Turbines for Tomorrow

ELECTRIC POWER RESEARCH INSTITUTE

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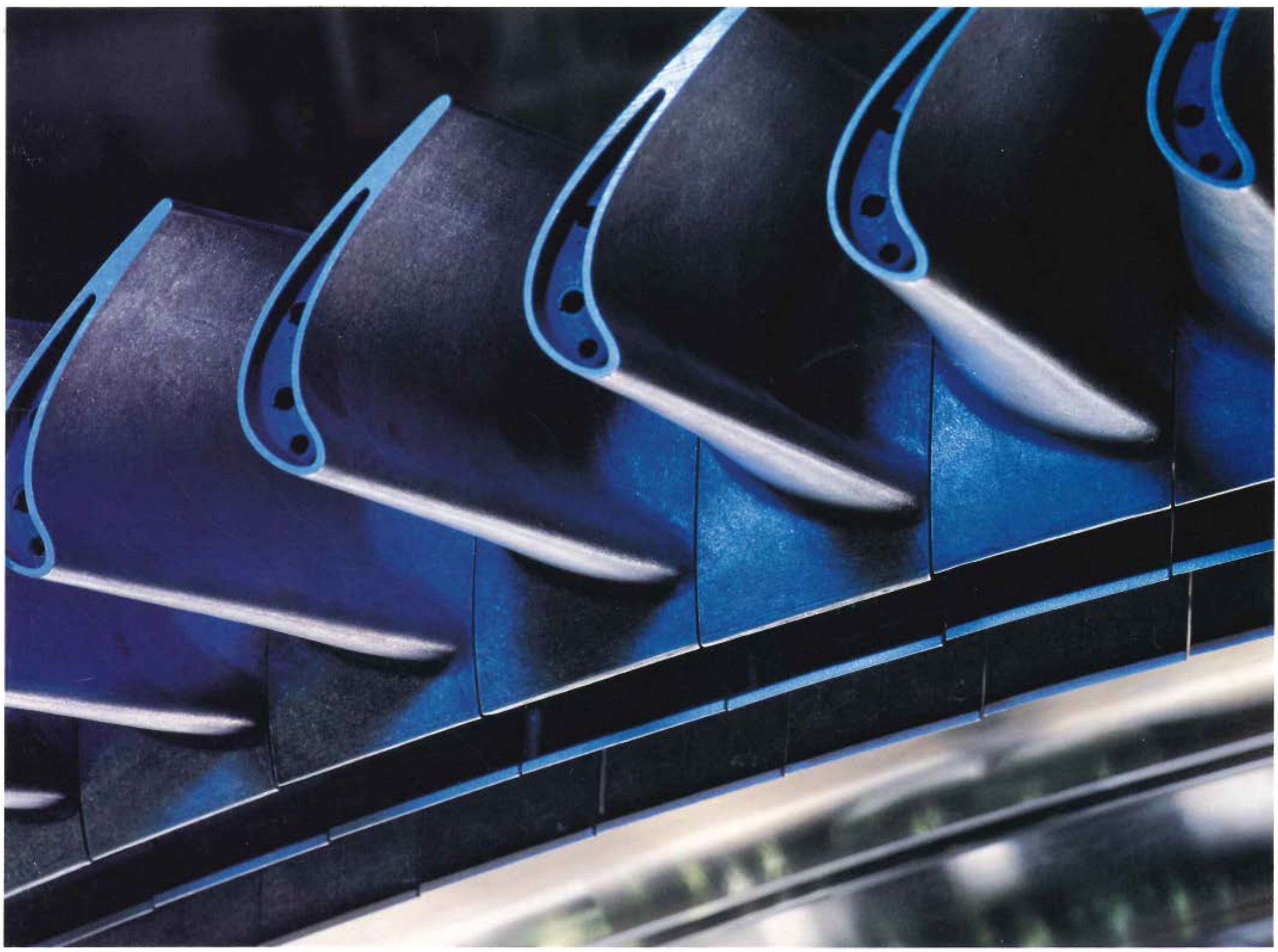

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Cover: Blades of General Electric's advanced combustion turbine, the Frame 7F model, which is now being manufactured in Greenville, South Carolina. Higher efficiencies and power ratings of the new machines emerging from several manufacturers are attractive to utilities considering capacity additions. (Photo by Ron May)

EDITORIAL

Combustion Turbines: A Resurgence of Interest

Combustion turbines may dominate the new generation additions expected over the next 10 to 12 years, according to recent analyses, possibly contributing 40–60% of a total new generation market of about 100 gigawatts. Thus, CT's are going to be pushed back into the spotlight, and as with any featured player, their strengths and weaknesses will be of particular interest. Although flexibility, efficiency, and cost are undeniable strong points, reliability has seldom been good for combustion turbines in utility service.

As EPRI became convinced of the potential for integrated coal gasification–combined-cycle power plants (IGCCs) in the 1970s, it was clear that the operating availability and mean time between forced outages of combustion turbines had to be improved dramatically if these systems were to become acceptable to our industry. As a consequence, EPRI initiated a major effort with all domestic CT manufacturers in the mid 1970s to enhance the inherent reliability of their offerings. This led to the design and development of a new breed of utility combustion turbines for which reliability and availability are as important as performance and cost.

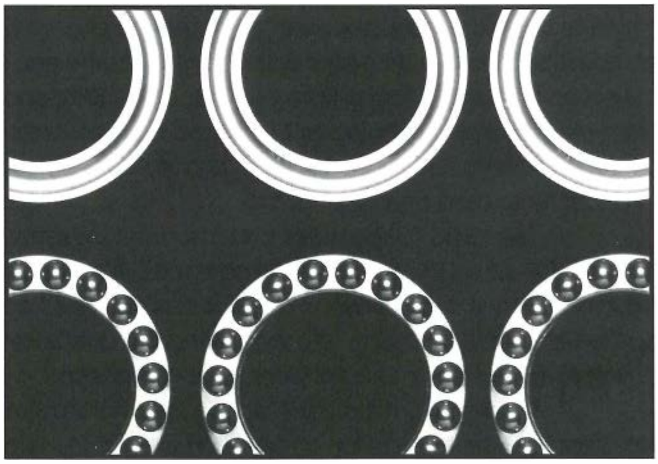
This effort is now paying off. The new turbines are much more mature in design and can be fired with oil, natural gas, or now even gasified coal. Improved structural alloys, coating materials, and cooling design innovations permitted increasingly higher turbine-firing temperatures, which translate to greater efficiency and fuel economy. But hotter firing temperatures can themselves challenge the machines' reliability, posing demanding requirements for on-line diagnostic monitoring and advanced cooling and design techniques.

Utilities typically have not provided rigorous O&M for their CTs because they were operated only a few hundred hours a year. Attitudes are changing, however, as utilities increasingly view combustion turbines as a strategic bridge to combined-cycle conversion and, eventually, to baseload operation on clean syngas from coal, as at the EPRI-sponsored Cool Water IGCC demonstration plant. The new turbines beginning to be offered by manufacturers appear ideal as the heart of such modular, phased IGCC construction, and several utilities have announced plans to pursue that route to capacity expansion in the 1990s.

The IGCC projects will provide some measure of how successful we have been in enhancing CT reliability, but the real proof will be their performance in meeting near-term peak power demand. EPRI is in a unique position to assist utilities as they deploy this new generation of combustion turbines, in testing and evaluating the durability and reliability of the machines, as well as developing new tools and software for their upkeep.

Meanwhile, even more-advanced, more-powerful combustion turbines are on the manufacturers' design boards for introduction around the turn of the century. Such present and expected developments, coupled with EPRI's commitment to improving operational performance and reliability, should give utilities confidence that combustion turbines can play a key role in meeting future demand for power.

Dwain F. Spencer, Vice President
Advanced Power Systems Division



DEPARTMENTS

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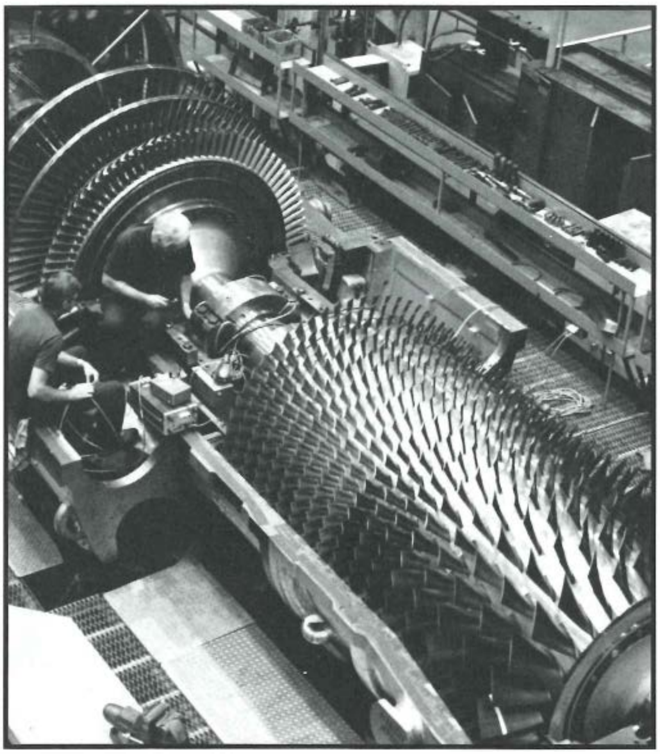

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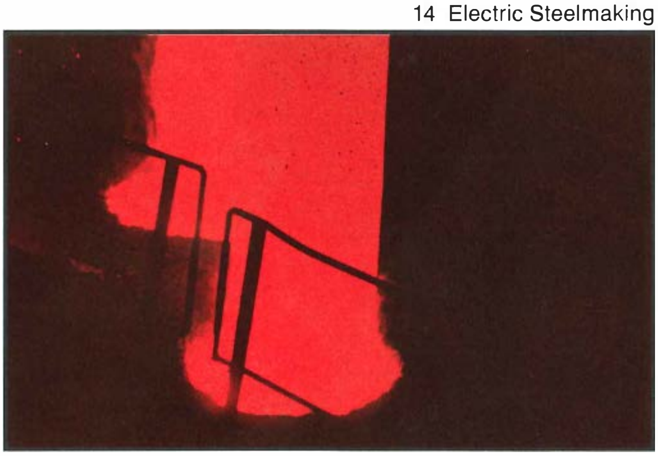
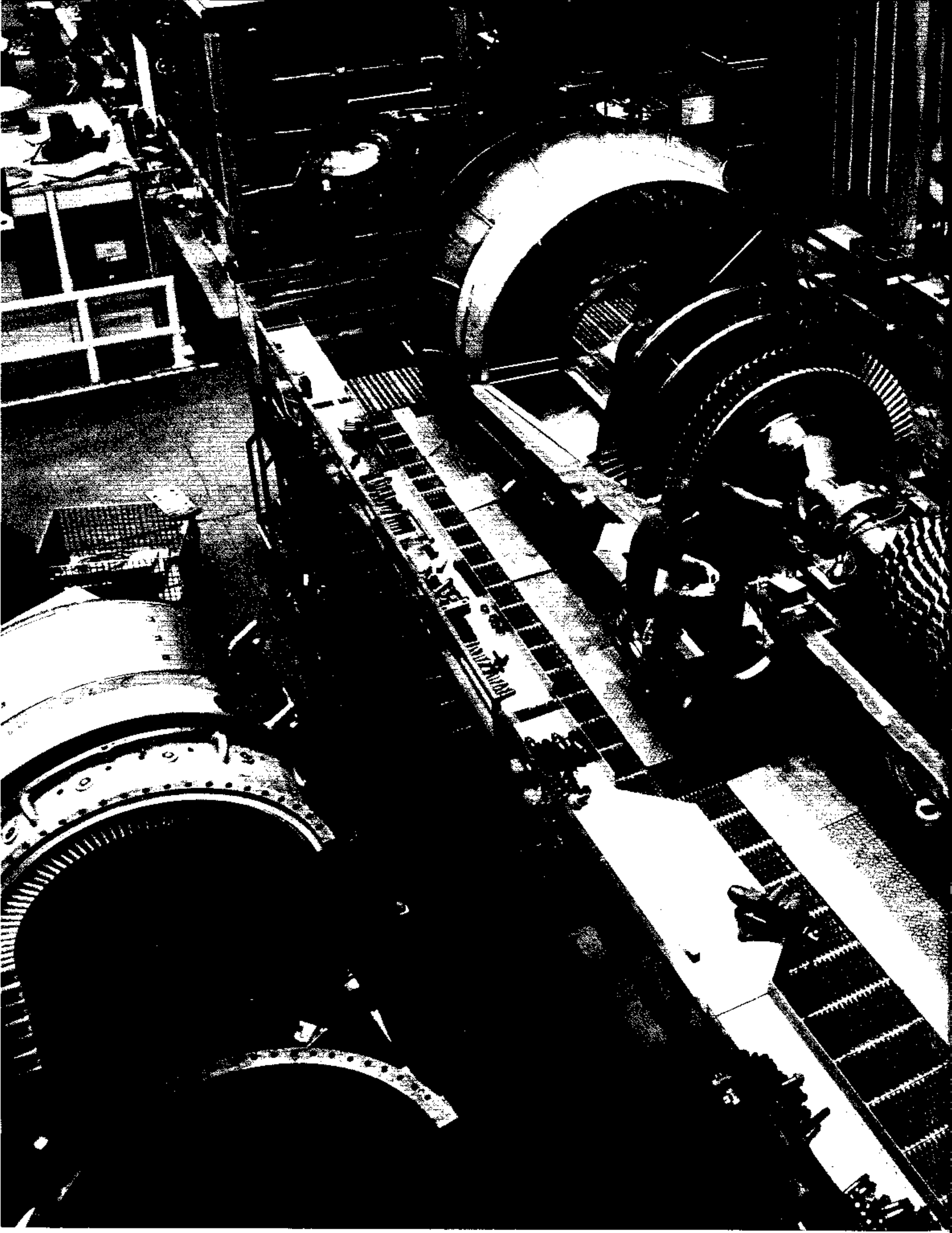
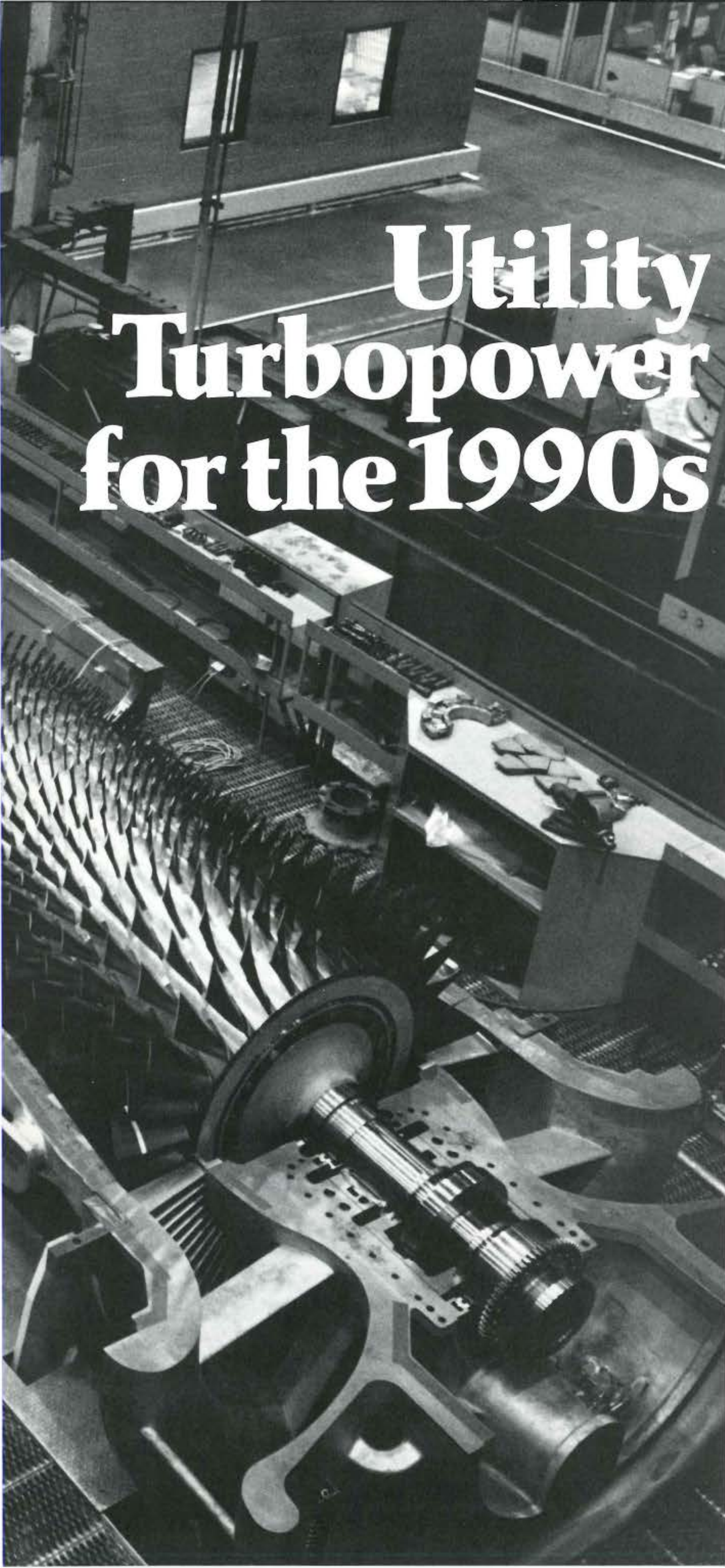




Utility Turbopower for the 1990s



The trend toward incremental capacity expansion is building a ready market for the advanced combustion turbines now being developed by major manufacturers. Their low capital cost, quick construction, and high efficiencies have put them at the leading edge of a purchasing wave gathering momentum for the coming decade.

For much of the time since they first began to be used by utilities in the late 1940s, combustion turbines have been the poor relation among generating plant options. Derived from early jet aircraft engines, the pad-mounted versions were relatively cheap in capital costs, but the premium fuel they burned relegated them to the role of peaking units, to be fired up only at times of the greatest demand for power.

Such cameo appearances in utility generation profiles led to a less-than-rigorous approach to combustion turbine maintenance, compounding a reputation for poor reliability. "The only good gas turbine is one that doesn't have to run"—one utility executive's epithet nearly 15 years ago—typified the industry's regard for combustion turbines.

Recently, however, combustion turbines have become the darlings of an industry searching for economy, efficiency, and above all, flexibility in increasingly uncertain times. In part as a result of concerted efforts by utilities through such organizations as EPRI and by the turbine manufacturers themselves, reliability has improved. The machines have gained sufficient respectability to take on an expanding role in utility power generation. In some cases, in combined-cycle configurations, combustion turbines are the heart of the most-efficient units a utility has on its system.

Other factors have contributed to a new view of combustion turbines among utilities as the linchpin of strategies for meeting future demand. The Powerplant and Industrial Fuel Use Act (PIFUA) of 1978, passed by Congress in the midst of the energy crises of the 1970s and in the face of a perceived impending shortage of natural gas, was repealed last year, ending nearly a decade of legal restriction on new construction and operating time. Under PIFUA limits, utility orders for combustion turbines ground to a halt while a new market niche for the machines—as prime movers in industrial and independent cogeneration plants—blossomed.

Now, however, the utility bridle is off. With natural gas production largely deregulated, the much-heralded gas bubble in resource outlooks of the 1980s has become a "gas sausage," in the words of one gas industry expert. Recent resource estimates are fueling assurances of at least several decades of conventional gas supplies at competitive prices. Utilities, meanwhile, are intently evaluating a new generation of heavy-duty industrial combustion turbines to bridge an anticipated capacity shortfall in the 1990s and to carry them through to the widespread adoption of advanced generating systems in the years beyond.

Poised for growth

"In terms of new generating capacity, combustion turbines are the growth area for utilities in the years ahead," says Ron Wolk, director of the Advanced Fossil Power Systems Department in EPRI's Advanced Power Systems Division. "On the order of 2500 MW of combustion turbines have been ordered in the last year, and that could grow to 5000 MW in a year or two."

Wolk's boss, Dwain Spencer, vice president and division director, is even bolder. "I'd almost bet that of the next 100 GW [100,000 MW] of utility generating capacity added in the United States, 75 GW will be gas turbine–based," Spencer predicts. "We see over 45 GW of indicated [but largely unannounced] orders for combustion turbine capacity over the next 12 years already, and I'd be amazed if that figure isn't over 55–60 GW by 1990."

The upturn in the utility market for combustion turbines confirms the strategic value they represent in long-term supply planning, as well as a simple reality revealed in continuing EPRI studies of generating-cost economics. As long as natural gas costs less than $6 per million Btu, gas-fired capacity's low capital cost ($300/kW for simple-cycle, $600/kW for combined-cycle) gives it the lowest projected cost of electricity compared with any alternative now available or expected in the next several years. In recent months, the cost of natural gas has been far below this, ranging from $2 to $3/million Btu, with some spot market purchases coming in under $2.

EPRI's analysis indicates that gas prices could increase by 50% to 100% from current levels before the life-cycle power cost of combined-cycle generation would exceed that of coal-fired baseload capacity built today. The questions of how much gas prices could rise and how fast, however, are at the crux of the trade-offs now being analyzed by utility planners. And that is where the combustion turbine's unparalleled flexibility becomes its saving grace.

EPRI has long envisioned combustion turbines as the cornerstone of phased construction of integrated gasification–combined-cycle (IGCC) systems. Initially, turbines are installed as simple-cycle peaking units, but as sharp demand peaks solidify into more-predictable demand, a heat-recovery steam generator is added to increase efficiency and power rating by driving a steam turbine from the combustion turbine's exhaust heat. The combined-cycle unit can then serve as cycling or even baseload capacity.

Combustion turbines, which can be installed and operating with minimal construction within about a year or two, epitomize the modular, incremental approach to capacity expansion. As demand grows further over the years, additional combined-cycle units can be added. And if gas prices exceed the break-even point with coal-generated electricity, a utility could build or buy the output of a coal gasification plant, fueling the combustion turbine with clean syngas and freeing it from the volatility of premium fuel prices.

Full demonstration of the IGCC approach at the 100-MW scale is now in its fourth year at Southern California Edison's Cool Water station in the Mojave desert, with virtually all technical and economic parameters exceeding the expectations of industry and EPRI backers.

