPRI studied the application of the LOMI and CAN-DECON solvents to fuel bundles that had been discharged after three cycles of exposure in Commonwealth Edison's Quad Cities-2 BWR. Highly irradiated stainless steel specimens were cut from a section of a LaCrosse BWR control blade and decontaminated at the same time as the fuel bundles. CAN-DECON was selected to represent dilute chelant processes, while LOMI represented processes involving stronger reduction. Both processes were preceded by the application of an oxidizing alkaline permanganate (AP) step to facilitate dissolution of chromium. Chromium-rich oxides typically form under PWR operating conditions.

The fuel bundles had been irradiated in symmetrical positions in the reactor core and for two cycles were in adjacent locations. The bundle exposures were 29,780 MWd/t ±0.1%. A significant number of fuel rods had been fabricated from the same lots of Zircaloy cladding. The two test bundles and the one control bundle were sipped before they were decontaminated to confirm that they contained no failed fuel. The fuel channels had been reused; their discharge exposure was 50,590 MWd/t ±2%.

The decontamination took place at the Quad Cities station in May 1986. The fuel assemblies were transferred from the storage rack into a specially constructed stainless steel decontamination chamber that was positioned in the spent fuel pool. The chamber held one fuel bundle and one set of control rod coupons that was attached to the fuel channel. The decontamination and waste-handling operations proceeded smoothly at the site in accordance with procedures developed by the contractors and the host utility. The only unanticipated event was a sample line leak that developed in the pump skid near the end of the CAN-DECON application.

The metals and radionuclides removed by the decontamination processes were monitored continuously. The LOMI process removed over six times more activity than CAN-DECON did. Chemical analyses performed during the decontaminations, post-decontamination sipping of the assemblies, and isotopic analyses of the waste resins showed no evidence of fission products or transuranics. The project's key objective was met: showing that fuel crud could be removed without inducing fuel rod failure.

Figure 1 Feasibility and cost-benefit evaluations show that full-system decontamination using the LOMI process is more effective than conventional, part-system techniques for both PWRs (a) and BWRs (b). The benefits, primarily resulting from lower radiation exposure to plant maintenance workers, are calculated on the basis of $10,000 per rem avoided.



Component examination

The spent resins containing the radionuclides removed by each of the solvents were stored in separate containers, from which individual samples were taken and analyzed. The spent resins were mixed, solidified in cement, and disposed of at Commonwealth Edison's Barnwell site.

The two decontaminated bundles and a control bundle that had not been decontaminated were shipped to the Babcock & Wilcox hot cell for detailed characterization of key components, using both nondestructive and destructive examination techniques. Visual examination showed streaks on the fuel rods in the bundle treated with CAN-DECON, suggesting incomplete removal of fuel deposits; the LOMI-treated bundle was shiny, suggesting complete removal of crud.

Measurements of oxide thickness on fuel rods from the decontaminated bundles, accomplished using a nondestructive eddy current method, showed values typical of three-cycle BWR fuel. Detailed characterization of key components following bundle disassembly relied primarily on optical and scanning electron microscopy. The surface of components fabricated from Zircaloy (fuel rods, spacer grids, and channels) showed no evidence of oxide attack by the decontamination solvents. This study, in fact, marks the first time BWR fuel channels have been so extensively characterized following in-reactor exposure. Hydrogen pick-up in Zircaloy components also was typical of values for the exposure levels reached. LOMI did not attack the thin, adherent oxide layer that formed on most surfaces of Inconel X-750 components (expansion spring, lantern spring, and finger spring), and there was no evidence of damage to the underlying base metal. The finger spring in the bundle cleaned by CAN-DECON suffered severe corrosion attack, and the lantern spring, moderate attack. Neither solvent caused damage to fuel bundle hardware made from stainless steel.

Examination showed that two spacer grids were cracked in the LOMI-treated bundle. However, after the bundles were returned to the Quad Cities site, it was found that the control bundle that was not decontaminated suffered similar damage to one spacer grid. It appears that grid spacer damage was induced by vibration during shipment. Such damage is minimized or eliminated during shipment of new bundles from the vendor to the plant by the use of restraining shims, but this procedure cannot be used for irradiated bundles.