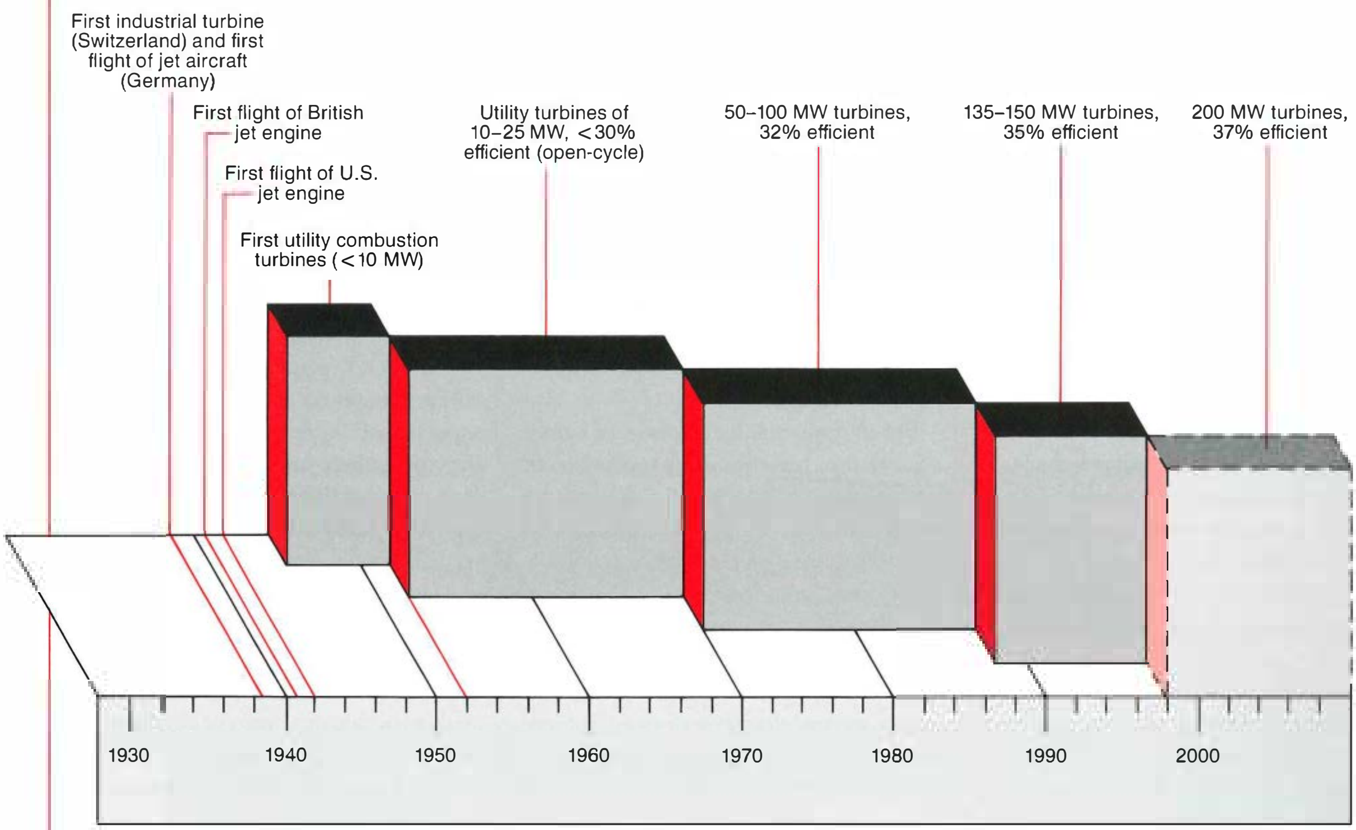
"When we first started talking to utilities about IGCC in the early to mid 1970s, the industry knew nothing about coal gasification, but they weren't worried about that; they were worried about the combined-cycle part of the power plant," recalls Spencer. "They said, 'You'll never get a gas turbine to operate long enough to consider it for baseload operation.' "

Such a perception (based on hard reality at the time) and the potential for development of IGCC both played a part in redirecting EPRI's modest efforts in combustion turbine R&D; emphasis shifted from very long range advanced machines to a near-term focus on improving the reliability of the industry's present fleet and ensuring the reliability of the next generation then under development by generating equipment manufacturers.

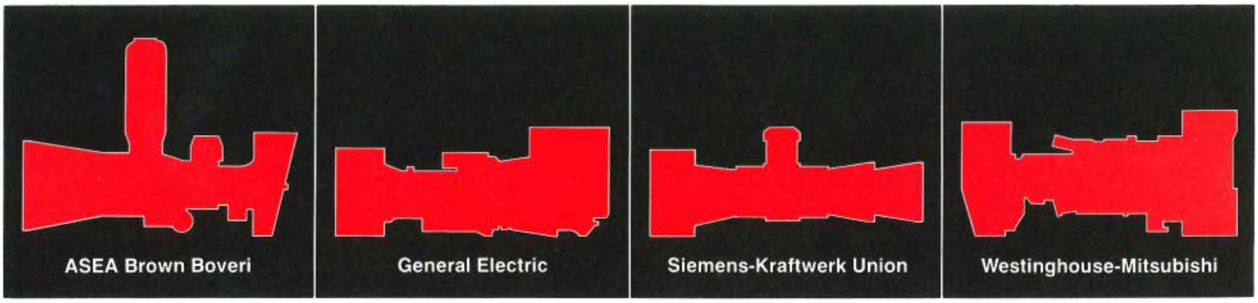
EPRI technical managers say the refocus has already begun to pay off, as evidenced by rising availability and declining forced-outage curves for machines utilities now increasingly rely on for peak power. "In the late 1970s, the manufacturers claimed the availability of their combustion turbines was as

Engine Evolution: Turbines Take Off . . .

The first jet engines and land-based combustion turbines were developed around the same time—in the late 1930s. Brown Boveri made the first successful industrial machines in Switzerland, while work was under way in Germany on aircraft engines. British and U.S. jets made their first flights a few years after Germany's. It was not until after World War II, however, that combustion turbines of sufficient size and reliability were developed for utility use. Since then, turbine manufacturers have produced successive generations of more-efficient, more-powerful machines at roughly 10-year cycles by increasing inlet temperatures and through various design and materials innovations.



. . . Competition Heats Up



Several turbine makers are bringing to an increasingly competitive international market a new class of advanced combustion turbines with power ratings of 135–150 MW. Beyond the present class of new machines, manufacturers are expected to offer even hotter-running, more-efficient turbines in the late 1990s with power ratings around 200 MW.

good as that of steam turbines, but they were failing to recognize that most of the gas turbines were only being called on to run about 10% of the time and some even less than that," says Spencer.

"It took some time to convince the manufacturers to think in terms of forced-outage frequency as the figure of merit. Around 1978 we proved to one manufacturer that the mean time between forced outages (MTBFO) for their machines in simple-cycle operation was only 165 h and for combined-cycle units, about 600 h. They almost couldn't believe it," Spencer adds.

Repercussions from such feedback of clear utility dissatisfaction with combustion turbine reliability reverberated through the manufacturers community, recalls Spencer. "By systematically analyzing years of reliability data and by looking in detail at the failure modes, EPRI has succeeded in reorienting the manufacturers toward a design and fabrication discipline centered on reliability, the results of which we are already seeing in some present-generation turbines.

"We have convinced ourselves and the industry of the prospect of being able to run these turbines as baseload combined-cycle capacity. Our best experience so far has been with the 80-MW General Electric 7E machine at Cool Water, where we have had only seven forced outages as a result of the combustion turbine in three and a half years of operation. Our MTBFO goals for the new models coming out are over 3000 h, but we won't know how well our involvement in the design process has helped to meet that goal until we obtain some units in the field and conduct some demanding, long-term durability tests," explains Spencer.

The new breed

The latest generation of combustion turbines being offered by the manufacturers—General Electric, Siemens-Kraftwerk Union, ASEA Brown Boveri, and Westinghouse (to be produced in Japan by Mitsubishi under license)—reflect technical improvements engineered into aircraft turbines some years ago as a result of the Pentagon's massive support (about three-quarters of a billion dollars a year) of jet engine performance and reliability R&D.

In successive generations of larger and more-powerful combustion turbines (the earliest units were rated 10–25 MW), increasingly higher energy efficiencies have been obtained by raising the design fuel-firing temperature at the combustor outlet. The most recently made turbines in service today are rated 70–100 MW and have a firing temperature around 2000°F (1093°C), with full-load, simple-cycle efficiency about 32%.

But all four major suppliers of utility combustion turbines are expected to offer turbines rated 135–150 MW, with firing temperatures around 2300°F (1260°C) and efficiencies of 35%. In combined-cycle operation, these units are expected to achieve efficiencies of 45–47%.

The advanced machines' hotter turbine inlet temperatures are made possible by several design and materials improvements originally developed for aircraft engines, including thin-film and internal passage air-cooling of the turbine blades and stationary vanes and, for some models, impingement cooling of a key hot-section component (the transition piece connecting the combustion chamber to the turbine section). Advanced coating materials are also used on some hot-section parts to help keep metal temperatures low and to limit hot corrosion.

The first of the new-generation combustion turbines out the factory gate is General Electric's 135-MW 7F model, which incorporates some innovations developed with EPRI support. Chief among them is a multinozzle combustor originally designed for steam injection to reduce formation of nitrogen oxides (NO_x) in the flame but which engineers later found also to improve the machine's reliability. By using six fuel nozzles rather than a single nozzle, the combustor can be slightly smaller, but the change greatly reduces pressure dynamics, which can lead to early failure of the shell-like transition piece just downstream.

EPRI has funded extended-cycle field tests of 20,000 h of the impingement cooling technology used in the 7F's transition piece. The first of the new General Electric machines is slated for delivery to Virginia Power's Chesterfield station later this year, where it will become the first phase of what ultimately may be a 200-MW IGCC plant.

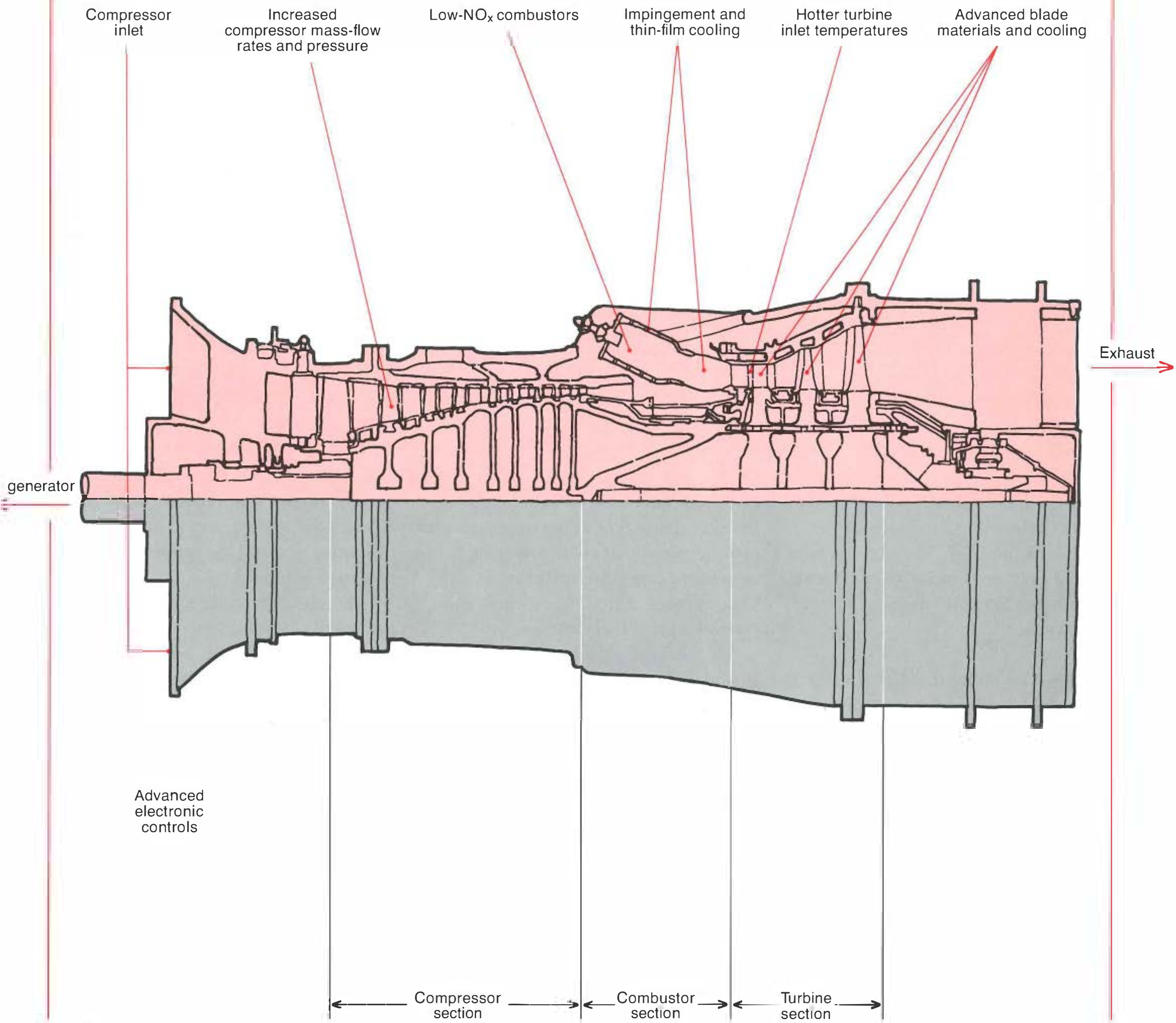
The substantially better performance expected of the new machines does not overcome their newness and the concern over reliability, however. "The only way we're going to find out how well these new turbines perform in service is through the durability tests we're planning for each of the new models," says Spencer.

EPRI is on the lookout for the second or third utility that purchases the new machines from each manufacturer to host 3–5 years of intensive testing and analysis for direct feedback to the manufacturer. For the first of the new machines expected to be tested, EPRI has placed a utility industry observer at General Electric's Greenville, South Carolina, factory to monitor the factory development and testing of the advanced model 7F turbine. A similar arrangement is being pursued with Westinghouse-Mitsubishi in Japan.

"The utility industry has never done the kind of testing we're planning for the new turbines," says Al Dolbec, program manager for power generation in EPRI's APS division. "For the most part it will involve normal operation under utility dispatch, but the machine will be heavily instrumented, and we will plan

What's New in Combustion Turbines

Materials and cooling of hot-section parts are keys to the increased power ratings and higher efficiencies of advanced combustion turbines becoming available from manufacturers. Higher-temperature materials and innovations such as multipass cooling of turbine blades and controlled cooling of combustors allow hotter-running turbines. All are expected to feature turbine inlet temperatures around 2300°F (1260°C), offering as much as 40% greater power rating, with only a small increase in size. Full-load, open-cycle efficiencies are expected to be about 35%. In combined-cycle operation, the machines are designed to achieve thermal efficiencies of 45–47% (higher heating value). Principal innovations are shown on a generic advanced turbine.



frequent inspections. We're looking for 15,000–25,000 h of running on one unit and perhaps 1000 starts on another to minimize new design risks. We hope to identify any design problems early on, before many more of that model are manufactured."

According to Ron Wolk, "Durability testing is something new in the way gas turbines are evaluated by the industry, and it may be the forerunner of the way a lot of utility equipment is evaluated in the future. This will be a unique role for EPRI, but the payoff in doing it is very high."

In addition to their value in fine-tuning design and manufacturing, results of the durability tests will be immediately useful to utilities in procurement decisions, according to Richard Priory, vice president for design engineering at Duke Power. "EPRI can really play a role in helping sort out the technical guidelines on which to base warranties.

"Our only enemy is time. There seems to be a substantial appetite out there for these machines, but we have to get ahead of the purchase wave, to get work done to support utilities' procurement activities. Once the horse is out of the barn, utilities will be pretty much consigned to dealing with the turbines as they are," says Priory, who heads a high-level industry committee that advises EPRI on advanced gas turbine strategy.

One utility that has already benefited from EPRI's expertise in combustion turbines is Texas Utilities Electric, which is planning to install a total of 15 current-model turbines for peaking power on its system by mid 1990. "Gas turbines are a strategic element in our resource plans," says R. K. Payne, the utility's vice president for engineering. "Because of the flexibility they offer in being built and installed in a short time and at low capital cost, they will allow us to adjust to short-term variations in our load growth pattern to complement our baseload generation resources.

"EPRI has been very helpful to us in developing specifications for soliciting bids from the manufacturers, and the ongoing reliability work will be of benefit to us throughout the operating lives of these machines," adds Payne.

Supporting the present fleet

The durability tests for the advanced combustion turbines arriving on the market represent an extension of reliability-centered R&D EPRI has been conducting for several years on the existing fleet of some 50,000 MW of turbines already in the field.

"We've been trying to bring the aerospace industry's approach to reliability and maintenance into the utility combustion turbine world, to gather a lot of data on what fails and why, model a machine's reliability, set goals for component failure and forced-outage rates, and achieve those goals with the kind of methodology and discipline used in aircraft engine design and maintenance," says Dolbec.

Ultimately, within a few more years, EPRI hopes to make available a large electronic data base on combustion turbine reliability that utility operators can tap and manipulate with emerging EPRI-developed codes for analyzing every major aspect, including procurement, operation, and maintenance.

"Because combustion turbines have historically been used strictly as peaking units for only a few hundred hours a year, utilities have not invested a lot in engineering for the machines, while at the same time much of the service support that the manufacturers used to provide is no longer available," explains Dolbec. "So we're working on a series of user-friendly software modules to help train virtually a whole industry on the analysis and care of combustion turbines."

About a dozen utilities are now using one or more of the first modules of what will eventually be a package of codes written with a natural language interface for ease of use. Expected to be completed by 1990, the software will also include an electronic bulletin board for gas turbine users to share problems and insights.

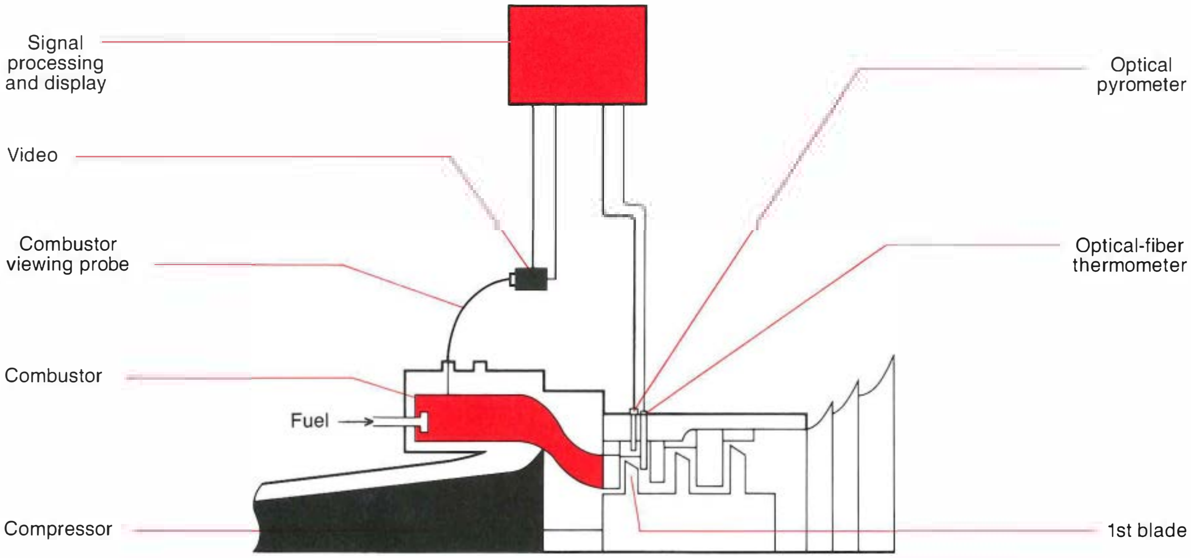
The software area of EPRI's combustion turbine efforts also includes a major, highly successful initiative to develop artificial intelligence–based expert systems to assist in troubleshooting common problems. Encoded with the best judgment and expertise of several engineers intimately familiar with a particular turbine model, an expert system can make available to a novice plant technician the insight of a true expert's many years of experience.

EPRI recently concluded the first phase of a demonstration at Jersey Central Power & Light's Gilbert combined-cycle station of an expert system for troubleshooting electrical ground faults, identified in reliability studies as a common cause of forced outages. With expert systems software developed by General Electric and sophisticated portable hardware developed by Honeywell, the gas turbine expert system (GTES) showed that novices, once familiar with the system, can identify a failure cause in about the same time as a seasoned engineer.

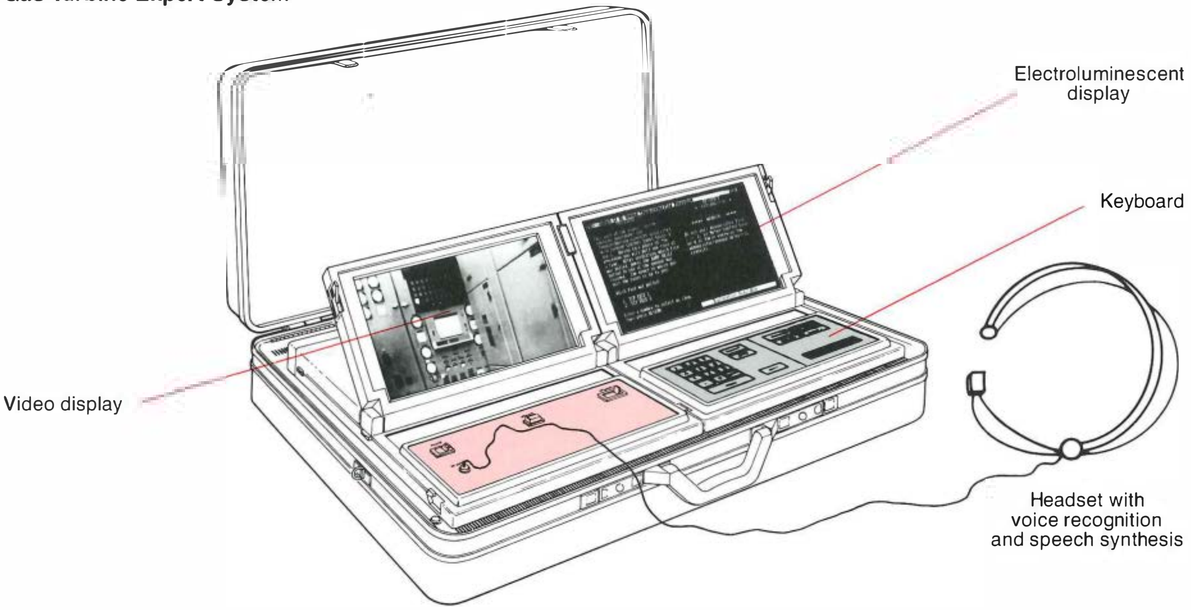
GTES's user interface includes a flat-panel electroluminescent display screen, built-in printer, headset, and voice recognition and speech synthesis technology. Such advanced features allow the troubleshooter free hands to inspect for clues while interacting with the expert that resides in the computer. Follow-on work is now focusing on additional software for assisting in turbine startup procedures, which require knowledge of every major system in the machine. Dolbec thinks there is a good chance the system could be commercially available with standard expert systems for each major turbine model within a few years.

New Tools for Turbine Diagnosis

Much of EPRI's work to improve turbine reliability focuses on developing better tools and techniques for diagnosing and analyzing turbine operation and component failure. An optical pyrometer, already available, can read the temperatures of over 90 blades in a single row of an operating turbine. A similar optical-fiber thermometer is being developed for monitoring hot-gas temperatures. An electronic video-based combustor viewing probe allows operators to observe actual flame shape and intensity while a turbine is on-line.



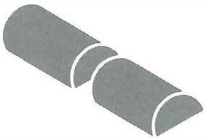
Gas Turbine Expert System



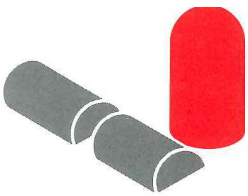
A gas turbine expert system (GTES), which has successfully diagnosed electrical ground faults, is being further developed to assist operators in a wider range of tasks; commercial versions of the customized, portable computer system could be available in a few years.

Flexibility for Phased Construction

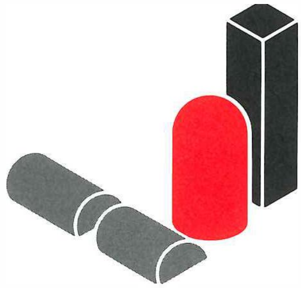
Combustion turbines offer an attractive approach to generating capacity expansion. Open-cycle oil- or natural gas–fired peaking units can be converted to baseload or intermediate combined-cycle capacity as demand changes, with the option of later conversion to firing with clean gasified coal if fuel economics change. Several utilities are planning the phased approach to integrated gasification–combined-cycle (IGCC) systems, with combustion turbines as the first step.



Combustion turbines

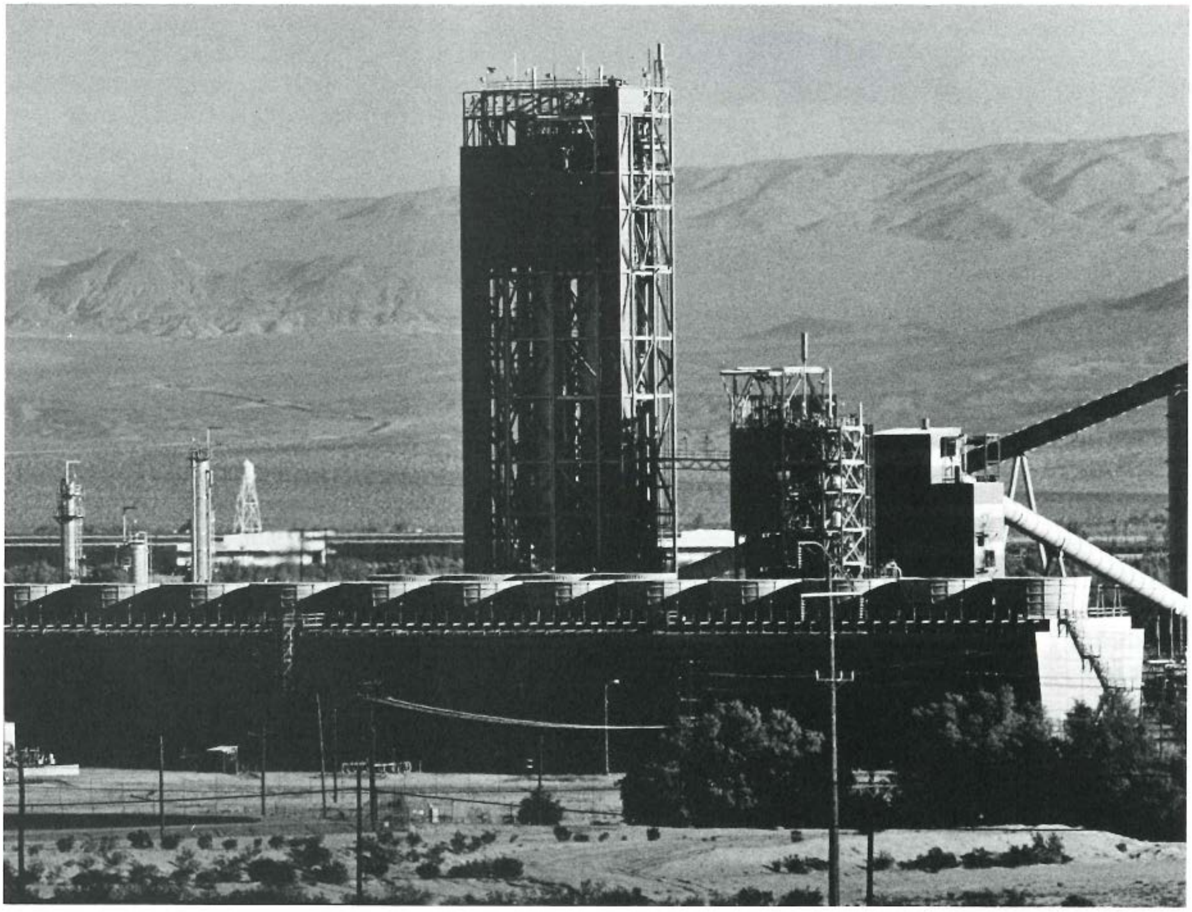


Combined-cycle



IGCC

Cool Water IGCC plant



Besides software, according to Dolbec, specialized instrumentation is another area where the retreat of the major manufacturers from extensive field service has left a vacuum. "We're developing a sort of doctor's bag of instruments for helping analyze the hundreds of things that can go wrong with a combustion turbine," he explains. "Diagnostic instruments are like insurance policies: they don't cost a lot, and if they save you one blade failure, they're worth the cost."

One of the first tools to go into the doctor's black bag is an optical pyrometer for taking the temperatures of each of over 90 blades in the first stage of an operating turbine. Mounted through a small hole in the power section, the fiber-optic device measures the infrared energy radiated by each blade and translates the readings to temperature plots for identifying blades that are running hotter than others. "What the temperatures are is less important than knowing which blades are hotter because those are candidates for early replacement," says Dolbec.

A similar device for actually viewing and recording flame shape and behavior inside the combustion zone has also been developed. EPRI is planning field trials for commercial prototypes of both the optical pyrometer and the combustor viewer later this year at a Houston Lighting & Power combustion turbine plant.

Another EPRI initiative designed to fill a need among utility users of combustion turbines is the recently commissioned Combustion Turbine Center (CTC). Using some space and facilities of EPRI's Nondestructive Evaluation Center in Charlotte, North Carolina, the CTC has been launched to conduct training and seminars for utility personnel.

The center is particularly intended as a focal point for technology transfer of EPRI research results to the widest possible audience of combustion turbine operators. A retired combustion turbine and key major components will be available at CTC for hands-on demonstrations. "The new center, coupled with the planned durability tests of new machines, represents a real commitment on EPRI's part to support the new utility thrust into combustion turbines," says Wolk.

Beyond the next wave

For the next several years, EPRI research managers will have their hands full keeping up with the coming wave of combustion turbine plants, supporting the older units in the field, and making sure all the bugs are worked out of the new machines coming. But they'll also be keeping an eye part-time on concepts emerging for still the next generation of machines, which roughly follow a 10- to 12-year development cycle. Already, researchers and manufacturers envision combustion turbines offered early in the next century to be about 200 MW in rating, with firing temperatures around 2500°F (1370°C), a simple-cycle efficiency of 37%, and an unprecedented combined-cycle unit efficiency of over 50%.

"The technology for those turbines is already flying around in airplanes," notes Dolbec. It includes higher-temperature blades made from single metallic crystals and other advanced materials for hotter firing and more-sophisticated cooling techniques. Researchers are also exploring possible improvements in thermodynamic cycles, using such techniques as intercooling and steam injection.

Although increased firing temperatures for combustion turbines show great promise in raising unit efficiency, the higher temperatures also result in increased emissions of air pollutants, primarily NO_x. The Environmental Protection Agency's emissions standards could require selective catalytic reduction on exhaust streams, a costly measure that would also reduce overall plant efficiency. Another emerging emissions concern for advanced turbines is volatile organic compounds from unburned carbon, particularly when firing distillate (oil) fuel. EPRI is closely monitoring the implications of evolving emissions standards for combustion turbines.

For now at least, EPRI's combustion turbine work is making it easier for utilities to plan capacity expansion with assurance they will not be overly vulnerable to natural gas prices and will be consistent with current federal emissions standards. "Utilities ought to feel confident that the equipment that will be supplied to them by the manufacturers now is in a class that should be competitive in an availability sense with the other generating units in their systems," says Dwain Spencer.

"They will always have to be concerned about premium fuel availability and price, but we think the phased-IGCC approach gives them a contingency in case natural gas prices escalate rapidly in the mid to late 1990s. We believe we've put them in a position to have real confidence in their decisions to again purchase and install combustion turbines." ■

Further reading

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This article was written by Taylor Moore. Background information was provided by Al Dolbec and Dwain Spencer, Advanced Power Systems Division.

The Rise of Electric Steelmaking

Advances in electric steelmaking are helping U.S. companies regain a foothold in international steel markets.

Even as global steelmaking capacity has outstripped demand and domestic markets for steel have languished, production by electric furnace steelmakers has steadily expanded. This is especially good news for electric utilities because a steel mill with electric furnaces is often a utility's single largest customer. Already electric furnaces account for approximately 40% of total steel production, and steady growth is expected to continue into the next century.

The reasons for such competitive strength in a declining market are complex. One major factor is energy efficiency. The total energy required to produce a ton of steel from scrap in an electric furnace is less than half that required to produce a ton of steel from iron ore in an integrated mill, which uses a blast furnace and a basic oxygen furnace. Another factor is that electric steel mills are less capital-intensive than integrated mills and can be operated economically at much smaller capacities.

For electric steelmaking to reach its full potential, however, considerable technologic development is still needed. Some of this development work can be used to further augment the inherent advantages of electric furnaces. Adoption of improved equipment and practices, for example, could theoretically double the production capacity of existing furnaces without increasing their installed transformer capacity. At the same time, research is also required to overcome some persistent difficulties in electric steelmaking, such as production of dust that has been classified as a hazardous waste and a source of electrical disturbances on utility power lines.

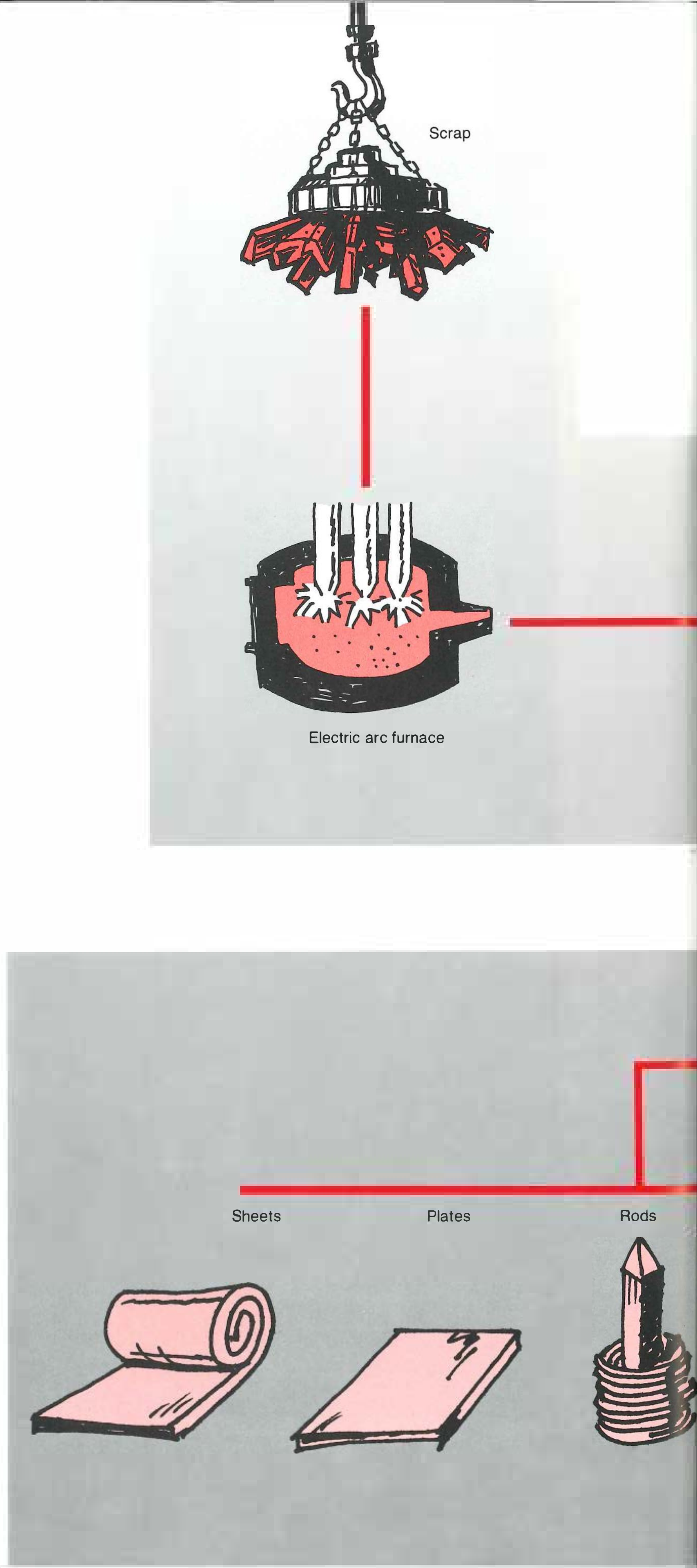
"At current levels of the yen and the dollar, American steelmakers have an incentive to return to the international marketplace," says Project Manager Robert Jeffress. "A key factor in regaining competitive advantage in these markets is the increased use of advanced electrical technologies for steel production."

Assessing prospects

Meeting the technology challenges of electric steelmaking is one of the primary goals of the Center for Metals Production (CMP), established in 1984 by EPRI and administered through the Mellon Institute of Carnegie-Mellon University. Located in Pittsburgh, Pennsylvania, the center conducts collaborative research on electrotechnologies that can improve the productivity and energy efficiency of metals production. Much of the center's work on electric steelmaking is cofunded by leading steel companies, electrical equipment manufacturers, and individual utilities.

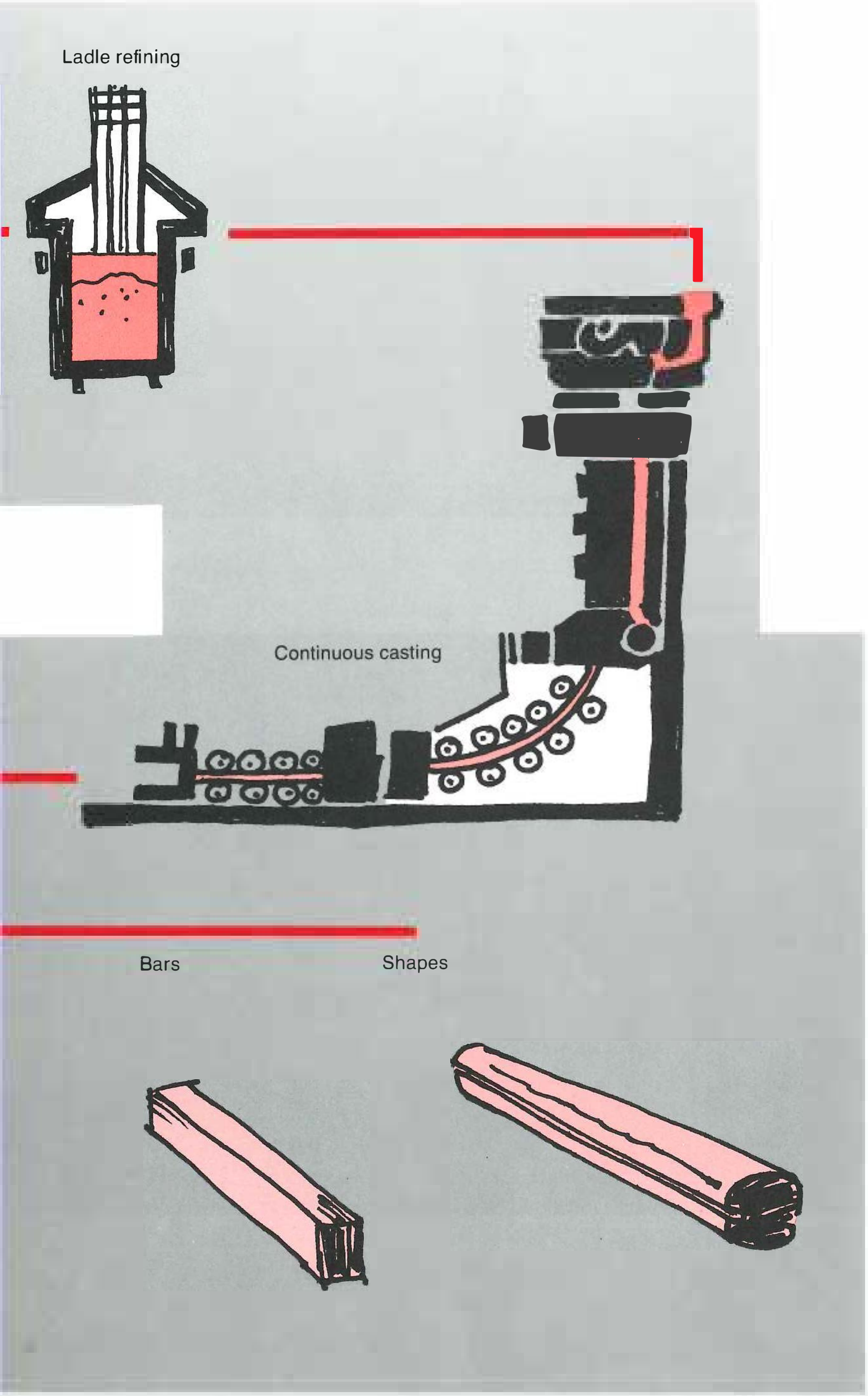
A recently published study prepared by CMP for EPRI and the U.S. Department of Energy assesses the technical and economic prospects for electric steelmaking through the turn of the century. The study concludes that electric arc furnace (EAF) production of carbon steel could rise from 23 million tons in 1985 to 42 million tons in the year 2000. An important component of this gain would come from technology that could enable EAFs to produce steel sheet and strip, in addition to capturing more than 80% of the market for their traditional products—steel rods, wires, bars, plates, and structural materials.

To bring about this accomplishment, the study recommended intensified R&D in three major areas: treatment of raw materials, improvement of EAF operating practices, and development of new equipment. Preheating scrap with exhaust gases from the EAF, for example, could result in significant energy saving. Better mixing of the molten slag-metal mixture could help lower carbon levels to prepare the steel product for forming into sheet and strip. And better insulation of water-cooled EAF wall panels could save 10–25 kWh of electricity per ton of steel.



The Electric Alternative

Making steady gains on traditional blast furnace steelmaking, electric arc furnaces now handle about 40% of total steel production. Rather than starting with iron ore, the furnace uses scrap steel, which is melted down by electric arcs from the furnace's three huge graphite electrodes. Steel alloying elements are added in the furnace, and the molten metal is poured into a ladle refining furnace for purification and fine adjustments in composition. Modern continuous-casting machines, which eliminate the casting and reworking of ingots, can then produce a variety of useful forms and shapes directly.



Already, improvements in technology have reduced the time required to process a batch of steel in an electric arc furnace (the so-called tap-to-tap time) from 180 minutes in 1965 to 70 minutes in 1985. Over the same two decades, electric energy consumption has also been lowered from 630 kWh per ton to 430 kWh per ton. Further research will not only continue to foster improvements such as these, the study concluded, but may also bring more fundamental changes, such as the conversion of some units from ac to dc electricity and the use of novel methods to produce steel with fewer impurities.

The electric steel cycle

Electric arc furnaces are used to produce steel in three different types of mills, which have evolved somewhat independently. Initially, EAFs were adopted to produce small quantities of specialty steels, and companies that make high-alloy or special carbon steels still depend mainly on electricity. During the 1960s reliable methods of casting carbon steel directly into billets led to a proliferation of EAF minimills that could supply bar products to local markets. Large integrated steel plants also began to add arc furnaces to provide more flexibility in the use of scrap as they phased out open-hearth furnaces.

Typically, an EAF consists of a squat, cylindrical vessel with refractory walls and a removable roof. Both the roof and wall panels are generally water-cooled, and the roof is penetrated by three graphite electrodes. After a charge of scrap is introduced into the open furnace, the roof is swung into position and the electrodes lowered toward the scrap. Electricity supplied by a three-phase transformer creates arcs between each electrode tip and the scrap, melting the steel. Once the scrap has been completely melted, the furnace is tilted on rockers, and the liquid steel is poured into a ladle. To allow for further composition adjustments, temperature control, and other refining treatments, the molten metal is often poured into a ladle refining furnace, which has its own electric arc heat source. From the ladle or ladle furnace, steel is usually poured into a continuous casting machine. With commercialization of continuous casting equipment, minimills utilizing electric furnaces and casting machines have been able to compete with large integrated mills in the market for steel bar and rod. New, thin-casting technology now being developed will further enable minimills to compete for the first time in the production of steel sheet and strip.

The United States now has more than 200 electric arc furnaces, with tap weight capacities that range from less than 50 tons of steel to more than 300 tons. The "average" American EAF has a shell diameter of about 18 feet, a transformer rating of nearly 36 MVA, and a capacity of 88 tons. If interest and depreciation are included, the average cost of making a ton of steel is about $173 in an EAF, compared with about $190 for an oxygen furnace in an integrated plant.

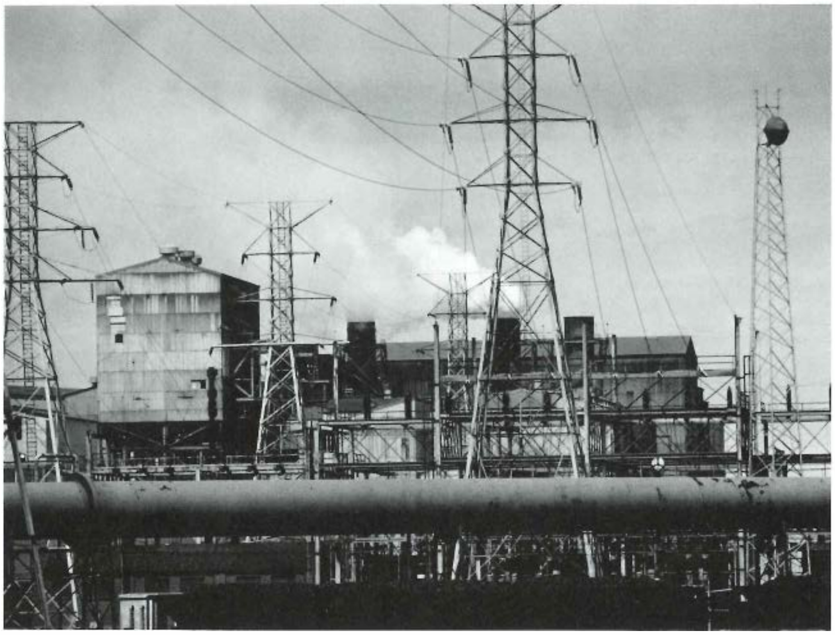
Overcoming hurdles

Some of the earliest research sponsored by CMP was aimed at overcoming two technologic hurdles that hindered even more widespread adoption of EAF steelmaking—discontinuous arcing and production of metallic dust that is becoming difficult to dispose of. Field testing has now been conducted on a variety of techniques proposed to increase arc stability, and a scoping study has been completed to assess present and emerging methods for treating EAF dust.

During the initial stages of melting, when an arc is acting on cold scrap, instabilities occur that can cause voltage variations on the adjacent utility power line. Some of these effects can be seen as the flicker of lights belonging to other customers on the line. Other disturbances, which involve higher-frequency harmonics imposed on the normal 60-cycle ac

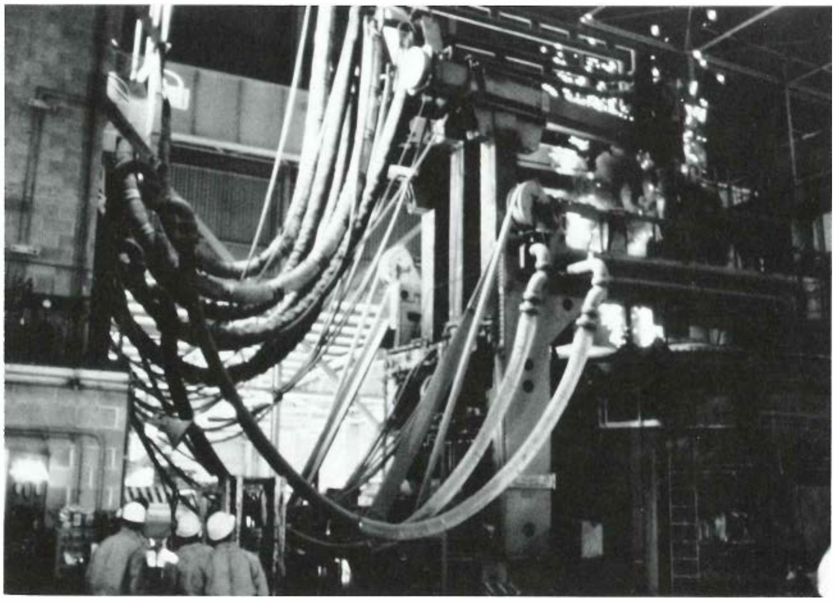
Tons of Steel

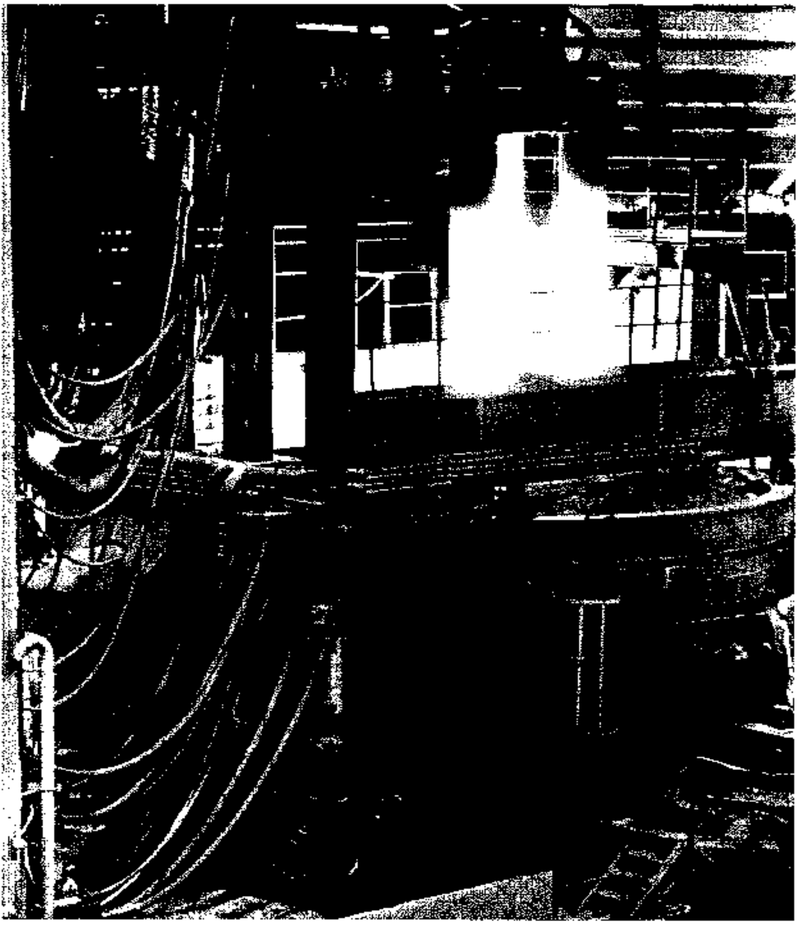
Currently, there are more than 200 electric arc furnaces operating in the United States, producing some 23 million tons of steel annually. A recent study cosponsored by EPRI and DOE estimates that by the year 2000, arc furnace steel production could reach 42 million tons a year by capturing more than 80% of the market for steel rods, wires, bars, plate, and structural materials and moving into such nontraditional product lines as sheet steel and strip.