The stainless steel specimens were examined at General Electric's Vallecitos Nuclear Center. No surface attack or evidence of intergranular attack was observed with either solvent. Measurements of susceptibility to stress corrosion cracking using controlled extension rate test specimens showed about the same amount of intergranular attack (about 30–40%) at failure. Times to failure were shortest with decontaminated and control specimens that were most highly irradiated, and time to failure increased as the fluence level decreased. Therefore, no deleterious effects could be attributed to the use of the decontamination solvents. A heavy, thick film was found on the specimens treated with CAN-DECON. This surface film was readily removed by means of ultrasonics.

The incomplete removal of crud from the bundle treated with CAN-DECON and films on the stainless steel specimens treated with this solvent suggest that activity and removed metal circulating in the chamber during the CAN-DECON decontamination resulted in deposits on all surfaces (full bundles, stainless steel specimens, and chamber walls). The deposits probably occurred when flow was stopped and the temperature was reduced toward the end of the CAN-DECON test, following discovery of the leak in the sample line, mentioned earlier. Temporary repairs were completed in four hours, but during this time the fuel bundle was exposed to stagnant CAN-DECON solvent at low temperature. The deposited material was dissolved in the subsequent test with the LOMI solvent.

Future directions

The initial results obtained from this program are encouraging, and no technical arguments have emerged against using LOMI for full-plant decontamination. The absence of deleterious effects in the highly irradiated stainless steel specimen suggests that in plant applications, decontamination solvents could be passed through the reactor pressure vessel.

The results from this field test have been incorporated in a recently completed study concluding that full-system decontamination of BWRs and PWRs is technically feasible and cost-effective for both the fuel-in and fuel-out cases. The cost data for the reference PWR (Zion) and the reference BWR (Quad Cities) are shown in Figures 1a and 1b. A technical review of the fuel decontamination results and other corrosion data was carried out by General Electric. The review panel found no unresolved corrosion issues associated with the use of the LOMI solvent without a preoxidation step for full-system decontamination with fuel removed. Accordingly, EPRI and interested utilities are moving to implement such a project.

Storage Technologies

Dynamic Benefits of Energy Storage

by Bert M. Louks, Advanced Power Systems Division

An earlier article in the *EPRI Journal* (April/May 1987, p. 38) presented the purpose and rationale for developing new planning tools to assess the so-called dynamic benefits of energy storage technologies. There are several types of energy storage technologies. They are: pumped hydro, batteries, compressed-air energy storage (CAES), and superconducting magnetic energy storage (SMES). All but SMES are used commercially. This present report describes these efforts, beginning with a review of the rationale.

Normally, the benefit of energy storage is thought of as consisting only of a saving in fuel cost by using storage for peak shaving. The fuel cost saving results from using stored lower-cost nuclear and coal energy instead of premium fuels for peaking. However, peak shaving is not the sole benefit. There are others, which fall into two categories: inherent and dynamic.

Inherent benefits, as the term is used here, are those that might result from constructing storage technologies in financially less burdensome modules and/or placing them near load centers, with resulting benefits to transmission and distribution systems and with improved customer reliability. *Dynamic benefits* are those that accrue to a generation system by use of the rapid time response capabilities of storage units during the charging and discharging operational phases.

In May 1984, DOE and EPRI cosponsored a symposium on the dynamic benefits of energy storage plant operation. Representatives of utilities from various nations presented papers, many of which discussed the dynamic benefits of energy storage technologies resulting principally from their fast-start and high-ramp-rate capabilities.

ABSTRACT *Energy storage can improve the operating flexibility and reliability of electric power systems. Two new computer models—DYNAMICS and DYNASTORE—are being designed to show utilities how to reap the many dynamic benefits storage systems provide.*

Some speakers deplored the fact that the more popular production cost models do not properly capture and report dynamic benefits. These models, based on convolution of load duration curves, do not accurately represent the chronology of events. Accordingly, EPRI felt it important to fund the development of two chronological models that would include modeling the capabilities of the various energy storage technologies—DYNAMICS and DYNASTORE. Decision Focus is developing DYNAMICS; Electric Power Consulting is developing DYNASTORE.