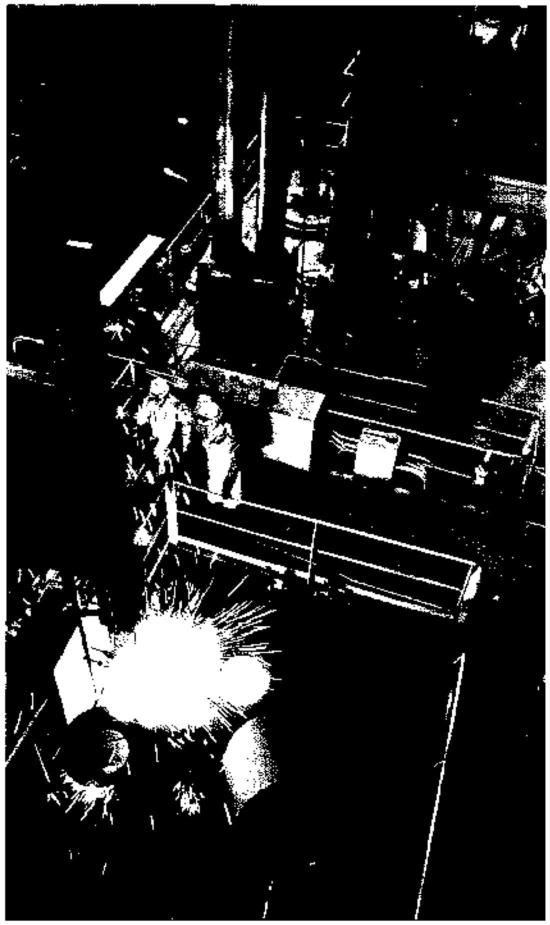


Electric steel mill

Power cables for furnace







Electric arc furnace

Ladle refining furnace

Continuous casting

Making steel bar

voltage, can damage sensitive electronic equipment. Isolating the utility network from such disturbances can entail considerable expense. In addition to the obvious utility concern, steel companies also want to see improved arc stability because it would lead to better utilization of electric power, increased productivity, and lower electrode consumption.

The CMP arc stabilization tests were conducted in 1985 by Sidbec-Dosco of Quebec on a large modern EAF at its Contrecoeur Works. Of the methods tested, injection of argon and lime into the arc through hollow electrodes proved particularly effective, reducing flicker by 20–25%. (The atoms of these materials are stripped of their electrons by the arc, forming a conductive plasma that in turn helps stabilize the arc.) Wide variations from batch to batch, however, indicated the need for further research to better understand electrode wear and the possible effects of electrode tip shape. The extremely fine dust found in the exhaust gases of an arc furnace is formed when vaporized molecules of metal react with oxygen and condense into particles ranging from 0.1 to 10 micrometers in diameter. About 20–40 pounds of dust, most of which is captured in baghouses for disposal, are generated per ton of steel. Dust particles are composed mainly of iron and zinc oxides, but relatively small amounts of leachable lead, cadmium, and chromium have resulted in the dust being classified as hazardous waste by the Environmental Protection Agency (EPA).

The full effect of such classification has not yet become clear. EAF dust has traditionally been placed in landfills, but 1984 amendments to the Resource Conservation and Recovery Act prohibit such disposal unless the EPA authorizes exceptions. Moreover, the amendments require most existing hazardous waste landfills to be retrofit with double liners. Despite uncertainties over how these regulations will be enforced, owners of electric steel mills now have an enormous incentive to find alternative means of disposal as soon as possible.

Dust to zinc

An important key to making such alternatives more attractive is the relatively high value (45¢ per pound) of zinc contained in EAF dust. Fertilizer manufacturers, in particular, provide one of the major markets for zinc, which is an essential plant nutrient. Until now, however, only about 10% of all EAF dusts have been sold to make fertilizer because their zinc content must be greater than about 25%, a level reached at less than half of U.S. mills. Such sales have also been restricted by geographic and seasonal factors.

The CMP scoping study revealed several options for processing EAF dust—either at a steel mill or in regional centers servicing several mills. The relative advantages among these options will depend on specific economic factors at various mills. Substantial testing and demonstration is also required for some of the technologies involved.

One option for on-site processing is to recycle dust through a furnace to upgrade its zinc content. During recycle, iron molecules in the dust tend to be absorbed into the melt, whereas zinc passes through to form new dust. Problems with excessive fuming and reduction in productivity, however, make this alternative unacceptable for most mills. Upgrading to more than a 50% zinc content would enable a mill to sell EAF dust as raw material to refiners of metallic zinc. Chemical fixation of EAF dust so that it can be buried in conventional landfills is also being pursued with EPA as a short-term option for on-site disposal.

A longer-range alternative is to produce metallic zinc at EAF mills by using a plasma arc reactor. In such a reactor, high-temperature ionized gases (the plasma) are generated by striking an arc between sets of electrodes. When dust is injected into the plasma, zinc vaporizes and is condensed in its metallic state outside the reactor. Iron and slag collect at the reactor bottom. In collaboration with 22 steel companies, CMP is cofunding a pilot plant study of a plasma furnace with Tetronics R&D and Bethlehem Steel. CMP expects to participate in a commercial demonstration of this promising technology.

A combustion-based process is being considered for use on a larger scale for regional processing of EAF dust. The St. Joe Flame Reactor in Monaca, Pennsylvania, for example, is a shaft furnace, in which a hot mixture of zinc ore and coke passes through the reactor. Vaporized zinc is condensed out of the exhaust furnace gas as zinc oxide. CMP is involved in a pilot test that uses the St. Joe reactor.

Optimizing quality and production

Recent innovative technologies are now being adopted to optimize EAF steelmaking. Ladle refining furnaces, for example, increase productivity by allowing an operator to tap steel from an EAF at a lower temperature and provide an opportunity to chemically refine the metal further. Also, conversion of an EAF from ac to dc power reportedly can reduce electrode consumption and produce fewer voltage disturbances on the lines.

In a separate and more economical operation, a ladle refining furnace enables a mill to further refine steel after it has left the EAF. Such additional treatment is becoming popular because of an increased demand for high-purity steels. Ladle refining can be used particularly to produce steels with very low sulfur, carbon, and hydrogen content. A ladle refining furnace also acts as a buffer between the steelmaking furnace and a continuous casting machine, thus providing greater flexibility of operation. (These furnaces are also being used by the major integrated producers in conjunction with basic oxygen furnace steelmaking.) The cost of ladle furnace operation is about one-third that of an EAF of the same size. By optimizing EAF melting and using a ladle refining furnace, a mill can save about $27 per ton of refined steel. Ladle refining furnaces — already common abroad, where energy costs have traditionally been high—are rapidly gaining popularity in the United States. CMP has published a report on the status of ladle refining furnaces and is also sponsoring demonstrations of resistance heating in the ladles used to transfer molten metal from furnaces.

A dc arc furnace usually has a single graphite electrode and uses contact pins on the furnace bottom to complete the electrical circuit. Decreases in electrode consumption of 50–60% have been reported in small furnaces. In addition, dc furnaces reportedly provide better temperature distribution in the metal bath, which may result in lower energy consumption and reduced refractory wear. The major disadvantages of these units include the cost of the dc power supply and downtime to replace the bottom electrodes, which currently have a short life.

Two small arc furnaces in the United States have been converted to dc operation, but several technical questions must be addressed before larger EAFs can be converted. CMP has completed performance tests at the 35-ton Nucor dc plant in Darlington, South Carolina, where a twin ac furnace was available for data comparison. A demonstration project of dc furnace operation at the 90–100-ton scale is now being planned, and CMP is looking for a host site.

Future developments

On the basis of insights gained from scoping studies and from interest expressed by potential cofunders, CMP is embarking on several new projects to further optimize arc furnace performance. Particular emphasis is being given to technologies that either lower the cost of producing current grades of EAF steel or improve its quality enough to open new markets.

One clearly available way to lower operating costs is through advanced process control. Computer-based control systems are already widely used to calculate energy requirements for a particular EAF charge and to control power levels automatically during the course of a heat. Present control systems, however, have several weaknesses, including poor reliability of sensors and speed in determining the composition of the molten furnace metal. To address these problems, new sensors are being developed and methods are being sought to conduct rapid in situ analysis of the molten metal.

One of the high priorities in research to improve the quality of EAF steel concerns ways of minimizing nitrogen content in the steel. Flat-rolled sheet steel for making automobiles requires a nitrogen content below 40–50 ppm so it can be formed successfully into auto body panels. Conventional EAF steels generally contain 70–100 ppm of nitrogen. A variety of operating techniques can be used to lower the nitrogen content of molten steel, including mixing with carbon monoxide, creating a foaming slag, using shorter arcs, and tapping from a furnace bottom rather than pouring. The quantitative importance of these and other techniques, however, remains unclear, so CMP will be starting a project later this year to determine the best combination of methods and furnace practices for reducing nitrogen.

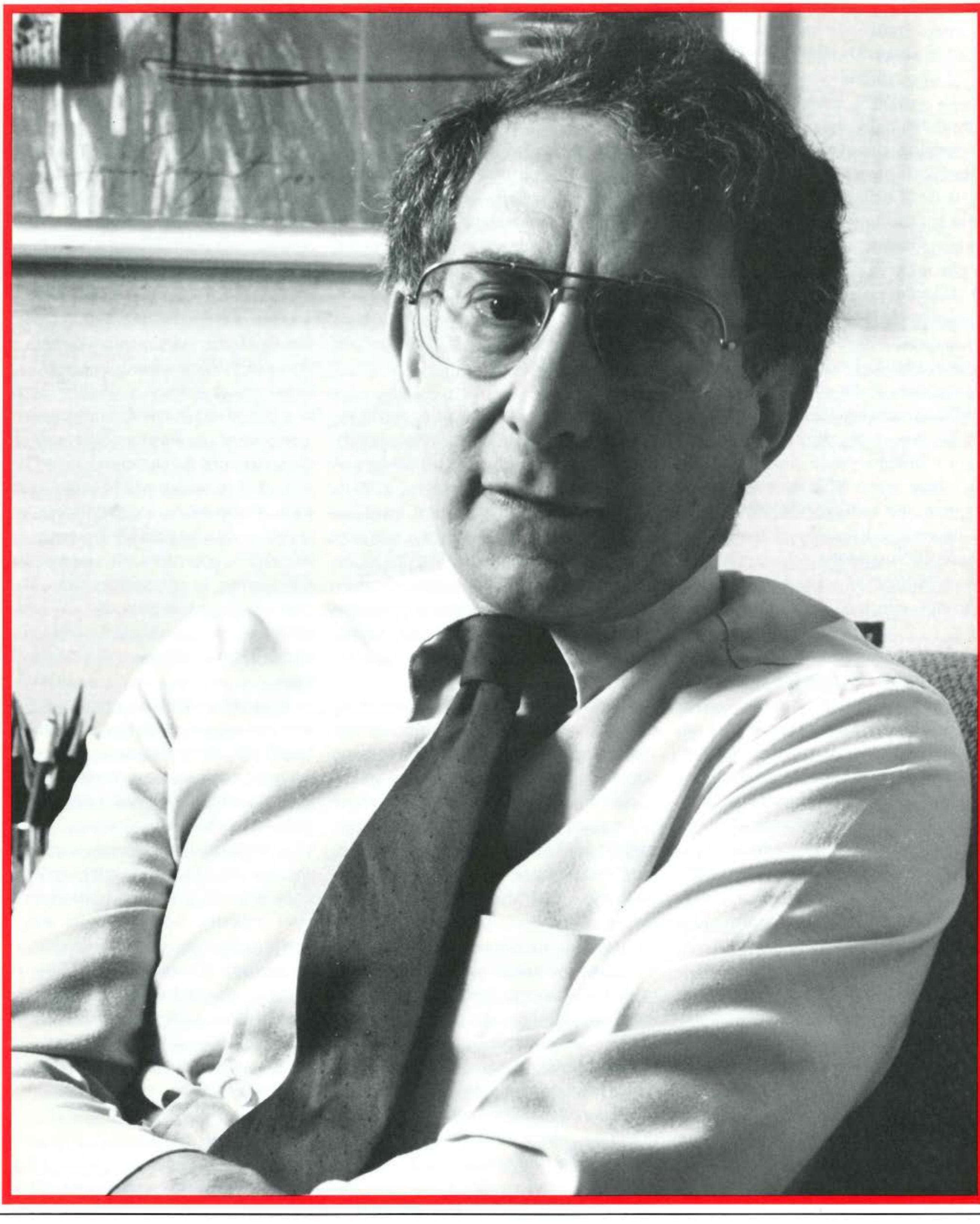
Further in the future, innovative technologies now emerging from laboratory trials may change electric steelmaking in more fundamental ways. Plasma torches, for example, might be used to replace graphite electrodes. Such plasma-based furnaces could provide rapid heat transfer and excellent controllability, but questions about higher energy consumption and limited current levels must be answered before the furnaces become commercially viable.

A furnace charge could also be melted by using currents induced in the scrap by magnetic fields from coils surrounding a furnace. Such coreless induction melting is already used for production of cast iron, and advances in computerization and power electronics may enable the technology to be used with steel as well. Energy consumption is about 10–25% higher than in an electric arc furnace, but coreless induction furnaces may find an economic niche in micromills with capacities of 20 tons or less.

Other new technologies may contribute to electric steelmaking outside the furnace. High-powered lasers can deliver enough energy to modify the surface properties of metals and are already being used to improve the magnetic characteristics of electrical steels. Thin-strip casting, which will help make minimills competitive in producing steel sheet, could also provide an energy saving of 20%, compared with conventional slab casting. In one such process, liquid steel is poured directly onto a rotating wheel to form a continuous strip, eliminating several forming and heat-treating steps.

"Our aim at CMP is to work with utilities and metals-producing companies to help keep this vital industry competitive in world markets," says Project Manager Robert Jeffress. "Utilities have much to gain from this work because keeping U.S. industrial customers competitive ensures stability and offers potential growth in their service territories. The steel industry, because of its size, its need for cost-effective technologies, and its limited R&D resources, has been particularly receptive to working with CMP. As a result of CMP's involvement in EAF technology development, I expect to see electric steelmaking continue to grow substantially in the years ahead." ■

This article was written by John Douglas, science writer. Technical information was provided by Robert Jeffress, Energy Management and Utilization Division.



WALTER BAER

Technology and the Business of Information

This member of EPRI's Advisory Council sees a close parallel between the information industry and the electricity industry: "Deregulation, competition, and new technologies are radically altering the way business is done."

"Few people I know have moved linearly in their professional careers over the years. Certainly when I got my doctorate in physics I had no idea that I'd eventually be building new businesses in the communications and information fields, but I'm delighted it's worked out that way."

The observation comes from Walter Baer, director of advanced technology for Times Mirror Co. (parent of the *Los Angeles Times*) since 1981 and a member of EPRI's Advisory Council since 1986.

Reading Baer's professional biography, you'd quickly conclude that his break with career linearity was a 1966 move from Bell Laboratories to a White House Fellowship on the staff of Vice President Hubert Humphrey. Baer himself prefers to peg the turning point at the end of 1968, still in Washington, when he was completing two years with the Office of Science and Technology (OST). He vividly remembers his work with the administration's Communication Policy Task Force, surveying technologic changes occurring in the United States and determining what their effect might be on telecommunications.

"This was at the beginning of the use of satellites in international communication and television transmission. Cable TV, which had been just a community antenna service, was starting to expand, with the prospect of bringing more programming and other services into homes. Computers, too, were profoundly changing the telephone network—and all telecommunications, for that matter. Seeing all those new possibilities and opportunities was fascinating. I felt like a kid in a candy store. That's when I knew what I wanted to do after I left Washington."

Technology and business

In the 20 years since then, Baer has worked successively—and sometimes simultaneously—as a telecommunications consultant, venture capitalist, cable TV research leader, energy policy research manager, and technology development director. His Times Mirror position was created when the company foresaw that changes in technology promised to make business more complicated, "but also more interesting," Baer adds irrepressibly.

"Print is still the dominant medium for the information we publish. But over time we see much of it taking electronic form. Bob Erburu, our CEO," he goes on, "wanted to develop our expertise in these new electronic technologies. So that's the basis of what I do—chart new courses for us that will increasingly use electronic distribution of information."

One example illustrates how the windows of opportunity open and close in telecommunications. Along with several cable systems purchased in the late 1970s, Times Mirror also acquired the microwave networks then used to transmit TV programming from midwestern cities to the cable systems in outlying cities and towns. "But microwave was a dying business for TV transmission by 1981," Baer points out. "Satellites were taking over, so our network manager took on a few small contracts to transmit voice and data traffic for new telephone carriers like MCI and Sprint."

Early success prompted a 1982 proposal to upgrade the microwave capability. "It sounded crazy to me at first," Baer admits. "Why invest still more when satellites and optical fibers were both coming on so strong? Then it began to look interesting. The new carriers wanted to go national, but their only options at the time were to build their own facilities or rent transmission capacity from AT&T, their principal competitor. We offered a third choice—leased capacity that would enable them to expand quickly and enjoy stable costs for a 10-year period."

The upshot was an investment more than three times larger than that originally proposed to Times Mirror management, solid success in negotiating long-term leases with several major long-distance carriers, and profitable sale of the expanded network only four years later, in 1986.

Baer's work today encompasses several of his interests. "I like to work in areas where technology, business, and politics intersect. Cable television is one example. Electric power systems are another." He roves inquisitively. He networks. He enjoys making connections with the people who in turn create networks of telecommunication. As he talks, he communicates totally, moving vigorously, punctuating his statements with a pencil tap, giving key words—even key syllables—a staccato tonal emphasis, and speaking with a smile you can hear.

Science policy versus practice

Wally Baer began life in a Chicago suburb, where his equally energetic father still runs an industrial supply business; he lived there until he entered college in 1955. Although interested in science and mathematics in high school, Baer chose to attend the California Institute of Technology largely on other grounds. "I liked the notion of coming to California. I'd never been west of the Mississippi, and that seemed more exotic than staying in the Midwest or going east."

Graduating from Caltech in 1959, he went straight on to the University of Wisconsin, earned a doctorate in physics in 1963, and joined the technical staff of Bell Labs at Murray Hill, New Jersey, early in 1964.

Later, when the White House Fellowship beckoned, Baer found himself momentarily reluctant. "I was enjoying my research in solid-state physics, and it wasn't at all clear that I should leave my lab, even for a year. But when I went down to Washington for the final set of interviews, I got caught up by the opportunity. My interests had been broader than just physics for some time," he recalls. "I'd worked on arms control and disarmament issues as a graduate student and also in New Jersey community affairs and politics."

Baer's work with Vice President Hubert Humphrey fit in with those interests. "We were trying to understand why many of the Great Society programs weren't working as intended. It was heady work for a physicist," Baer says, "and it was also sobering, as the social unrest and protests about the Vietnam war spilled over into the domestic agenda."

Because Humphrey chaired the Space Council and the Marine Science Council at that time, Baer also became involved in technology matters. This included reviewing California's early effort to help aerospace companies diversify into what were called civil systems, such as water pollution, criminal justice, housing, and education. "We thought that program might be a model for federal use, but I concluded it would be very, very difficult to channel aerospace technologies and skills directly into such different markets."

His next two years, spent with OST, appealed more directly to Baer's growing interest in science and technology policy. In fact, his first brush with energy issues occurred when Donald Hornig, President Johnson's science adviser, asked Baer to compare the technical manpower resources of the telecommunications and the electric power industries. "This was in 1968, and the power industry had little R&D capability of its own—even very few people with advanced degrees. I remember concluding that there was a lot of room for additional effort."

Telecommunications and energy policy

But it was really Baer's work on the Communication Policy Task Force that launched him in his new career direction. In 1969 he and two Washington colleagues moved to California and organized a venture capital and consulting company. Their objective was to build new businesses based on the communications and information technologies that were starting to appear.

As examples, Baer cites long-distance communications and telephone equipment. "Competition there was just beginning. Before 1968 you could rent your phone only from the phone company; anything else was called a foreign attachment and was prohibited by regulation. That sort of regulation was obsolete in the new technology environment. We saw some exciting opportunities for other providers to tie into the network and make things happen."

Cable television was another early interest, and within a year or two Baer found himself doing work for The Rand Corporation on developments in that

field. By 1973 that consultancy had become virtually full-time; Baer was leading a Rand project on the likely directions for cable TV and how it would affect business interests, local governments, and television viewers. "So I joined Rand's communications program in 1974, and then, in the late 1970s, I took on leadership of its energy policy program as well."

Baer soon found himself immersed in the international security aspects of energy policy. "Oil import disruption was an urgent topic then; so was the nuclear fuel cycle and its implications for the spread of nuclear weapons. We were interested in domestic policy issues of energy resources, too—in particular, nuclear power and synthetic fuels."

Rand's studies included the economics of the breeder and light water reactors and their policy ramifications. "We concluded that the breeder was not essential to U.S. energy supply during the twentieth century," Baer recalls, "and as you can imagine, this wasn't a popular conclusion with the Department of Energy, a leading proponent of the breeder. And since DOE was our main source of support, we were biting the hand that was feeding us. But that was kind of a Rand tradition, coming out with results that ran against conventional wisdom."

Studies of coal gasification, synthetic liquids, and shale oil also yielded unexpected results. "We were trying to understand why everything cost three or four times as much as the experts originally estimated. Our conclusion seemed to be rather simple-minded and, again, not easy to accept. Technologists, we said, are basically optimists; they assume things will go smoothly. But the more they learn, the more difficulties arise, and the more expensive projects become."

Baer is sure everyone has this experience in off-hour endeavors. "When I try to do something around the house, I nearly always underestimate the time and money it's going to take, often by a factor of 2 or 3. It really wasn't too surprising, then, to find the same thing in synfuel plant estimates—the earlier the estimate, the more it was under."

Transforming electric utilities

In 1981, after Baer had been at Rand for seven years, telecommunications still had an edge over energy in his thinking. "And," he acknowledges, "I felt that the real action was in the private sector." This was when Times Mirror knocked.

It was several years after that, in 1985, when EPRI also knocked, inviting Baer to a term on the Advisory Council. This is a group of some two dozen individuals, drawn from many U.S. academic, commercial, scientific, professional, and regulatory positions to advise EPRI on its priorities, plans, and programs for electric utility R&D.

The opportunity had its special appeals. One was an institutional familiarity that dated back to 1972, when Baer sat next to Chauncey Starr on a transcontinental flight and thus learned about EPRI, Starr's brand-new enterprise at that time. Another appeal was Baer's sense of Richard Balzhiser, EPRI's president today and, like Baer, also a former White House Fellow who had served in OST.

Approached about the Advisory Council, Baer at first protested that he'd been out of the energy business for four years. "But Dick insisted, 'We're not asking you as an energy expert, we're asking you because you know *something* about our business and *a lot* about related technologies in the information and communications fields.' "

Baer doesn't see himself as representing any particular constituency on the Advisory Council, but he feels that his experience at Bell Labs and some of his later work on R&D strategies have relevance for EPRI. "Perhaps most important," he says thoughtfully, "I'm also in an industry where deregulation, competition, and new technologies are radically altering the way business is done."

Baer suggests that electric utilities, like Times Mirror and the information industry, must deal with a much wider array of competitive processes and practices than heretofore. He emphasizes that well-placed and timely information itself can improve productivity. "By understanding customer needs, utilities can match supply and demand more precisely and perhaps avoid building some new plants. Telecommunication and information technologies enable us to substitute intelligence for brute force resources."

Baer cites issues of centralization and decentralization as common concerns. Newspaper reporters routinely use per-

"I like to work in areas where technology, business, and politics intersect. Cable television is one example. Electric power systems are another."



sonal computers to write stories on location or at home, then transmit them in data form by telephone to the newsroom. Copy is edited and composed centrally, but distributed by satellite, optical fiber, or microwave to many points for printing. Operations are thus decentralized, but the system remains under centralized control.

"I think utilities are seeing analogous trends and opportunities," Baer says. "Technology encourages decentralizing some electricity generation, as well as wheeling power among dispersed sources and users. But at the same time it allows centralized control of the network." His point is that telecommunication and information technologies are leading to better ways of managing the grid, using resources, and pricing the service. "They may also lead to new forms of organization and ownership of generating and distribution facilities.

"Whatever business you're in," Baer concludes on a philosophical note, "you simply can't expect it to remain static for the next 10 years, or even for the next 2 or 3."

Improving end-use efficiency

Baer's position in the information business is his vantage point for observing electric utilities. The Advisory Council is a forum where he and his colleagues can share and report what they see. "I think we function as an early warning system for EPRI and also as a kind of conscience. We can say things that aren't said by the staff or the member utilities."

As an example, Baer says that during his term the Advisory Council has consistently encouraged EPRI to increase its spending on R&D to improve the efficiency of electricity end uses. "That's one of our essential functions—to make proposals and suggestions and keep repeating them so as to make clear what the concerns are outside the utility industry."

Baer acknowledges that end uses are highly diverse and complex, "a messy area from the technology development standpoint. It's not easy to get new ideas adopted when you have so many widely dispersed customers." But he's convinced that this is a high-payoff area. "EPRI will enhance the markets for electricity if it helps utility customers improve their productivity.

"But more than that, it seems to me that both business and residential customers focus on the *services* that electricity makes possible and on the *values* that are enhanced, rather than on electricity as a raw commodity. The electricity providers (and I use that plural form deliberately) must be as concerned with the value added from services as they are with providing electrons."

Again drawing a parallel to publishing, Baer says that it isn't intrinsically important whether information comes through the door in a newspaper or by wire or fiber or microwave to a personal computer. What's important is that the information is there when the customer wants it, in the form he or she wants it, and at an affordable price.

"I look at the electric power business similarly," Baer says. "Customers want certain services at prices they can afford; how the electricity to perform those services is generated and how it gets to them are of much less concern."

Does the Advisory Council need consensus to be effective? Or are its members so recognized for their individual expertise that individual messages carry weight? Baer believes that there are positive answers to both questions. For expertise, he mentions the utility regulatory commissioners, who have special knowledge of the world in which utilities operate. "In addition, I think it's impressive when a consensus emerges, as it did, for example, on the importance of end-use R&D."

Cooperating in R&D

Electricity technologies and electricity industries of the future are one thing. Sponsored research organizations and how they conduct their business today are another. When Baer talks about EPRI itself, he uses the word *impressive*—impressive in helping utilities set their technical development priorities, in managing individual R&D projects, and in demonstrating new technologies.

When Baer was at Rand, he studied technical demonstration programs and concluded that it was exceedingly difficult for the federal government to sponsor such projects effectively. "Demonstrations are big and costly, and when a government agency leads the effort, all sorts of political actors get in the way. EPRI's experience has been much better. It's been able to mount demonstration

"Telephones, television, and now computers have helped decentralize authority and made it more difficult for governments to exercise central dominance."

projects and have them show results in a cost-effective and timely way. That's a very impressive accomplishment."

Baer tempers his praise of EPRI's demonstration projects with recognition of their inherently high cost and their implications for EPRI's relatively austere overall R&D budget. He suggests that utility support for EPRI should be more widespread, but it seems to be limited by certain structural factors. "One is a longstanding tradition that utility suppliers do the R&D. I noted this in my OST study 20 years ago, and I think the issue is still here today."

Baer also notes the great range in utility size and form, isolation and interconnection, degree of vertical integration, metropolitan and rural setting, generation mix, and so on. He describes the industry as fragmented. "This fragmentation may have been appropriate in earlier days, but it seems excessive for the needs of U.S. society in the 1980s and 1990s." And the result? "I believe a number of utilities are underscale, undercapitalized, and operating under cost pressures that make it difficult for them to believe they can afford to invest in long-term research."

Baer believes fragmentation is still encouraged by the state-by-state nature of utility regulation, as well as by tradition. "Part of our national strength is indeed the diversity the 50 states offer," Baer says, "but a corollary weakness is the difficulty of coordinating efforts on a national scale. Over time, I think—at least, I'm hopeful—there'll be some consolidation in the industry and also a greater recognition that everyone does need to pull together on R&D support."

Empowering individuals

Even before he ever went to Washington, Baer believed that scientists could and should contribute to the resolution of social issues. "I was a generation behind the physicists who worked on the Manhattan Project or other weapons programs, but like many of them I thought our training and background made it almost incumbent on us to take some active social role. That's one reason I wanted to serve as a White House Fellow with Hubert Humphrey.

"But I was naive in thinking that technology alone could provide answers to what are basically social and political problems. There's no technical fix to nuclear weapons or arms proliferation, so after I left Washington and all through the 1970s I guess, I felt more detached. Problems had gotten so complicated, it seemed there wasn't much that any of us could do; and if we didn't have current classified knowledge, what contribution could we make?"

Today, though, communications technology enhances the influence of individuals and small groups. Baer sees this in the widespread dissemination of information by satellite, the increased use of personal computers, and the growth of the electronic networks that link them together—even in the proliferation of VCRs.

"Orwell had it all wrong," says Baer. "His book *1984* foresaw communication technologies as servants of despotic government, extending authoritarian control and taking away the individual's privacy and autonomy. But that's not the way it has worked out. In western nations, telephones, television, and now computers have helped decentralize authority and made it more difficult for governments to exercise central dominance. And it seems that other countries, including the Soviet Union, are beginning to experience the same pattern."

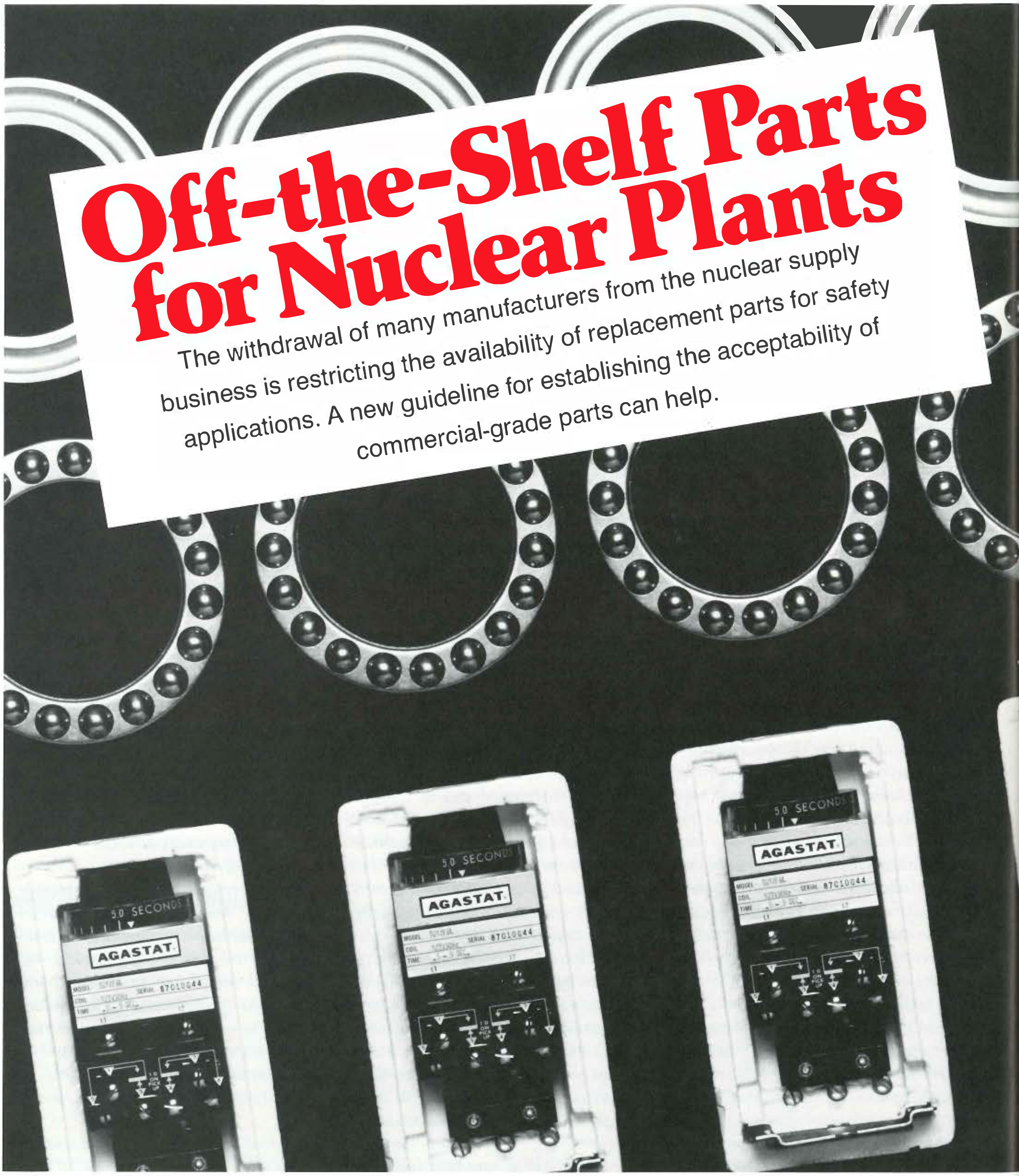
Business data, instruction, news, remote control commands, entertainment, weather, schedules, market reports—whatever the message content or purpose—the aggregate effect of telecommunications is to inform people and thus, in today's popular usage, to empower them. The significance is clear to Baer. "Individual empowerment is essential to a democratic society, and any invention that empowers citizens, whether it's technical or social or political, is basically constructive."

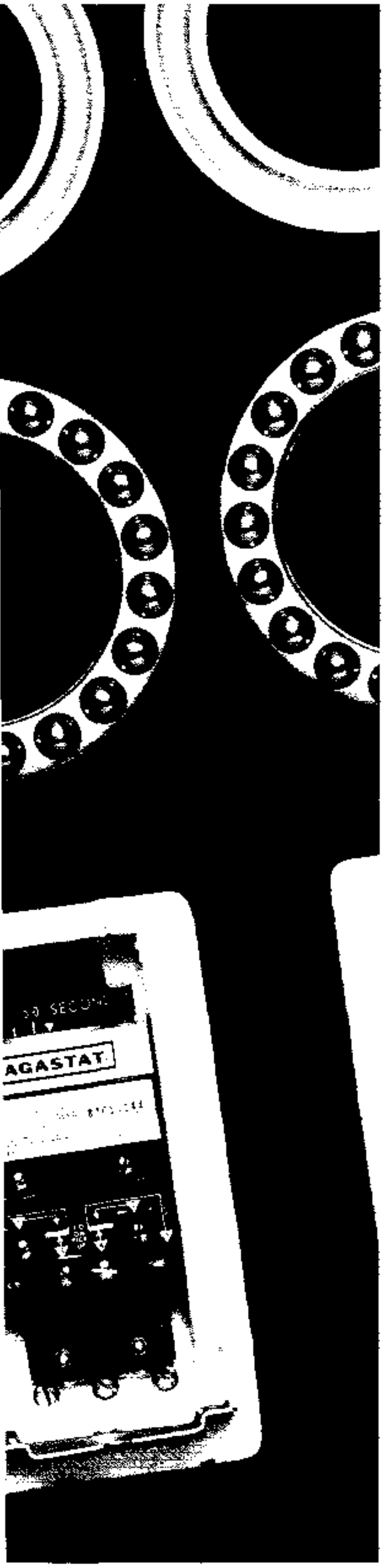
Baer therefore sees the explosive growth in his business—information and communications technologies, from satellites to personal computers—as helping to empower individuals and groups. "My professional work," he concludes, "is consonant with my overall view that these technologies are giving people more control over their lives." ■

This article was written by Ralph Whitaker, feature editor of the *Journal*, and is based on an interview with Walter Baer.

Off-the-Shelf Parts for Nuclear Plants

The withdrawal of many manufacturers from the nuclear supply business is restricting the availability of replacement parts for safety applications. A new guideline for establishing the acceptability of commercial-grade parts can help.





Thousands of years ago, the Greeks studied a problem in which a ship is taken apart at intervals over time and its components replaced by new ones. If all the parts are eventually replaced, the Greeks asked, is it still the original ship? Today, modern man is more likely to focus on the practical aspects of such a problem: If the components in a system are often replaced, how can the owner and operator ensure its integrity?

One practical answer to the question of the ship of Theseus, as the Greeks called it, is to insist that the shipowner maintain a high standard of quality in every replacement item. This approach to quality assurance (QA) parallels the regulations of the Nuclear Regulatory Commission (NRC), which requires nuclear utilities to verify and document the quality of thousands of safety-related items used in replacements and modifications—from nuts and bolts to larger pieces of mechanical and electrical equipment, such as valves, motors, and pumps.

Program requirements to ensure the quality of safety-related items are mandated by section 10CFR50, Appendix B, of NRC's Regulations, which defines QA as " . . . all those planned and systematic actions necessary to provide adequate confidence that a structure, system, or component will perform satisfactorily in service." Appendix B also establishes controls (such as tests, measurements, and documentation requirements) that must be implemented to ensure that safety-related items meet their intended requirements.

Traditionally, utilities have relied on suppliers to establish quality and qualify items as acceptable for safety-related applications under NRC regulations. As orders for new nuclear plants in the United States have dwindled, however, many suppliers have responded to the decreased demand by reducing the production of so-called basic components—items designed and manufactured specifically for nuclear safety-related applications. Others have dropped out of the nuclear supply business altogether or have discontinued the QA programs defined by 10CFR50.

As a result, utilities must increasingly make use of off-the-shelf or commercial-grade items in safey-related applications. NRC Regulation 10CFR21 defines commercial-grade items as those used in other industries, not built to any nuclear-specific requirements, and available through supplier catalogs and parts lists. If properly applied, they can be used in selected safety-related applications and provide quality equal to or better than the items they replace. This allows utilities to continue generating electricity when the replacement items they need are no longer available from nuclear suppliers or are available only through special orders, which may require long lead times.

Use of commercial-grade items also presents utilities with new responsibilities. When using commercial-grade items in safety-related applications, utilities must shoulder more of the burden of proving and documenting the acceptability and quality of the items they procure. This acceptance process, called dedication by NRC, has caused uncertainty among utilities seeking to take control of their technical destinies. Utilities have interpreted regulations differently, arriving at different conclusions about the extent of activities needed to ensure quality. In some cases, utility commercial-grade programs have drawn criticism from NRC and fines for improper documentation or controls.

Today, however, ambiguities and uncertainties are giving way to a clear and unified industry approach. Since 1986 the EPRI-sponsored Nuclear Construction Issues Group (NCIG) has brought together experts from around the industry to develop a first-of-its-kind guideline for the evaluation and acceptance of commercial-grade items for safety-related applications. This work culminated earlier this year with completion of the *Guideline* *for the Utilization of Commercial-Grade Items in Nuclear Safety-Related Applications (NP-5652)*, a document that has received enthusiastic praise from NRC, utilities, and other industry organizations. "NCIG has put together a framework on which utilities can structure commercial-grade programs that meet their individual needs, enhance safety and reliability, and satisfy the NRC," says Warren Bilanin, EPRI program manager for NCIG. "In the operational environment of the utility industry today, with nuclear suppliers becoming more and more scarce, the completion of this guideline is a matter of both economy and necessity."

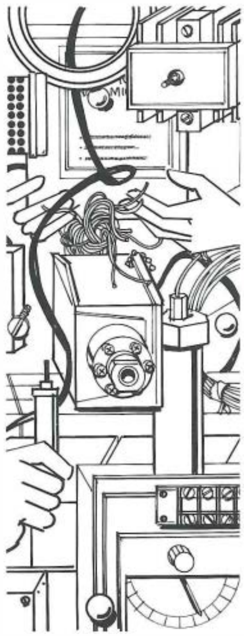
A generic process that works for all

The new guideline, essentially a methodology for accepting commercial-grade items, begins with a technical evaluation of the items that the utility wishes to procure. This includes determination of the item's safety-related function, verification of the fact that the component under consideration is indeed a commercial-grade item, and identification of the critical design and performance characteristics that must be verified before the item can be used in a power plant. Although the guideline does not list the critical characteristics of all safety-related items used in the nuclear power industry, it does provide representative examples of items and characteristics.

The critical characteristics—from the hardness and dimensions of small rubber O-rings to the horsepower of giant diesel motors—guide utilities through the procurement process. "Commercial-grade suppliers use varying types of quality programs, and they sometimes make changes in their materials and manufacturing techniques that can affect the suitability of their products for safety-related applications," explains Doug Aaron, director of auditing in the QA Department of Pacific Gas and Electric. "In the face of

Options for Acceptance

The Nuclear Regulatory Commission requires that the quality of commercial-grade parts be established before they are used in safety-related nuclear plant applications. Four methods of accepting items are detailed in EPRI's new commercial-grade acceptance guideline.



Special Tests and Inspections
The utility can perform or commission tests and inspections of the item as it is received from the manufacturer. The tests are keyed to the characteristics critical to each part for its particular use in the plant.

Commercial-Grade Surveys
Utilities can qualify parts by performing audits of the supplier's quality assurance program at the manufacturing site. The audit generally consists of a focused survey of the supplier's production and testing practices for a number of items.

Source Verifications
When a single item is needed, the utility can qualify the part by actually supervising its manufacture and testing at the supplier's plant. This option is generally faster than a full survey, but the verification is good only for one batch of parts supervised.

Performance Records
In cases where a commercial-grade item has been used successfully for many years in a safety-related application, a utility can use a documented record of its good performance to establish quality.

Going Commercial With Confidence

The first document of its kind, the commercial-grade acceptance guideline offers several benefits to utilities that incorporate it into their quality assurance and procurement programs.

Improved Availability of Parts
With the number of nuclear-grade suppliers decreasing, effective procurement of commercial-grade items ensures the availability of safety-related items for nuclear plants.

Cost-Effective Acceptance Procedures
The guideline allows utilities to concentrate on those specifications and technical requirements critical for each item, thereby promoting the efficiency of the acceptance process and reducing unnecessary tests and paperwork.

Top Quality at Low Cost
Accepted commercial-grade items perform as well as their nuclear-grade counterparts, which can be 10 to 1000 times more expensive.

Improved Regulatory Compliance
Implementation of the guideline's methodology can ensure and clearly document utility compliance with NRC regulations governing the dedication of items for safety-related applications.

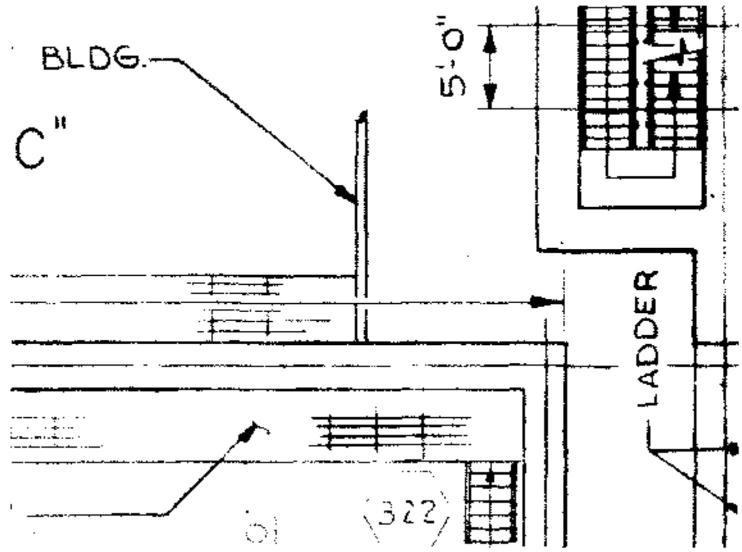
all this variety and change, it's the utility's responsibility to ensure that the component it receives and installs in a plant has the ability to perform its safety-related function."

After identifying critical characteristics, utilities choose from the guideline's four different methods for accepting the items: special tests and inspections performed or commissioned by the utility; surveys of the QA controls exercised by commercial-grade suppliers; source verifications in which utility personnel witness and document the manufacture and testing of a specific item or line of components; and reliance on the successful performance record of a given supplier and component. The guideline offers selection criteria to help utilities use these methods independently or in combination, depending on the type of item being procured and the practices of the commercial-grade supplier.

Special tests and inspections, for instance, are most appropriate when relatively simple items (such as fasteners or valve stems) are furnished from multiple suppliers. The utility verifies the critical characteristics after receiving the item, beginning with a standard postreceipt inspection and continuing through laboratory tests, and in some cases, post-installation tests. These activities range from measurements of the hardness and dimensions of steel bolts to laboratory shake-and-bake tests to ensure the seismic and environmental qualification of such components as gaskets and O-rings.

"Take the case of a steel fastener we use in the saltwater intake pumps at San Onofre," says Ken Baldwin, a Southern California Edison procurement engineering supervisor and vice chairman of the NCIG Task Group that developed the guideline. "The original manufacturer is no longer producing the fastener in quantity, so to procure it through a special order to a supplier with a 10CFR50 quality program could take us as long as

The Nuclear Construction Issues Group



The Nuclear Construction Issues Group (NCIG) was established in 1984 by several utilities seeking to develop generic, cost-effective solutions to common problems encountered in the construction of nuclear power plants. On request of the members, EPRI assumed program management responsibilities for the group in 1985 and has since expanded its activities to provide industry resolution to a range of construction, engineering, modification, and repair issues.

Completion of the *Guideline for Utilization of Commercial-Grade Items in Nuclear Safety-Related Applications* is one of several tasks implemented by NCIG that are already benefiting nuclear utilities. These include record-keeping guidelines for retention of technical data, guidelines for piping system reconciliation, and resolution of selected nuclear power plant welding issues. The tasks are proposed by interested utilities and completed by a special task group led by a utility chairman. Completion of a task can involve review and acceptance by NRC and industry groups, such as the Nuclear Management and Resources Council.