DYNAMICS is mathematically sophisticated, using Lagrangian relaxation optimization techniques for unit commitment and dynamic programming for unit dispatch. DYNASTORE uses a simpler heuristic technique for unit commitment and the conventional equal lambda method for unit dispatch. DYNASTORE also permits interactive unit commitment. An interim report on DYNASTORE has been published (EPRI AP-5550).

This article describes specific dynamic benefits the two computer codes are addressing, together with preliminary measures of some of them.

- Spinning reserve benefits
- Minimum load benefits
- Ramp rate benefits
- Frequency regulation
- Other benefits

Because energy storage technologies have quick-start capability, a storage plant can provide the spinning reserve often carried by thermal units any time stored energy is available. With storage providing spinning reserve, thermal units (which otherwise would be derated to provide spinning reserve) can now operate up to full capacity at lower heat rates, resulting in an appreciable saving in fuel cost. In addition, during charging, both the charging and storage capacity can be classified as spinning reserve, thereby relieving extra generating capacity for spinning reserve duty.

When storage is not available, a unit providing spinning reserve operates at less than full capacity (unit 2 in Figure 1a). However, when storage is available (Figure 1b) and when storage is being charged, the charging load and storage capacity qualify as spinning reserve, allowing unit 2 to run at full capacity.

When the storage unit is generating at less than its full capacity, its reserve capacity qualifies as spinning reserve, and unit 2 is permitted to continue at full output. For a period after 6 p.m. (see Figure 1b) when storage energy is nearly depleted, unit 2 has to provide spinning reserve. However, over the day, the cost of electricity for cus-

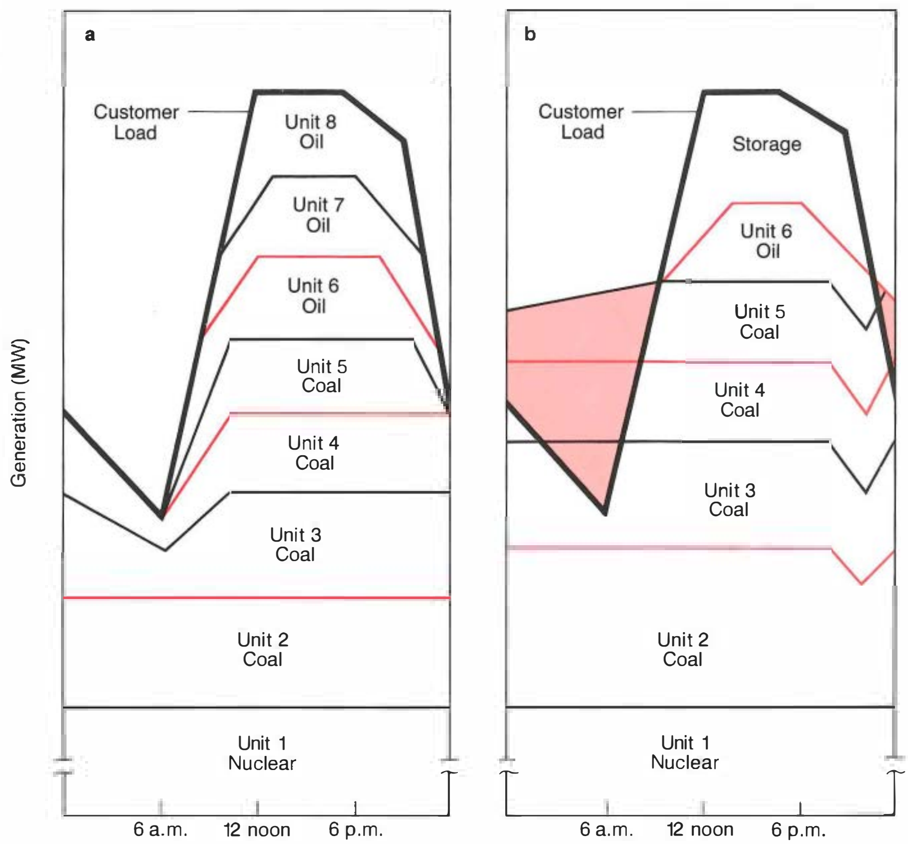


Figure 1 This figure is a very stylized drawing of a daily load curve, showing how generation units are dispatched throughout the day (a) when the system does not include energy storage, and (b) when it does. In figure 1b, unit 2, which is less expensive to operate, can run at full capacity while the storage system provides spinning reserve. Shaded area on b represents energy used for charging the storage plant.

tomer load is lowered because unit 2 (which is, on the average, cheaper to run than the overall generation mix) is able to generate at a higher output level and at a better heat rate.