Some of NCIG's current tasks include technical evaluation guidelines for use of commercial-grade items, new motor repair specifications, and a guideline for maintaining and extending the shelf life of limited-life parts. "The success of the commercial-grade items effort encourages us to go forward with the tasks we are now implementing and planning," says NCIG Chairman Walter Weber, staff adviser at Union Electric. "Our ongoing work involves the same commitment to teamwork, timely results, and interaction with industry organizations that characterized the commercial-grade items task." □

18 months. By taking the commercial-grade route and then testing and measuring it ourselves, we ensure its quality, we save money, and we maintain the inventory of replacement parts we need to ensure the availability of our plant. Without that fastener and complete confidence in its quality, we aren't going to operate."

Monitoring suppliers for quality

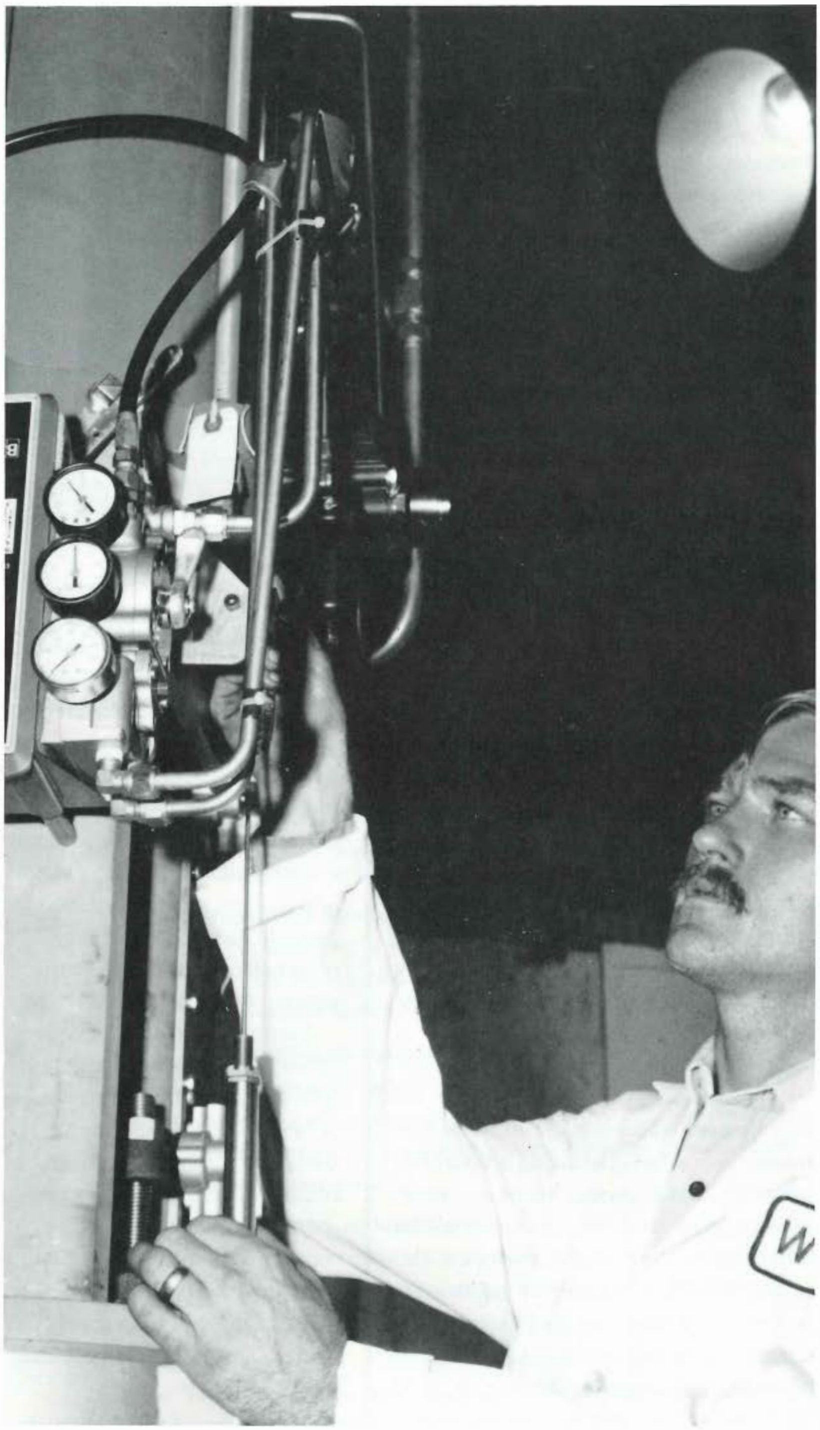
Although special tests and inspections can help utilities verify the characteristics of many commercial-grade items, they may not be necessary in cases where the supplier is already maintaining an effective QA program of its own. By conducting a commercial-grade survey or a source verification of a commercial-grade supplier, the utility can minimize its need to conduct special tests and can instead take advantage of work already completed by the supplier.

The more extensive of these two acceptance methods is the commercial-grade survey. Using this method, utility auditors visit the supplier's facility and qualify a wide scope of QA activities, such as design control, procurement and control of materials and subcomponents, assembly, calibration of measuring and test instruments, and the supplier's own inspections and bench tests. Many utilities already conduct these surveys with steady suppliers of nuclear-qualified items. For purposes of commercial-grade procurement, these surveys can allow utilities to take advantage of the rigorous quality standards implemented by military suppliers, by nuclear suppliers who may no longer be in the business of qualifying certain items, and by other suppliers adhering to special standards and codes.

Utilities may choose to use a similar but less comprehensive acceptance method —a source verification—in situations where a single item or shipment of items is needed within a limited time frame. Utility QA personnel must carefully monitor and document the supplier's quality

Testing for Critical Characteristics

The acceptance guideline outlines key characteristics that should be tested for some of the most common replacement items. Such information can help a utility select the best method or combination of methods for accepting each item and ensure the efficiency of the process.



program just as they do in a commercial-grade survey, but in these cases their attention is directed to the production of a specific item.

Recently at Union Electric's Callaway plant, for example, a burned-out motor on a control building air conditioner required rewinding. After making a temporary modification on the air conditioner to keep all control building equipment cool and safe and avoid the need for a plant shutdown, the plant staff performed a source verification at a local motor manufacturer who was willing to rewind the motor much more quickly than the original nuclear supplier.

"The original supplier was out of state and would have needed more than a week to rewind and return the motor," says Ken Kuechenmeister, an assistant manager in Union Electric's Materials Department. "The local supplier, on the other hand, could rewind the same motor in a couple of days. If a situation should arise in the future where we need a motor rewind in a hurry to avoid any impact on the availability of the plant, we can now consider using local shops."

The confidence that many utilities have developed in commercial-grade suppliers over time is reflected in the final acceptance method detailed in the guideline: reliance on a documented record of acceptable performance by an item procured from a given supplier. In this method, the utility ensures the quality of the item by citing performance records and by documenting the past use of tests, surveys, and source verifications to successfully accept the item. In conjunction with this method, the utility may also want to survey the supplier to ensure that no changes have been made in the manufacturing process that might alter a component's critical characteristics.

Performance records for this acceptance method can include results from the utility's own maintenance records and surveillance tests, industry product tests, national codes and standards applied in the manufacturing process, and nuclear industry performance data bases, such as INPO's NPRDS. To use this method properly, utilities must take special care to show a clear correlation between satisfactory performance and the required critical characteristics.

"The value of this method is that it can negate the need for costly tests and surveys that might not be needed to ensure the quality of the item being procured," says Bill Craig, formerly of Arizona Public Service and former chairman of the Commercial-Grade Item Task Group. "The performance record can speak for itself and show that the supplier and the utilities have both been doing their jobs. As the guideline comes into wide use and industry consistency evolves, utilities should be able to use this method more often to generate cost benefits."

Putting the guideline to work

In a final phase of its development, the guideline has been delivered to the Nuclear Management and Resources Council (NUMARC) and to NRC for their review. "Our staff members have indicated that this guideline is a welcome development and a much needed yardstick by which the industry can examine and improve its commercial-grade acceptance programs," says Robert Baer, chief of NRC's Engineering Issues Branch. "Although I couldn't guarantee at this point that there will be no conditions in our endorsement, I see every indication that NRC could issue a letter of approval before the end of the year, if asked to do so."

Improved confidence in complying with NRC regulations is just one of the benefits expected by utilities, several of which are already incorporating the guideline into their existing procurement and QA procedures. Other benefits will accrue from reductions in redundant and otherwise unnecessary tests, inspections, and paperwork; from the direct cost savings available through increased use of commercial-grade items; and from reduced maintenance costs, improved reliability, and enhanced safety. In addition, the guideline could help any utility ordering a new nuclear plant in the next decade to significantly reduce construction costs through the use of commercial-grade items in safety-related systems.

As the guideline comes into increased use, utilities are also very likely to gain from a more standardized industry approach to gathering data on component characteristics and the performance of components and suppliers. Through the Nuclear Suppliers Quality Assurance Committee (NSQAC), several utilities are already sharing the cost and information derived from QA audits performed on nuclear suppliers. Now, with the arrival of the new guideline, the possibility of utilities teaming up to perform QA surveys of commercial-grade suppliers is an attractive one as well. Another idea appealing to today's visionaries is the formation of a collaborative QA and engineering support center through which utilities could share information and commission technical evaluations and acceptance activities.

"One of the most important results from this NCIG task is demonstration of the fact that these types of technical issues are some of the best issues to tackle through a cooperative industry approach," says Bilanin. "If there's one thing that all nuclear utilities have in common, it's a strong interest in ensuring the quality and integrity of their power plants." ■

This article was written by Jon Cohen, science writer. Technical background information was provided by Warren Bilanin, Nuclear Power Division.

TECH TRANSFER NEWS

New Reference Books on Electrical Systems

In the past, several electrical equipment manufacturers published reference books that were widely used by utility personnel to make decisions on design, system planning, and preventive maintenance and to deal with plant emergencies. Unfortunately, many manufacturers have stopped publishing or updating these references, leaving utilities (until recently) without an up-to-date, practical reference manual to cover the various electric power apparatus and electrical phenomena encountered in power plants across the industry.

In response to this situation, in 1982 EPRI began development work on *The Power Plant Electrical Reference Series* (EL-5036), a multivolume resource that is now available at no charge to member utilities. Prepared by Stone & Webster Engineering Corp., the series includes 15 handsome, hardbound books, each copiously illustrated and focusing on a specific area of technology.

Member utilities are encouraged to order the series in complete sets of all 15 books. The individual volumes in the series include the following topics: electric generators; power transformers; auxiliary system planning; wire and cable; grounding and lighting protection; motors; auxiliary electrical equipment; station protection; dc distribution system; electrical control and instrumentation; cathodic protection; electric freeze protection and process heating; communications; electrical noise reduction; plant improvements and modifications. An accompanying paperbound volume, *Abstracts and Topics,* is a guide to the entire series. The series will be regularly updated and new volumes may be added to keep pace with advances in technology.

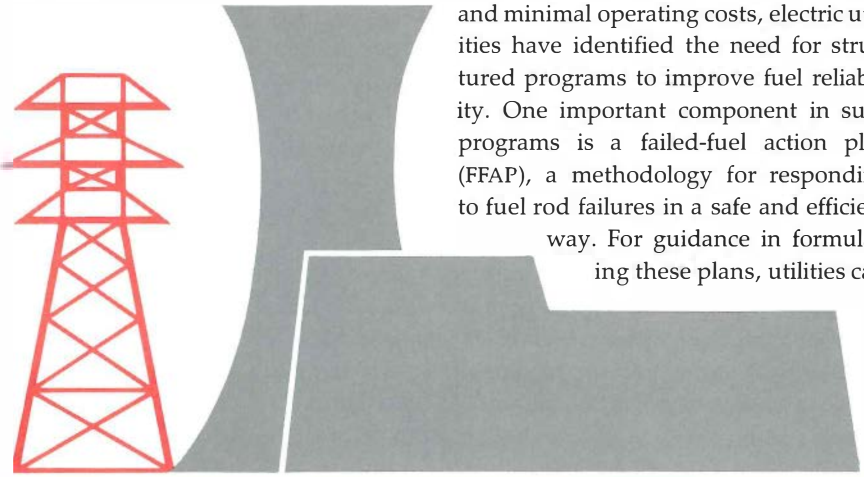
An attractive addition to any reference shelf or library, the series is primarily designed as a practical resource to help utilities save time and money and will be an aid to engineers in solving problems.

- Prevention of forced outages through proper installation, application, and protection of equipment
- Recognition of potential problems and their prevention
- Selection of appropriate maintenance methods to ensure trouble-free operation of equipment
- Reduction of equipment installation time and expense
- Proper specification of equipment being ordered
- Better coordination and integration of system components

"These volumes fill a need for a single reference that synthesizes information from many sources," says Dave Sharma, EPRI project manager for the series. "The result is a reference series that provides key concepts and formulas that are applicable to the operation and maintenance of a power plant. Each volume contains useful diagrams, charts, and tables, as well as solid examples of real-world problems and solutions."

Utility response to the new series has been overwhelmingly positive, with more than 2000 sets already distributed to the industry. Member utilities can request the series from the EPRI Research Reports Center, P.O. Box 50490, Palo Alto, California 94303, (415) 965-4081. ■

EPRI Contact: Dave Sharma (415) 855-2302



Guidance on Failed-Fuel Action Plans

Over the last 20 years, improvements in fuel designs and changes in operating practices have greatly reduced the incidence of fuel rod failures in U.S. commercial reactors. However, as the overall performance of plants continues to improve and as the industry strives to achieve excellence in fuel performance and minimal operating costs, electric utilities have identified the need for structured programs to improve fuel reliability. One important component in such programs is a failed-fuel action plan (FFAP), a methodology for responding to fuel rod failures in a safe and efficient way. For guidance in formulating these plans, utilities can turn to a new resource, *Failed-Fuel Action Plan Guidelines* (NP-5521-SR).

The guidelines offer several general tools to help utility personnel develop and carry out an FFAP. These include guidelines for effective coordination between corporate utility staff and plant personnel; a summary of the technical basis for specifying fuel reliability parameters in PWRs and BWRs; a general methodology for deriving cost-benefit analyses; a set of generic action levels and suggested activities for utility management and plant staff; a summary of successful utility practices; and an appendix outlining methods for collecting, analyzing, and reporting fuel performance data.

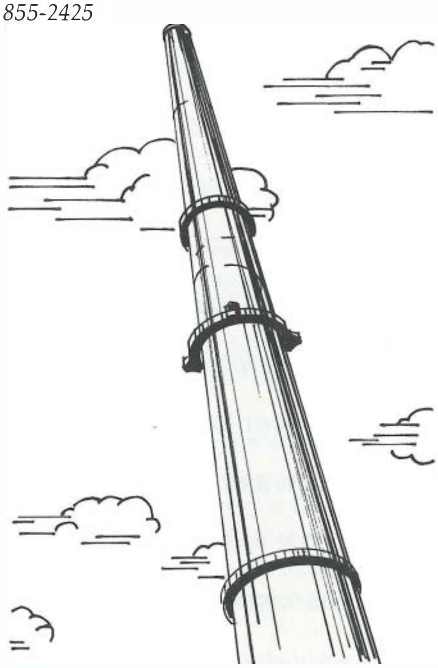
"The guidelines are not intended as a standard for evaluating performance at specific plants," says Rosa Yang, EPRI project manager. "Instead, they provide a framework and a reference to aid utility staff in developing plans for their plants."

The guidelines were developed in 1987 by a committee formed by utility experts and the Institute of Nuclear Power Operations. Prior to revisions and publication of the final draft, the guidelines were circulated to all U.S. nuclear utilities for evaluation. The final version reflects a balanced summary of views held across the industry. EPRI plans to revise and update the guidelines periodically to reflect the latest utility experience. A companion report (NP-5458) presents a methodology for determining the economic consequences of failed fuel. ■ *EPRI Contact: Rosa Yang (415) 855-2481*

Choosing Rubber Liners for FGD Systems

The performance of rubber liners in utility wet flue gas desulfurization (FGD) systems has varied enormously, along with related effects on power plant availability and on utility maintenance costs. Some rubber liners have been in service for more than 10 years without significant degradation, while others have developed problems within 1 year and have caused forced outages during replacement. Accordingly, utilities have been uncertain about how to specify and maintain the liners to meet performance and availability requirements.

Now, however, utilities can confidently replace, test, or specify new rubber liners by using a first-of-its-kind resource, *Specification Guidelines for Flue Gas Desulfurization Rubber* (CS-5528). Based on a literature survey and interviews with experts, the guidelines provide utilities with purchasing criteria, as well as design, application, and inspection requirements to ensure a quality installation. Technical data include factors crucial to achieving long, low-maintenance rubber liner life, including resistance to moisture, chemical attack, ozone, and oxidation; and sensitivity of the rubber's cure or coating. In addition, the guidelines describe standard laboratory tests for identifying these factors and screening candidate materials. ■ *EPRI Contact Chuck Dene (415) 855-2425*



Guidance on Specifying Low-Sulfur Coal

In complying with the Clean Air Act of 1970, utilities have relied heavily on coals that are lower in sulfur, either naturally or as a result of cleaning. However, the quality of low-sulfur coals varies considerably, sometimes leading to such unforeseen problems as reduced power station availability and efficiency or increased operating and maintenance costs. Now fundamental information on coal quality and cleanability—vital in specifying coals that yield the lowest electricity costs and SO_2 emissions—is available in a new resource, the *Coal Quality Information Book* (CS-5421).

To compile this comprehensive guide to North American coals, engineers at the EPRI Coal Quality Development Center obtained raw-coal samples from five of eight U.S. coal-producing regions and two Canadian provinces. The samples, weighing from 500 to 2000 tons each, were used to determine raw-coal quality characteristics, to investigate the potential of crushing coal to liberate ash and sulfur, and to produce from 50 to 100 tons of clean coal at different quality levels. The guide currently includes 16 bituminous coals, one subbituminous coal, two lignites, and one anthracite culm (screened coal refuse).

When used with EPRI's coal quality impacts model (RP2256-2) and coal cleaning cost model (RP2251-1), the book can help utilities estimate the busbar costs of changing coals and determine the cost of cleaning a particular coal. Utilities have used the book to develop coal purchase specifications and a coal feed system for a fluidized-bed combustor. EPRI plans to update the guide biannually, providing data for 20 additional coals. A microcomputer-based version, the coal quality information system, is slated for release in 1988. ■ *EPRI Contact: Clark Harrison (412) 479-4181*

Nuclear Plant Corrosion

MULTEQ Water Chemistry Code

by Peter Paine, Nuclear Power Division

ABSTRACT *Although virtually pure, the feedwater in pressurized water reactor (PWR) steam generators contains enough residual species to cause corrosion when the feedwater finds its way into flow-restricted areas (e.g., crevices) where boiling can occur. Boiling concentrates the residual species into corrosive brines that attack generator tubes and support structures. Direct measurement of water pH in the flow-restricted areas is not possible, but a new water chemistry computer code, MULTEQ, provides plant chemists with a valuable tool in their efforts to control water chemistry.*

The tubes and support structures used in pressurized water reactor (PWR) steam generators are subject to a variety of corrosion-induced phenomena. Studies by EPRI and the Steam Generator Owners Group (SGOG), for example, show that residual species, even in essentially pure feedwater, are concentrated by boiling that occurs in flow-restricted areas—in crevices between the tubes and support structure, under piles of sludge, and under scale on tube surfaces.

The concentration processes are limited only by the available superheat (primary temperature less secondary temperature) and diffusion of feedwater impurities through the porous deposit matrix. The concentration process is known to be a strong function of boiling rate and a weak function of feedwater chemistry. That is, given adequate time, the residual species in the feedwater can be concentrated into corrosive brines.

Purer feedwater can significantly lengthen the time required for corrosion to start but does not necessarily arrest the corrosion processes. Because of the superheat available in a typical PWR steam generator, secondary-side crevices can contain a liquid phase that is more than 50 wt% caustic or acidic sulfate or chloride solution at equilibrium conditions.

EPRI and SGOG studies of various corrosion mechanisms—denting, pitting, wastage, intergranular corrosion (IGC), and intergranular stress corrosion cracking (IGSCC)—show that all are functions of local pH. But it is not possible at present to measure water pH in localized areas of a nuclear power plant. Recent advances in pH-measuring probe design do make it possible to measure pH in laboratory autoclaves, but only with great difficulty (NP-5193).

Predicting pH

The MULTEQ water chemistry code was developed to predict pH at a user-defined temperature from user input chemistry data. The code uses a matrix calculation process to predict pH. In initial validation analyses, MULTEQ pH calculations compare quite favorably with experimental pH temperature curves. Additional validation experiments are ongoing.

Objectives of the MULTEQ code are twofold: to predict potentially corrosive conditions in flow-restricted areas in steam generators and to correlate plant chemistry data, including the effect of condenser inleakage, the effect of condensate polisher operational transients, and the effect of deliberate additions of pH control agents.

MULTEQ is a user-friendly, interactive FORTRAN computer program that calculates the composition, pH, and concentration of an aqueous solution as that solution is concentrated at a user-programmed temperature. It is designed to be used by PWR chemists concerned with solution pH and concentration in PWR steam generators.

MULTEQ operates on an IBM PC (or IBM-compatible computer) to predict pH versus temperature, pH versus concentration factor or ionic strength, and pH versus superheat. It also prints out precipitates, volatile species, and species in solution.

Steam generator temperature is controlled by the steam pressure; however, in flow-restricted areas exposed to both steam pressure and the reactor system's higher temperature, local temperature is also a function of the ionic strength of the solution. MULTEQ contains three optional crevice models, corresponding to three ways in which the solution may be concentrated.

The first model assumes a closed (static) system in which the ratio of the mass of water in the vapor phase to the mass of water in the liquid phase is varied while the total mass is held constant, and in which the precipitates are in equilibrium with the liquid and vapor phases. This option can be used to model double-ended tube–support plate crevices.

The second crevice model option is the same as the first, except that precipitates are removed from the system as they form; it can be appropriately used to model tubesheet crevices and sometimes tube–support plate crevices. In this model, potential buffer systems in the precipitate are removed and hence have no subsequent effect on the liquid or vapor phases.

The third option assumes an open (flowing) system in which the mass of liquid water flowing into the system is equal to the mass of water vapor flowing out. It is used to model bulk/blowdown water formation and the accumulation of chemicals in sludge piles or scales. Concentration occurs when nonvolatile residual species enter with the flowing feedwater stream and cannot leave in the vapor or steam phase.

There are two principal differences between the static models and the flowing model. In the flowing model the vapor leaves the system so that the volatiles escape more readily, and the computation time is at least 10 times longer.

MULTEQ handles four classes of species: user-specified primary species, combination species in solution, combination species limited to the vapor phase, and precipitates. Primary species are species that may combine to form combination species or precipitates; they may be charged or neutral. The user specifies the composition of the system by keying in the total concentration of each primary species that is present.

Combination species in solution arise from the reaction of two or more primary species or other combination species. Combination species are characterized by a charge, mass balance contributions, and an equilibrium ratio between constituents. Neutral species (primary or combination) may partition into the vapor phase.

Some species may be limited to the vapor phase. These are species that have appreciable concentration in the vapor phase but are presumed to have concentrations in the liquid phase that are small enough to be negligible in that phase. Precipitates are combination species that are characterized by solubility products relating the components and mass balance contributions. Precipitates and vapor phase species always have neutral charge.

One of the advantages of MULTEQ is the separation of the species data base and the program code itself. The species file is read each time the program is executed. A representative species data set is supplied with the program, but it can be altered to meet particular needs without making any changes to the program code (thereby avoiding recompilations and relinkings).

Activity coefficients

As the concentration of an aqueous solution increases, it becomes necessary to formulate reaction quotients in terms of effective concentrations called activities. The ratio of the activity of a species to its true concentration is called its activity coefficient. The equation used to calculate activity coefficients is a version of the extended Debye-Hückel equation developed by Meissner-Lindsay.