At nighttime, when customer load is at a minimum, some units are operating at minimum loads with very poor heat rates, or they are shut down. With energy storage on the system, units otherwise minimum-loaded at night can operate at higher capacities and better heat rates when providing electricity to charge storage. Or, alternatively, unit shutdowns and startups might be avoided for the same reason. In this latter case, startup and added maintenance costs resulting from thermal cycling can be avoided.

These benefits are apparent in Figure 1. Without storage, unit 4 cannot be backed down to less than one-third of full capacity for process hardware reasons. As a result, unit 3 must be backed down (at most) to one-half of its capacity. These units are then operating at less than optimum efficiencies for 10 hours of the day. However, the units can operate at full capacity and maximum efficiencies for all 24 hours when storage is available, and electricity for customer load can be generated at lower fuel costs.

Because of the minimum load, unit 5 must be shut down at midnight and restarted at 6 a.m. when storage is not available. With storage, this unit can operate all day, and startup and added maintenance costs from on-off cycling can be avoided.

Figure 1 also illustrates ramp rate benefits. Without storage, units 3, 4, 5, 6, and 7 cannot ramp up fast enough to supply required load. In each case, early startup of more-expensive units is required to help meet load. As shown in Figure 1b, ramping limits of units 3, 4, and 5 are no longer a problem, and energy from storage is used to assist unit 6 in meeting customer load.

Another ramp rate benefit occurs when load suddenly decreases at night. If thermal units cannot ramp down fast enough, a utility has two choices. First, it can start ramping down units only when load begins to fall. But if ramping down rates are too slow, surplus electricity may be generated, which will have to be "dumped" to neighbors at times when they may not need it. Second, thermal units can be ramped down before load begins falling. This action would result in turning down inexpensive units sooner than economically justified, as shown in Figure 1a. Storage can help by ramping down its generation to follow the load and/or switching into its charging mode to absorb the dumped power.

Energy storage is also ideal for frequency regulation because of its rapid ramping capability. All storage technologies can provide frequency regulation because of their fast ramp rate capability. All, except for pumped hydro, can do this function in both charge and discharge modes. Pumped hydro can do this function only in discharge mode.

Frequency regulation requires that a certain amount of megawatt output in a unit be reserved for the regulation function. This is called regulating reserve or regulating margin. Regulating margin can be thought of as a more stringent form of spinning reserve. It is spinning reserve on a unit that is equipped to maintain system frequency.

Like spinning reserve, frequency regulation costs money because it requires a certain amount of spare generating capacity to be dedicated and reserved. Frequency regulation may cost more because only certain units with the necessary setup can serve that duty. For example, if an expensive oil-fired unit is needed for frequency regulation all the time, it must be on-line all the time, even when it is not economical for it to be on-line.

The advantage of having energy storage for frequency regulation is that it may allow a steam unit to be taken off frequency control and loaded to its output, where it is at its most cost-effective level. Therefore, even if the economics do not require the storage plant to be operated at its maximum capacity, its spare capacity under frequency control is worth additional savings.

Energy storage may provide several other benefits. One can be called capacity credit. For example, Figure 1b shows that when storage is available, units 7 and 8 can be placed in standby reserve. Another benefit can accrue when there is a sudden forced outage of a thermal unit. In this instance, storage facilities can rapidly cover the outage and keep it covered until reserve combustion turbines can be brought on-line. This benefit is in addition to the spinning reserve benefit previously described. The previous benefit is the value of providing "standby" spinning reserve. The benefit of covering a forced outage is the value of the ability of storage facilities to instantaneously cover the outage. Storage facilities can also be used for voltage and power factor correction.