Activity coefficients are functions dependent on both temperature and ionic strength; four principal assumptions were made in formulating the chosen equations.

- All monovalent ions have the same activity coefficients.
- The activity coefficient of a multivalent ion of a given charge may be expressed in terms of the monovalent activity coefficient.
- Sodium chloride (NaCl) is the model substance and all monovalent cations behave like Na^+ and all monovalent anions behave like Cl^-.
- The Meissner-Lindsay equation for the activity coefficient of NaCl is accurate from 50 to 335°C (122–635°F) and for ionic strengths up to 100 molal. In fact, this formulation is quite accurate from 150 to 300°C (302–572°F) for ionic strength less than 10 molal, and it gives reasonable results over the entire range.

Table 1
INPUT FOR MULTEQ ANALYSIS OF SIMULATED RESIN INCURSION

Parameter	Baseline	After Incursion
pH at 25°C	8.8–9.0	6.0
Cation conductivity (μS/cm)	0.4	25
Chloride (ppb)	50	50
Sodium (ppb)	40	100
Silica (ppb)	100	330
Ammonia (ppb)	200	590

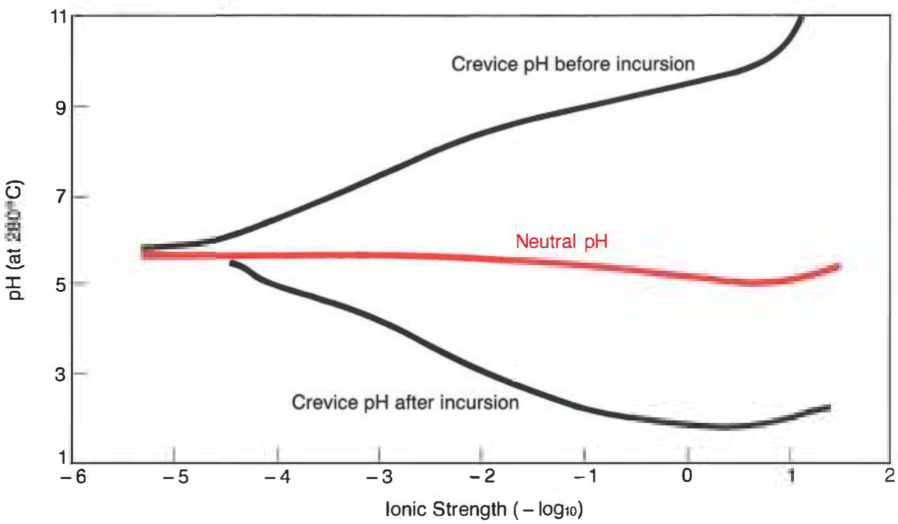
The above assumptions were made to simplify the complex question of activity coefficients and to provide a first-order approximation that does not depend on individual ionic species. As for neutral species, they too are assumed to have an activity coefficient. The activity of liquid water is also estimated.

Using MULTEQ

The uses of the MULTEQ code, which attempts to correlate and analyze hideout return data, blowdown data, and mass balance data, have been explored recently during several training sessions sponsored by Commonwealth Edison, Alabama Power, New York Power Authority, and Baltimore Gas & Electric. MULTEQ has also been used to answer questions about the pH effect of an ion-exchange resin dump, the effect on crevice pH of adding boric acid, and the effect on steam generator pH of adding morpholine instead of ammonia. In addition, some utilities are using MULTEQ to correlate cation conductivity measurements with the measured species in the steam generator.

Several applications of MULTEQ have been studied in detail. In an analysis of the effect of a simulated ion-exchange resin intrusion, the MULTEQ-calculated crevice pH suggested that corrosive conditions may form. Table 1 presents the ambient temperature data that would ordinarily be measured

Figure 1 MULTEQ simulation of an incursion of ion-exchange resin. Measured 25°C pH and cation conductivity were matched with MULTEQ's 25°C calculations, and MULTEQ was then exercised at operating temperatures to make these predictions of crevice pH.



at a power plant, which were used as input to MULTEQ; Figure 1 shows crevice pH before and after the simulated incursion, as well as neutral pH. For this simulation, the user matched the 25°C measured pH and cation conductivity with MULTEQ's 25°C calculations by adding chemical species that were not measured by the plant chemists, but are known to be present. Then, MULTEQ was exercised at operating temperatures to make the predictions shown in Figure 1.

As a result of the MULTEQ predictions, the plant chemist would recommend increased sampling for other species and then immediate shutdown. After shutdown, MULTEQ would be used to correlate hideout return data to indicate when the plant should go back on-line. The MULTEQ predictions are, of course, only one input that the plant operators should consider in making shutdown and restart decisions.

Plant blowdown water chemistry has been analyzed for several units. Predictions of caustic-forming waters, which may lead to IGC or IGSCC, have been calculated and verified by subsequent nondestructive and destructive examinations of the steam generator tube bundle. In other units, predicted acid conditions were corrected by modifying condensate polisher operations.

The MULTEQ water chemistry code has proved to be a valuable aid to plant chemists, helping them make decisions that will promote the long-term integrity of PWR steam generators.

Component Reliability

On-Line Monitoring of Component Wear

by Stephen Gehl, Coal Combustion Systems Division

Metal loss or wastage in fossil fuel plants—caused by solid particle erosion, corrosion, and wear—limits the life of boiler tubes, turbine blades and nozzles, bearings, valves, and many other components. With on-line monitoring methods that directly measure the wastage rates of key components, utilities can replace worn parts or take corrective action before in-service failures occur. However, until recently, few methods were available for detecting material loss from critical surfaces, and none could accurately determine component condition on-line.

Now EPRI and its contractor, the Spire Corp. of New Bedford, Massachusetts, have developed wastage monitoring techniques based on the principle of surface layer activation (SLA). These techniques use an accelerator ion beam to generate radionuclides in selected surface and subsurface locations of a component without affecting its mechanical properties. The induced radionuclides emit characteristic gamma rays that are strong enough to de-

ABSTRACT *EPRI has developed a novel technique for on-line detection of wear in key power plant components—surface layer activation, which consists of monitoring changes in gamma-ray emission from activated components. It has been field-tested in plant applications, and a commercial on-line system is now available.*

tect yet safe for personnel. As the component wears, the loss of activated atoms reduces the gamma-ray intensity. By monitoring the reduction in gamma emissions over time, utilities can accurately track material loss. One of the key advantages of the SLA technique is its totally nonintrusive nature. The radiation detector can monitor the weak signal coming from the component even through several inches of surrounding steel. This means that the sensor can be located outside a valve body or pipe, for example, and make all measurements remotely.

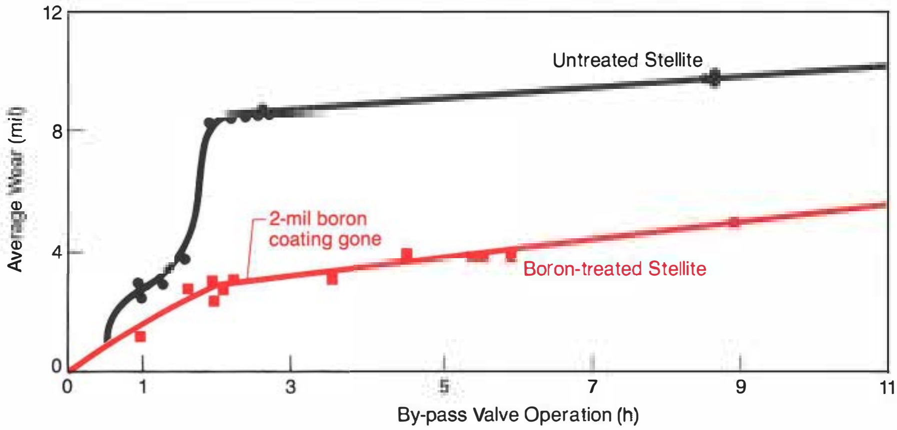
A variation of this technique calls for using a filter to collect the radioactive debris that accumulates during wear; by monitoring the filter, utility personnel can determine metal loss. Correlation of material loss data with operating conditions allows utilities to determine maintenance intervals, obtain early warning of potential damaging conditions, and receive quick feedback on the performance of new component designs and material selection.

In situ monitoring of steam turbine valves

Field tests of material-loss monitoring by SLA have shown the applicability of the technique to several fossil fuel power plant components. For example, EPRI tested a system for turbine stop/bypass valve monitoring at Dayton Power and Light's Stuart station in May 1985. At Stuart this valve carries the entire steam flow to the turbine during startups. Oxide exfoliation in upstream pipes and boiler tubes had led to serious erosion of the valve. Frequent replacement of the valve disk at regular intervals had been necessary at Dayton to prevent failure. Because of the difficulty in predicting erosion rates, the valve disks were replaced long before fully expended. Many older cycling plants with this design have the same problem. These high maintenance requirements made the stop/bypass valve an excellent candidate for on-line monitoring.

At Dayton Power and Light, the Spire test team monitored two valve disks side by side during a series of startup cycles. One valve disk had a skirt made of conventional Stellite (trademark of Stoody Deloro Stellite, Inc.); the other disk had a Stellite skirt with a high-temperature boron diffusion treatment to increase the surface wear resistance. The project team exposed a rectangular area on each disk to a 12-MeV proton beam, which generated the radioisotope cobalt-56 to a depth of approximately 0.009 in (0.23 mm). At the anticipated erosion rate, this depth would allow researchers to obtain wear data for several startup cycles before removal of all the activated material. Scintillation counters monitored the activated regions of the valve disks through the approximately 12-in (300-mm) thickness of the valve body.

Figure 1 Erosion of valve disks in the tests at Dayton Power and Light's Stuart station. The results indicate the ability of the SLA technique to measure the lower initial wear rate and eventual disappearance of the boron diffusion coating. Erosion rates were higher for both valve disks during the first two starts (within the first three hours).



The test results demonstrated that the erosion resistance of the diffusion-treated valve was superior to that of the untreated valve during the first two startup cycles (Figure 1). However, because the treated layer had eroded away by the end of the second startup, the subsequent erosion rates of the two disks were essentially the same. In this test, the real-time monitoring provided a rapid and accurate comparison of the performance of the valve disks.

The field test results and an associated economic evaluation confirmed the cost-effectiveness of on-line monitoring and allowed Dayton Power and Light to plan disk replacement on the basis of actual erosion rates rather than at conservatively derived fixed intervals. The resulting extension of disk life by a factor of 3 produced an annual saving of nearly $138,000 for eight valve disks in four steam turbines (EPRI First Use FS6305B).

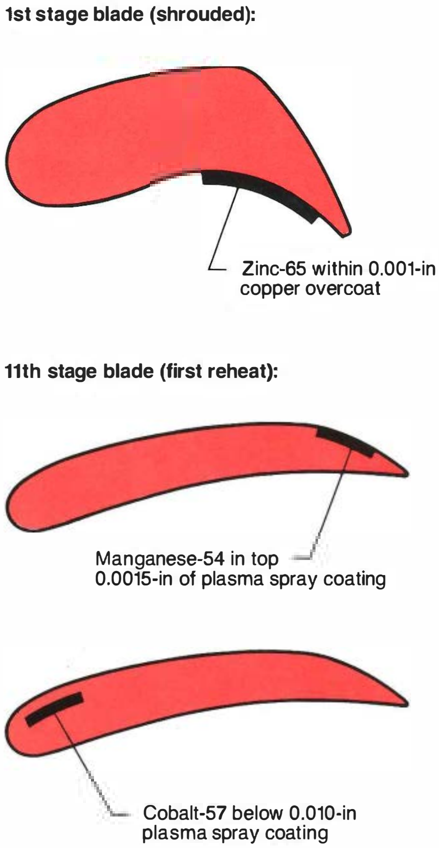
The test also showed the value of real-time data in evaluating erosion reduction strategies. In this case, the boron diffusion treatment offered protection for only a brief period and was therefore of limited value in preventing valve erosion. The data also show that the erosion rates are highest in the first few hours of operation after a prolonged shutdown. Thus, passing particle-laden steam around the turbine during this critical period may be an effective way of reducing erosion damage.

On-line monitoring of turbine blade erosion

In some applications, measuring the debris produced by the wear of an activated part is preferable to monitoring the part itself. For example, in an ongoing demonstration of SLA monitoring at Potomac Electric Power's Chalk Point station, test personnel are using this alternative method to monitor high-pressure turbine blade erosion because the shielding of the thick turbine casing makes direct measurement of the blades impractical. Researchers collect and monitor debris on a filter in the condensate line.

This application uses multiple isotopes to

Figure 2 Implantation of isotopes in turbine blades allows the extent of turbine blade wear to be monitored without taking the unit out of service. Isotope material worn from the blade is collected and measured to determine blade erosion.



monitor wear depth. With implantation of isotopes at different depths in the test blades, appearance of an isotope on the filter indicates that erosion has reached the implantation depth of that isotope. At Chalk Point, the test blades had received a chromium carbide plasma spray for improved wear resistance. Test personnel deposited isotopes in three blades: zinc-65 in the copper overcoat on the original blade surface of a first-stage blade, manganese-54 within the chromium carbide layer of an eleventh-stage blade, and cobalt-57 in the base metal below the plasma spray coating of another eleventh-stage blade (Figure 2).

Immediately after the startup of the unit, the zinc-65 from the copper overcoat and the manganese-54 from the plasma spray layer were clearly detected. These isotopes gradually disappeared after four days of operation. Further monitoring confirmed that these isotopes had been exhausted, indicating that erosion had removed the upper portion of the plasma spray coating. In addition, the rapid disappearance of the zinc-65 peak confirms that the debris does not collect or pool in the system but is rapidly purged once generated. Another significant indication from these data is that after nearly a year of monitoring, none of the cobalt-57 from the buried layer has yet appeared. This suggests that even though the manganese-54 layer had been exhausted in one eleventh stage blade, the plasma spray layer in the other had not been breached, at least at the location of the implanted isotope. Future filters containing cobalt-57 will give a quantitative indication of the durability of the chromium carbide coating.

The initial test results indicate that debris collection rates are sufficient to monitor erosion reliably in steam turbines, using small sources that present no hazards or handling problems. In addition, the test shows that the debris monitoring location can be some distance from the turbine without producing spurious signals caused by debris holdup in the piping system. With careful selection of the monitoring locations and isotopes, test personnel can monitor both bulk material loss and changes in blade shape for a limited number of areas.

Other applications

In tests at Kansas Power & Light's Jeffrey Energy Center, the SLA method was used to monitor bearing wear in a wet-motor boiler circulation pump. The demonstration, which monitored both rotating and stationary components of the main rotor shaft bearing, showed that the SLA method can detect and accurately measure material loss of less than 0.001 in (0.03 mm) over a period of six months or longer.

In a laboratory feasibility study, researchers have evaluated the use of SLA to monitor wall loss in boiler tubes. The results suggest two possible applications.

- Radioisotopes located at or near the tube surface can provide data on real-time wall loss rates as a function of plant operating conditions.
- Burying the isotopes some distance below the surface will produce an alarm when the wall thickness in critical regions of the boiler decreases to the point at which replacement is necessary.

Figure 3 shows a boiler monitor with the radiation detector viewing the activated area through the boiler casing and insulation.

The favorable results of these demonstrations suggest other potential applications. For example, SLA monitoring may help utilities track erosion-corrosion in condensate and feedwater piping, wear in coal pulverizers, and wastage in attemperators. The Spire Corp. is offering a commercial product, called Spi-Wear, based on the research. Ultimately, EPRI plans to develop a handheld monitor for spot-checking components throughout a plant. This approach will allow utilities to monitor metal loss online with a minimum of effort and cost.

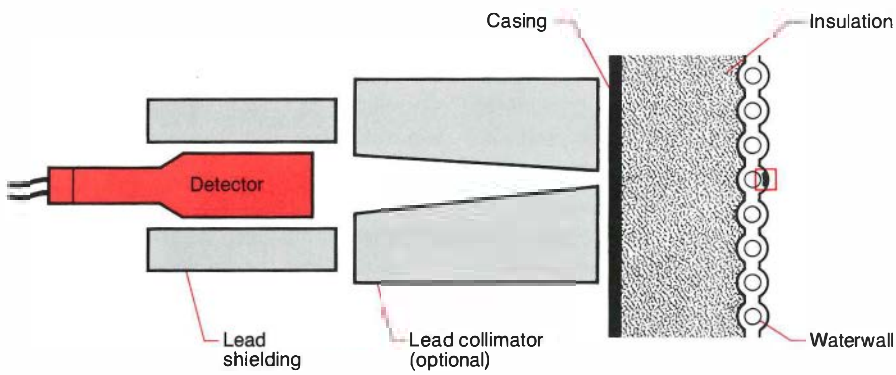


Figure 3 This schematic shows the position of the radiation detector as it examines the activated area through the boiler casing and insulation.

Potential Effects of Climate Changes on Electric Utilities

by Tom Wilson, Environment Division

ABSTRACT *Accelerated changes in Earth's climate—particularly the global warming that many scientists are predicting—could add a new and complex variable to the utility planning problem. Past changes in climate occurred so gradually that over the 10–50-year periods of concern to utility planners the climate could be considered constant. Analyses of two cases, however, show that even a moderate rise in the average global temperature could affect requirements for new generating capacity and that failure to anticipate and provide for such a change could be costly to both utilities and their customers.*

Many experts predict that Earth's average temperature will increase significantly within the next century. A National Academy of Sciences (NAS) report released in 1983 projected that within 50 to 100 years increases in the atmospheric concentration of carbon dioxide (CO_2) would cause the global average temperature to rise by 1.5–4.5°C (2.7–8.1°F). More-recent reports from a variety of sources have suggested even more rapid global warming caused by the effects of increased concentrations of such gases as methane, nitrous oxide, and chlorofluorocarbons.

Historically, climate has changed slowly, remaining virtually constant over the 10–50-year periods considered in making utility capital investments. Thus for their purposes, the utilities have been able to regard climate as a constant. However, if the more rapid changes that are being predicted materialize, the assumption of a constant climate may lead to costly planning errors.

There are scores of variables that establish the demand for and supply of electricity, and many of them would be influenced by significant changes in climate. The following are examples of the implications that climatic changes could have for utility planners.

- Peak demand and load curves could be affected by changes in heating and air conditioning electricity requirements induced by changes in temperature and humidity.
- Hydroelectric and plant cooling-water supplies could be affected by changes in temperature and precipitation.
- Regional power demands could vary if climatic changes disrupt population trends.
- Demand in irrigated agricultural areas could fluctuate as a result of climate-induced changes in soil moisture.
- System reliability could be affected if climatic changes result in more-frequent and more-severe storms.
- Generating plants in certain coastal areas could be affected by variations in the sea level.
- Fuel prices could rise if higher temperatures and loss of hydroelectric capacity cause global energy demand to increase.

In 1985 EPRI, EPA, EEI, and New York State ERDA sponsored a study to develop preliminary information about the potential magnitude of projected effects of climate change on the electric utilities. The study, conducted by ICF, Inc., examined the implications of uncertainties in future climate for two cases: the New York State utility system and a southeastern utility.

The study focused on the year 2015, a date that was far enough in the future to permit some effect to be observed but still within the planning horizon for making certain types of utility decisions. The researchers studied the first two potential consequences of a change in climate described above: temperature effects on heating and air conditioning power requirements and the effects of streamflow on the availability of hydropower.

The analysis for each of the two case studies consisted of three basic steps: (1) developing climate change scenarios, (2) estimating the weather sensitivity of electricity supply and demand, and (3) estimating the economic risks of alternative planning assumptions.

In an effort to cover the many uncertainties in the forecasts and the range of predictions about future climate, a range of scenarios was developed for each of the key climate variables. The basis for the estimates used in the regional climate scenarios was a series of forecasts of global climate changes obtained from three general circulation models (GCMs) of Earth's atmosphere. The GCMs were developed by NASA's Goddard Institute for Space Studies, the National Center for Atmospheric Research, and the Geophysical Fluid Dynamics Laboratory of the National Oceanic and Atmospheric Administration.

GCMs are large computer models that use mathematical equations to represent the physical laws governing Earth's climate (e.g., conservation of momentum, heat, and moisture). The three GCMs used to develop scenarios for this study involve three-dimensional representations of the atmosphere—latitude, longitude, and height above the surface—plus representations for ocean dynamics and for ice and snow. In particular, the models were used to estimate the potential effects of doubling the concentration of atmospheric CO_2.

The GCMs are complex and best used to calculate "snapshots" of future conditions, given a change in CO_2 levels. Accordingly, a one-dimensional model of the atmosphere and oceans, calibrated to the GCM results, was used to develop a range of scenarios of how climate change might occur over time.

In the second step in the analyses, both statistical and structural approaches were used to model the weather sensitivity of the demand for electricity. The statistical approach developed the weather sensitivity relationships by applying regression analysis techniques to past data on temperature and aggregate system load. The structural approach, in contrast, used disaggregated utility end-use data. In this latter approach, weather sensitivity was analyzed for each end use by using statistical engineering simulation models; the end-use loads were then aggregated to obtain weather-adjusted system loads.

Electricity supply sensitivity was derived from statistical analysis relating hydroelectric generation to streamflow. Because of the relatively small temperature changes predicted to occur over the 30-year period of the analysis, the temperature sensitivity of other generating options was presumed to be negligible.

In the third step, utility planning models were applied to determine the economic risks associated with alternative planning assumptions. Estimates of electricity sales, annual and seasonal peak demands, generating capacity requirements, fuel utilization by fuel type, and capital and operating costs were made for each climate scenario on the basis of the capacity-expansion model analysis.

Estimates of the effects of a change in climate on the study utilities were generated for a large number of scenarios, encompassing alternative climate conditions and weather sensitivity estimates, in addition to a variety of assumptions regarding demand growth in the absence of climate change. The conclusion drawn from these analyses is that climate changes possible over the next 30 years may significantly affect the electric utility industry. The high-temperature-change scenario, defined by a 0.95°C (1.71°F) increase in average annual temperatures for the southeastern utility and a 0.77°C (1.38°F) increase for the New York system, best illustrates this conclusion.

Table 1 presents estimates of the climate change–induced increases in 2015 peak demand, total energy, and energy generation costs for the high-temperature change (change in average summer temperature). As can be seen, although the assumed summer temperature increases in the two regions are nearly the same, the resulting estimated change in peak demand for the southeastern utility is more than double that for the New York system because the southeastern utility's peak demand was estimated to be far more temperature sensitive than that of the New York utilities.

The effects of the increase in average summer temperature on total energy demand are significantly different for the two study regions: 0.45% for the New York system and 3.4% for the southeastern utility. The difference is caused primarily by the use of air conditioning throughout the year in the southeastern utility's service area, whereas in New York, air conditioning is used principally in the summer. In fact, the total annual energy requirements in upstate New York decrease with an increase in average temperatures because winter heating loads are thereby reduced.

Table 1
EFFECTS OF GLOBAL WARMING ON STUDY UTILITIES FOR YEAR 2015

Parameter	New York	Southeastern
Summer mean temperature increase (°F)	1.46	1.87
Peak demand change (%)	3.32	7.04
Total energy change (%)	0.45	3.40
2015 cost if change planned for (in 1985 $ million)		
No temperature increase	−39	11
Temperature increase	102	212
2015 cost if change not planned for (in 1985 $ million)		
No temperature increase	0	0
Temperature increase	174	267

Note: All estimates based on statistical estimation of weather sensitivity and low streamflow assumptions.

The annualized cost (i.e., capital and fuel costs) of supplying this additional electricity demand is $267 million for the southeastern utility and ranges from $48 million to $174 million for the New York system, depending on assumptions made about the availability of hydroelectric power. The $174 million estimate is based on an assumption of a future climate that would significantly reduce streamflow. As a result, enough new capacity would have to be obtained to cover not only the lost output but the temperature-related increases in demand as well.

Because the extent and timing of future changes in the climate are uncertain, the utilities must make today's decisions with information that is less than perfect. Table 1 also shows the economic risks associated with the following possibilities.