Dynamic benefits will most likely vary considerably from system to system. Using a small sample system and the DYNASTORE code, the following benefits were calculated. They are expressed in capital costs equivalent to the daily saving in operating cost, assuming the savings occur 200 days a year.

- Spinning-reserve benefit: $450/kW of storage capacity
- Load-following benefit: $60/kW of storage capacity
- Minimum load benefit: $80/kW of storage capacity

Side-by-side sample case runs using DYNAMICS and DYNASTORE codes indicate that they produce similar results. Both codes have been tested by utilities with satisfactory results, although the interpretation of results from the DYNAMICS code at the present time has to be done with care.

Energy storage can improve the operating flexibility and reliability of electric power systems and can yield many more benefits than the single peaking fuel cost saving that many credit to energy storage. EPRI is hopeful that such models as DYNAMICS and DYNASTORE will be able to exhibit many of these additional benefits.

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NP-5793 Final Report (RP2455-13); $32.50
Contractor: Robert L. Cloud Associates, Inc.
EPRI Project Manager: T. Griesbach

Catalytic Methods of Deoxygenating Water
NP-5794 Final Report (RP1571-2); $25
Contractor: Atomic Energy of Canada Limited Research Co.
EPRI Project Manager: T. Passell

Control-Room Deficiencies, Remedial Options, and Human Factors Research Needs
NP-5795 Final Report (RP1637-6); $32.50
Contractor: Joseph L. Seminara
EPRI Project Manager: H. Parris

Hydrogen Water Chemistry to Mitigate Intergranular Stress Corrosion Cracking: In-Reactor Tests
NP-5800M Final Report (RP1930-4); $25
NP-5800SP Final Report; $15,000
Contractor: ASEA-Atom
EPRI Project Manager: D. Cubicciotti

Method for Detecting Resin Leakage in LWR Coolant
NP-5802 Interim Report (RP1447-2); $25
Contractor: The American University
EPRI Project Manager: T. Passell

Effects of Liquid Droplets on Fuel-to-Fluid Heat Transfer in Rod Bundles With and Without Blockages
NP-5809 Final Report (RP959-5); $32.50
Contractor: University of California at Los Angeles
EPRI Project Manager: J. Sursock

Experimental Simulation of a Small-Scale Babcock & Wilcox Reactor Model
NP-5811 Final Report (RP2304-1); $40
Contractor: SRI International
EPRI Project Manager: J. Kim

A Proof-of-Concept Transient Diagnostic Expert System for BWRs
NP-5827-SR Special Report; $32.50
EPRI Project Manager: J. Naser

PLANNING AND EVALUATION

EPRI Fuel Forecast Review, Vol. 1: 1984–1986 Research Results
P-5711 Final Report (RP2369-20)
Contractor: Putnam, Hayes & Bartlett, Inc.
EPRI Project Manager: H. Mueller

Capital Requirements for the U.S. Investor-Owned Electric Utility Industry: 1985–2005
P-5830 Final Report (RP1920-3); $25
Contractor: Putnam, Hayes & Bartlett, Inc.
EPRI Project Manager: S. Chapel

New Computer Software

The Electric Power Software Center (EPSC) provides a single distribution center for computer programs developed by EPRI. The programs are distributed under license to users. No royalties are charged to nonutility public service organizations in the United States, including government agencies, universities, and other tax-exempt organizations. Industrial organizations, including nonmember electric utilities, are required to pay royalties. EPRI member utilities, in paying their membership fees, prepay all royalties. Basic support in installing the codes is available at no charge from EPSC; however, a consulting fee may be charged for extensive support.

For more information about EPSC and licensing arrangements, EPRI member utilities, government agencies, universities, and other tax-exempt organizations should contact the Electric Power Software Center, Power Computing Co., 1930 Hi Line Drive, Dallas, Texas 75207; (214) 655-8883. Industrial organizations, including nonmember utilities, should contact EPRI's Manager of Licensing, P.O. Box 10412, Palo Alto, California 94303; (415) 855-2866.

DCMP: Methodology for the Integration of HVDC Links in Large AC Systems
Version 1.1 (PRIME); EL-4365
Contractor: Manitoba HVDC Research Center
EPRI Project Manager: Mark Lauby

DIRECT: Transient Energy Function Program
Version 1.2 (IBM, VAX); EL-4980
Contractor: Ontario Hydro
EPRI Project Manager: Giora Ben-Yaacov

DTAC: Data Transfer and Conversion
Version 1.1 (IBM, VAX); EL-4294
Contractor: Boeing Computer Services
EPRI Project Manager: Mark Lauby

EFIAS: EPRI Fuel Inventory Access System
Version 1.0 (IBM-PC); P-5724
Contractor: Lotus Consulting Group
EPRI Project Manager: Howard Mueller

EXPOCALC: Exposure Measurement Tool for Transmission Line Electric Fields
Version 2.1 (IBM-PC); EA-5765
Contractor: Enertech Consultants, Inc.
EPRI Project Manager: Stanley Sussman

FORECAST MASTER: Statistical Forecasting Package
Version 2.1 (IBM-PC); EM-5309
Contractor: Business Forecast Systems
EPRI Project Manager: Ray Squitieri

FORETELL: EPRI Forecasting Toolkit
Version 1.0 (IBM-PC); EM-5095
Contractor: Burns & McDonnell Energy Co.
EPRI Project Manager: Steven Braithwait

FOWL: Fossil Fuel Combustion Waste Leaching
Version 1.12 (IBM-PC); EA-5742-CCM
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: Ishwar Murarka

FUELBURN: EPRI Fuel Burn Forecasting System
Version 1.0 (IBM-PC)
Contractor: Applied Decision Analysis, Inc.
EPRI Project Manager: Howard Mueller

MIDAS: Multiobjective Integrated Decision Analysis System
Version 1.1 (IBM-PC); P-5402
Contractor: Mark S. Gerber Associates
EPRI Project Manager: Hung-Po Chao

NORGE-P: Nuclear Reload Management
Version 4.4 (IBM-MVS, CDC)
Contractor: S. Levy, Inc.
EPRI Project Manager: Walter Eich

RELIEF: Customer Response to Interruptible and Curtailable Rates
Version 1.0 (IBM-PC); EM-5630
Contractor: Laurits R. Christensen Associates
EPRI Project Manager: Philip Hanser

RTGC: Calculating Rating of Temporary Grounding Cables
Version 1.0 (IBM-PC)
Contractor: Ontario Hydro
EPRI Project Manager: Richard Kennon

SABCGPP: Simulator-Analyzer for Binary-Cycle Geothermal Power Plants
Version 1.0 (IBM-PC); AP-5253
Contractor: ESSCOR
EPRI Project Manager: Jonne Berning

SAFER: Stress and Fracture Evaluation of Rotors
Version 9.1 (VAX); EL-5593
Contractor: EPRI NDE Center
EPRI Project Managers: James Edmonds, Ramaswan Viswanathan, Thomas McCloskey

SIMTRAN-E: A SIMULATE-E to RETRAN-02 Datalink
Version MOD1 (IBM, CDC); NP-5509
Contractor: EI International
EPRI Project Manager: Walter Eich

SIMULATE-E: Three-Dimensional Steady-State Analysis of LWR Power Reactors
Version 3-A (IBM, CDC); NP-4574s-CCM
Contractor: S. Levy, Inc.
EPRI Project Manager: Robert Breen

SSSP: Small-Signal Stability Program
Version 1.0 (VAX); EL-5798
Contractor: S. Levy, Inc.
EPRI Project Manager: Mark Lauby

TANKS: Underground Tank Risk Management Model
Version 3.0 (IBM-PC)
Contractor: Decision Focus, Inc.
EPRI Project Manager: Victor Niemeyer

CALENDAR

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

DECEMBER

5–7
Information and Automation Technology for Serving Electric Utility Customers in the 1990s
Scottsdale, Arizona
Contact: Veronika Rabl, (415) 855-2401

7–9
Resolution of Seismic Issues in Low-Seismicity Regions
Orlando, Florida
Contact: Carl Stepp, (415) 855-2103

13–14
Seminar: Competition and Competitive Assessment Methods
Washington, D.C.
Contact: Sherman Feher, (415) 855-2838

13–15
Power System Operations: Research Needs and Priorities
Dallas, Texas
Contact: David Curtice, (415) 855-2832

MARCH

7–9
Symposium: Energy Utilization
San Francisco, California
Contact: David Rigney, (415) 855-2419

7–9
Solid-Particle Erosion in Steam Turbines
New Orleans, Louisiana
Contact: Tom McCloskey, (415) 855-2655

APRIL

18–20
Workshop: Coal Weighing and Sampling
St. Louis, Missouri
Contact: Clark Harrison, (412) 479-3503

MAY

2–4
4th National Conference on Demand-Side Management
Cincinnati, Ohio
Contact: Steven Braithwait, (415) 855-2606

Authors and Articles


Iveson


Kalhammer


Stringer


Maulbetsch


Schneider


Alpert


McGowin

Supercomputers for the Utility Future (page 4) was written by John Douglas, science writer, with guidance from **Bob Iveson,** staff technical adviser for EPRI's Electrical Systems Division.

Iveson is responsible for strategies in transmission research, including matters of computer architecture, software development, artificial intelligence, and mathematics. For nine years, until last February, he had managed the Power System Planning and Operations Program. He was previously with New York State Electric & Gas Corp. for 20 years, including nine years as supervisor of transmission planning for the New York Power Pool. Iveson graduated in electrical engineering from Rensselaer Polytechnic Institute and earned an MS from Syracuse University. ■

Directions in Exploratory Research (page 16) was written by Ralph Whitaker, *Journal* feature editor, with background supplied by four EPRI specialists in exploratory research management.

Fritz Kalhammer, an EPRI vice president and the director of the Energy Management and Utilization Division since 1979, has also been responsible for directing exploratory research for the past two years. He came to EPRI in 1973 to guide R&D in fuel cells and battery energy storage. Formerly he was with SRI International for 12 years, where he managed the electrochemistry program. Kalhammer has BS and MS degrees in physics and a PhD in physical chemistry from the University of Munich.

John Stringer, manager of the Materials Support Program, helped organize EPRI's exploratory research program and initially served as its technical director. He came to EPRI in 1977 from the University of Liverpool, where he had taught for 17 years, eventually heading the metallurgy and materials science department. Stringer holds bachelor and doctoral degrees in engineering from Liverpool.

John Maulbetsch, one of two senior science advisers for exploratory research, was named to that post after 12 years with the Coal Combustion Systems Division, where he successively managed programs in heat, waste, water management, and air quality control. He previously worked for seven years as a research director with Dynatech Corp. Maulbetsch earned BS, MS, and PhD degrees in mechanical engineering at MIT.

Tom Schneider, also a senior science adviser, has been with EPRI since 1977; first as program manager for energy storage, then as director of the Energy Utilization and Conservation Technology Department, and recently (on loan) as president of the Lighting Research Institute. Prior to working at EPRI, he worked as a research physicist at New Jersey's Public Service Electric & Gas Co. for four years. Schneider has a BS in science from Stevens Institute of Technology and a PhD in physics from the University of Pennsylvania.

Sy Alpert, named Research Fellow in January 1988, has been at EPRI since 1973, first as technical director for synthetic fuels and later as technical director for the Advanced Power Systems Division. Before he came to EPRI, Alpert had worked for 15 years at Hydrocarbon Research, Inc., and briefly for Chem Systems and SRI International. Alpert graduated in chemical engineering from the Polytechnic Institute of Brooklyn and earned an MS in economics at Rutgers. ■

Energy From Waste: Recovering a Throwaway Resource (page 26) was written by Anne Knight, science writer, in cooperation with **Charles McGowin** of EPRI's Coal Combustion Systems Division.

McGowin, who is the division's technical manager for analysis, also manages R&D on municipal solid waste conversion and the economics of fluidized-bed combustion. Before joining EPRI in 1976, he was a senior research engineer with Shell Development Co. for seven years. He graduated in applied science from Lehigh University and also earned a BS in chemical engineering there. He has MS and PhD degrees from the University of Pennsylvania. ■

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

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October/November 1988

EPRI JOURNAL

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