- The utility makes no provision for the climate change, and the change either does or does not occur.

▫ The utility plans for the change, and the change either does or does not occur.

If no plans are made for the change and the change does not occur, then no generating capacity would be added in anticipation of climate change, and there are no costs associated with the outcome. However, if the utility does not anticipate the change but it does occur, short-term, relatively expensive measures (e.g., power purchases, construction of oil- and gas-fired turbines) would have to be undertaken to meet the unanticipated growth in demand.

Alternatively, if the utility does anticipate the climate change it would most likely construct additional baseload capacity in anticipation of demand growth. If the anticipated climate change does not materialize, the utility might find itself with excess capacity. However, if the climate change is provided for and if the change occurs, the utility would stand to save money.

The estimates in Table 1 indicate that for both utility systems, the largest costs are incurred when there is climate change, and it was not anticipated in the utilities' long-term plan: $174 million and $267 million in 2015 for the New York and southeastern utilities, respectively. These costs exceed by $72 million and $55 million, respectively, the costs that would have been incurred had the effects of the climate change been anticipated.

But what happens if these utilities plan for climate change and it does not occur? Interestingly, the New York system would derive a benefit of $39 million for adding additional baseload capacity, even though the climate does not change. This reflects a saving in fuel cost obtained by replacing oil- and gas-burning facilities with new coal-fired units. The southeastern utility would pay a penalty of $11 million if it built capacity in anticipation of a climate change that does not occur, but the potential savings of $55 million it would obtain if the change does occur might overshadow the penalty.

The results of this study are certainly preliminary but nonetheless suggest the potential importance to utilities of incorporating climatic data and projections in their plans.

The ICF study results will be published in early 1988. Plans are being made to extend the analysis in several ways: first, opportunities for improving the data, assumptions, analytic approaches, and estimation methods that were used will be assessed; second, the scope of the research will be broadened to include a wider range of climatic effects on utilities; and third, the analysis will be conducted at additional utilities.

Equipment Life Extension

Power Transformer Advances

by Ben Damsky, Gil Addis, and Dave Sharma, Electrical Systems Division

The transformer has been a commercial product for more than a century, and one might expect the many years of volume production to have produced a fully mature product. Although this is generally true, new materials, altered loading practices, and changing business environment are challenging traditional transformer design and use.

A recently developed low-loss, amorphous alloy may reduce the voltage-dependent core losses by two-thirds. This replacement for magnetic steel became available just when the cost of producing electricity was rising and utilities found they could save money in the long run by paying a premium for low-loss transformers. New coil designs have been developed, and this radical change, coupled with the new core material, should lead to a truly advanced transformer. In addition, improved understanding of how overloading affects transformer life sparked interest in the effects of bubbles formed at the hot conductors under overload. Until recently, little was known about this phenomenon, and new guidelines for loading are evolving from research.

ABSTRACT *All electricity flows through many transformations before it is used. Consequently, even small improvements in transformer efficiency can save utilities tens of millions of dollars each year. EPRI's comprehensive research program in transformer core losses, coil losses, and life extension will expedite the use of the most advanced technology in power transformers and help utilities realize the potential savings.*

Amorphous alloy cores

In 1979 the Electrical Systems Division planted the seeds that are about to flower into a revolutionary low-loss power transformer design (RP1290). Under a contract with EPRI, Allied Corp. began exploring the use of its new amorphous alloys in transformer cores. Since then, work has progressed steadily on a prototype, and in 1982 EPRI asked Westinghouse Electric to design a 500-kVA transformer with an amorphous core (RP2236). That unit was installed on the Niagara Mohawk system in July 1987, and it has met every expectation. Although many distribution transformers with amorphous cores have been installed across the country, the Niagara Mohawk unit is not only the largest transformer of its kind in the world but it was also the first installed unit with stacked core laminations. Its most outstanding feature is that the core loss is only one-quarter the core loss of a conventional unit.

The manufacture of such a transformer—cutting and assembling laminations into a compact, efficient core—is challenging. That the process must be highly automated and the resultant core must tolerate significant short-circuit forces without degradation adds to the engineering complexity.

In 1982 the standard ribbon produced by Allied was so thin (approximately 0.001 in, or 0.025 mm) that its acceptance as commercial lamination material for power transformers was threatened. A study of methods for casting thicker ribbon encountered serious difficulties, and another approach was funded. Allied named the product Powercore, a strip produced by combining several thin ribbons (six is a typical choice) into a thicker consolidated strip (Figure 1). The result is thinner than conventional grain-oriented steel by a factor of 2 but thick enough for commercial use. Allied has learned how to maintain a close tolerance on the alignment of the incoming ribbons and is concentrating on reducing the cost of the consolidation process.

Westinghouse has been studying optimal methods of cutting and handling the unusually tough and brittle material. The company has completed specifications for equipment to cut laminations automatically, and this unit is estimated to be operational in 18 months. Core designs are under way, and construction of a 2500-kVA transformer will start this year.

The goal of this project remains to reduce core losses to one-third of conventional losses at a modest increase in initial cost.

Vapor bubble formation in overloaded transformers

The objectives of a related project have been to establish the parameters that influence transformer loss of life and to find test methods that suppliers can use during manufacture to detect material defects. Contracts were awarded to General Electric (RP1289-1) and to Westinghouse (RP1289-2). Both companies tested the response of several types of cellulosic insulations to hot spot temperatures generated during overload. Bubbling during rapid overload directly affects dielectric strength of conductor insulation, and the insulation, in turn, could partially break down to increase the moisture content at elevated temperatures (Figure 2). Thus transformers that have accumulated moisture are at greater risk when rapidly overloaded.

A generally accepted theory is that little or no aging occurs until hot spot temperatures reach the vicinity of 180°C and that transformers can withstand overloading routinely at this level without appreciable loss of life. However, research indicates that the insulation system is most vulnerable to dielectric failure during an overload, when the temperature is suddenly elevated to a level that can vaporize any moisture present in the paper. This leads to another mode of failure.

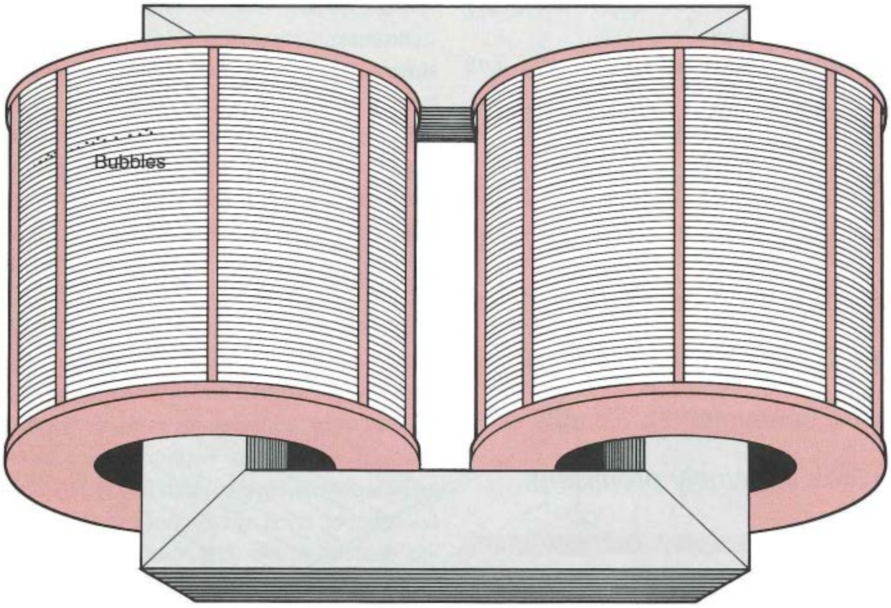
It may be that dielectric breakdown is more likely to precipitate failure than is aging. One conclusion investigators reached suggested the need for further research into the formation of vapor bubbles, and new projects were initiated in late 1983 with Westinghouse (RP1289-3) and General Electric (RP1289-4) to address this problem.

General Electric has recently developed a concept for a simple computer model that estimates the temperature at which vapor bubbles form in oil-paper transformer insulation systems when overloaded rapidly. This concept was described in an IEEE paper presented at the 1984 Summer Meeting of the Power Engineering Society.

Hot spot temperature is assumed to be between 125 and 170°C. In this range, bubble formation can result when the water vapor is released at such a rate that it exceeds its saturation level in oil. This can be a result of the desorption of water vapor from cellulose during rapid overload, the degradation of paper, and combinations of these events. Data generated in the current research will become input to the model for revising pre-

Figure 1 Amorphous metal direct casting is seen as the process of the future. Producing thin material in a single step makes it much more energy-efficient than the present cold rolling process used with silicon steel.

Figure 2 Special windows in the transformer tank wall permitted researchers to sight bubbles—the probable location of the hottest conductor in an overloaded transformer.



dictions about possible scenarios for bubble formation. A personal computer program for modeling of bubble formation is in prerelease testing.

Lower coil losses

The objective of this project, in which both Westinghouse and Phelps Dodge are contractors, is to develop advanced power transformer windings that will substantially reduce losses, size, weight, and cost (RP2618). The work performed so far has demonstrated the application of a new winding cable that has superior dielectric and loss performance in both core-form and shell-form model transformers. The parametric studies carried out as a part of the project confirmed that the advanced winding concept can substantially reduce total transformer cost. Work on developing the detailed winding technology is in progress.

Condenser Performance

Targeted Chlorination Controls Condenser Biofouling

by Winston Chow, Coal Combustion Systems Division

Biofouling is a major cause of reduced heat transfer in condensers, leading to diminished plant performance and availability. For example, an increase of 0.2 in of mercury at 60°F (677 Pa) in condenser back pressure caused by fouling in a 250-MW coal-fired plant can cost a utility about $250,000 annually in excess fuel and replacement power costs. In roughly 70% of the cases reported, such fouling resulted from microbiologic slime growth and accumulation (CS-2469).

Although bulk chlorination (the conventional method of biofouling control) is considered the most effective, its usefulness has been significantly compromised by stringent discharge regulations. Under current EPA guidelines, the allowable discharge concentration of chlorine residuals is 0.2 mg/L total residual chlorine (TRC), and the discharge is restricted to two hours a day per plant unit for once-through cooling-water systems. These imposed constraints on the use of chlorine have forced utilities to find new ways of maintaining clean condensers, including developing new technologies for more effective chlorine use, substituting other chemicals, applying mechanical or physical controls, and employing surface barriers, such as synthetic coatings.

EPRI has been exploring alternative biofouling control techniques. Targeted chlorination is one of the most promising (RP2300-2). This technique involves applying a relatively high-dose chlorine solution (0.5–2 ppm) to small segments of the condenser inlet tubesheet for short periods (5–15 minutes). The process is repeated sequentially to each segment until the entire tubesheet has been chlorinated. The benefits of this technology are fourfold.

- Chlorine use is more effective.
- Total chlorine consumption is reduced.
- Condenser thermal performance is improved.
- Current regulatory requirements for chlorine effluents can be met.

To implement targeted chlorination, researchers developed four mechanical designs. They evaluated hydraulic feasibilities for each design, using a 1 to 9.6-scale laboratory condenser model (CS-4279).

Fixed-nozzle design

Of the four designs, EPRI found fixed nozzles to be the most practical for further development (Figure 1). The attributes of the fixed-nozzle design include the following.

- Industry acceptance of the technology is favorable.
- It is flexible enough for adaptation and retrofit in existing condenser configurations.

ABSTRACT *Microbiologic fouling accounts for approximately 70% of all biofouling problems experienced by electric utilities. It is a key contributor to poor condenser performance. In spite of its economy, availability, and effectiveness, chlorine's attractiveness as a biocide has been compromised by discharge regulations. A new technique, known as targeted chlorination, allows utilities to control microbiologic accumulation, limit the discharge of chlorine to receiving waters, and reduce overall chlorine consumption. Results after three consecutive months of testing look extremely promising.*

- Its simplicity and operating flexibility minimize maintenance.
- Its installation and retrofit costs are modest, and it is highly reliable.

Getting chlorine into sections of the tubesheet and distributing it evenly to the targeted tubes require a proper nozzle-delivery system. Researchers developed a mathematical model to predict the distribution of chlorine concentration on the tubesheet as a function of the nozzle and jet stream characteristics. The model used results from laboratory hydraulic studies on fixed nozzles. Investigators also developed a procedure to optimize the nozzle system for condenser application. Then they developed a microcomputer software program that incorporates the mathematical model and allows utility engineers to design and adapt a fixed-nozzle chlorine distribution system easily.

The hydraulic tests showed that the inlet cooling-water flow in the waterbox deflects the jet stream from the nozzle. The jet stream spreads radially on the tubesheet and is gradually drawn through the condenser tubes. Therefore, two subregions bound the mathematical model solutions: an initial momentum-dominated near field and a cross-flow-dominated far field. Results showed that the predicted concentration from this mathematical algorithm compared well with the measured concentrations from tests in the laboratory condenser. The optimization program for the fixed-nozzle system uses the following design parameters.

- Number of nozzles
- Nozzle diameter
- Nozzle discharge velocity
- Nozzle distance from the tubesheet
- Chlorine injection concentration

The mathematical chemical jet stream injection model was applied at New England Power's 250-MW Brayton Point Unit 2 condenser to determine the chlorine distribution on the tubesheet and the locations of the nozzles on the condenser waterbox cover in preparation for the EPRI demonstration. Twelve nozzles were installed at the plant on the basis of the injection model's results. Following the decision to demonstrate the fixed-nozzle design at Brayton Point, EPRI commissioned two predemonstration studies in 1986. One involved determining chlorination schedules for seawater conditions. The other evaluated potential corrosion effects of high chlorine dosages on AL-6X condenser tube material of the type at the Brayton Point plant.

Targeted chlorination schedules

To optimize the targeted chlorination schedules (dosages, duration, and frequency), a heat-exchanger test facility was constructed at the University of Miami. The test facility, which consists of two identical shell and tube heat exchangers, was the site of duplicate test runs on chlorination schedules with dosages ranging from 0.5 to 20 ppm, treatment durations of 3 to 60 minutes, and frequencies of once and twice a day. A total of 12 chlorination schedules were investigated. The seawater supply system draws water from adjacent Biscayne Bay. Each shell, 8 in (20.3 cm) in diameter and 10 ft (3 m) long, contains seven AL-6X super–stainless steel tubes. Further, each tube is an independent system with respect to tube flow control; each has temperature-measuring devices at the inlet, center point, and outlet.

The effectiveness of alternative targeted chlorination schedules was determined by calculating heat transfer resistance coefficients, pressure drop, and biomass accumulation in the tubes. Test results showed that fouling was sensitive to frequency. Two applications each day were found to be more beneficial than one (i.e., 0.5 ppm for 15 minutes twice a day was more effective than 0.5 ppm for 30 minutes once a day, and 2 ppm for 7.5 minutes twice a day was more effective than 2 ppm for 15 minutes once a day). In addition, dosages of 1–2 ppm were as effective as dosages of 5–20 ppm. However, dosages of 0.5 ppm and lower required more exposure time to chlorine to control biofouling.

The fixed-nozzle design results from Brayton Point and the Miami test data indicate that full-scale applications would require a 1–2-ppm dose for 10 minutes two or more times a day, with from four to six fractional sections of the tubesheet treated sequentially. This number of fractional areas combined with the application duration are a direct consequence of the effluent limit of 0.2 ppm TRC and the duration limit of two hours a day. In some cases, even 0.5 ppm of chlorine, applied for 15 minutes two or more times a day and aimed at two or four condenser sections, may be sufficient.

Dilution of the chlorine at the unchlorinated sections and reaction with outlet water should render the TRC at the plant effluent barely detectable. Demonstration of the adequacy of low dosages (i.e., 0.5–1 ppm) applied two or three times a day for maintaining condenser cleanliness is significant. It confirms the technical merit of the fixed-nozzle design to achieve effective biofouling control while reducing the chlorine consumption and complying with plant discharge requirements.

The 12 nozzles on the Brayton Point Unit 2 condenser allow flexibility in varying the chlorine dosage, coverage of tubesheet sections, duration, and frequency. For example, the peripheral tubes can be treated more frequently than tubes in the air-cooling zone. Also, depending on the number of treatment cycles desired, treatment strategies for 12, 6, or even 4 sections of the tubesheet can be devised.

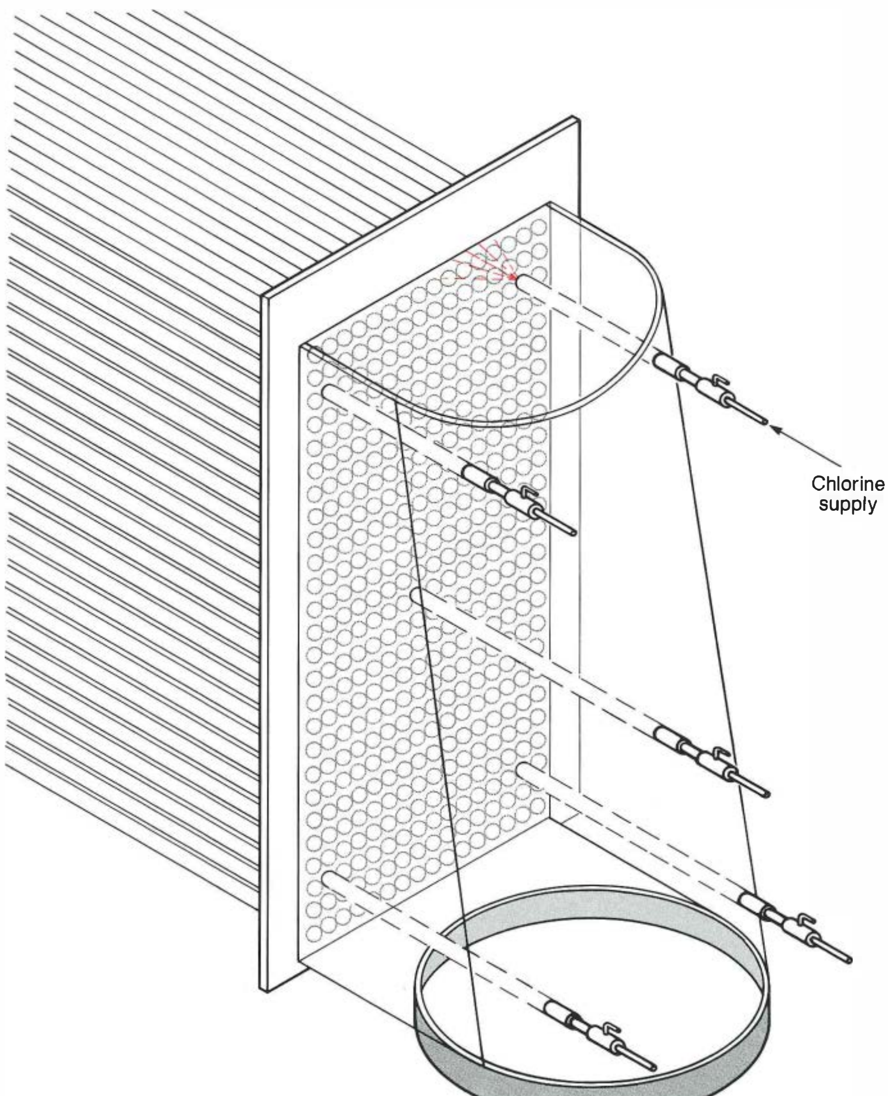


Figure 1 The fixed-nozzle targeted chlorination system design involves an array of nozzle penetrations through the condenser waterbox. Each nozzle is aimed toward a specific section of the condenser tubesheet. The pattern of the nozzles permits the tubesheet sections to receive partially overlapping treatment from adjacent nozzles, thereby ensuring complete coverage of the entire tubesheet during each condenser chlorination cycle.

Chlorination schedule predictive model

To help translate data collected from the Miami study to Brayton Point and to other seawater sites, researchers used an empirical model being developed by EPRI at the University of Miami (RP2300-9). This model, known as FOULCOMP, uses disinfection kinetics derived from the on-site cooling water, coupled with some background plant biofouling data, for its calibration. Once calibrated, the model can provide a first-order prediction on the degree of biofouling expected for any chlorination scenario (e.g., chlorine concentration, time of contact, and number of treatments per day). The data from the Miami study were used to adapt the model to seawater applications.

Once FOULCOMP was calibrated for the cooling-water conditions at the station, it was then used to approximate the minimum chlorine concentration, contact times, and treatment frequency required in the targeted chlorination scheme there. To accomplish this, actual disinfection kinetics derived from Brayton Point's cooling water were compared with the data from the Miami test facility, and fouling results were extrapolated. For initial testing, the specified chlorination schedule was to inject 10 ppm from each nozzle (resulting in 1 ppm exposure at the tubes) for 5 minutes twice a day sequentially through all 12 nozzles.

Corrosion evaluations

Material integrity was also a critical issue. The question of whether high chlorine dosages (up to 20 ppm), even over short periods, may result in accelerated tube or tubesheet corrosion needed an answer. To evaluate the corrosion potential of AL-6X tubes and to provide an early indication of the corrosion consequences of implementing targeted chlorination, a corrosion test facility was installed at the Brayton Point station. The facility consisted of parallel arrays of six AL-6X stainless steel tubes, each ⅞ in

(2.2 cm) in diameter by 20 ft (6.1 m) long. Manifolding the test units permitted simultaneous testing of two replicate tubes under two chlorination dosages (5 and 20 ppm), as well as under no treatment (unchlorinated) as the baseline. Water was obtained from the plant's screen-wash system. The nominal tube flow velocity was maintained at 7 ft/s (2 m/s), typifying conditions in the Brayton Point Unit 2 condenser. The corrosion test facility also included the necessary equipment for injecting and accurately controlling the chlorine in the tubes.

Researchers investigated the consequences of targeted chlorination on galvanic corrosion between AL-6X tubes and Muntz metal tubesheets by simulating a tubesheet-tube galvanic cell at one end of each tube. To facilitate acquisition of in situ electrochemical data in the different tube branches, specially designed segmented tube cells were installed toward the end of each tube length.

The electrochemical data collected included polarization scans, electrochemical potentials, and galvanic currents. To determine the corrosion rates of the Muntz collars, researchers measured weight loss after the test period. At the conclusion of the test, they visually and microscopically inspected the tubes.

Tests to determine the short- and long-term effects were carried out between August 1986 and September 1987, using chlorination schedules of 5 and 20 ppm for 15 minutes, three times a day. Over the test period, the AL-6X corrosion rates reached a reasonable steady state with values typically lower than 0.0001 mm/yr. These values are consistent with expected behavior for the AL-6X alloys. Measured average galvanic corrosion rates of the Muntz metal tubesheet material indicate that targeted chlorination reduced galvanic corrosion of the Muntz metal. In fact, targeted chlorination exhibited a beneficial effect here, reducing corrosion from 3.14 mm/yr on the unchlorinated tubes to 0.66 mm/yr on the tubes treated with 20 ppm chlorine. A physical inspection found no measurable pits and no evidence of crevice corrosion at the inlet or in the area of the simulated tubesheet-tube joint.

Brayton Point test results

At Brayton Point, each of two parallel single-pass condensers has a surface area of 115,000 ft^2 (10,684 m^2) and contains 16,892 tubes. These tubes are 30 ft (9 m) long, AL-6X super–stainless steel, with an outer diameter of ⅞ in (2.2 cm) and a Birmingham wire gage of 220. The design flow velocity is 7 ft/s (2 m/s). The cooling water is brackish, with the temperature varying between 35 and 83°F (1.67 and 28.3°C).

One condenser contains twelve 4-in-diameter (10.2-cm) nozzles that deliver the chlorine solution sequentially to the targeted tubes (Figure 2). A dilution pump draws water from the waterbox for reinjection. Concentrated sodium hypochlorite is pumped from a storage tank outside the plant and injected into the nozzles by metering pumps. To guide the sequential injections, a programmable controller governs the operation of the air-operated valves and pumps. The other plant condenser will continue to employ conventional bulk chlorination of 1-ppm chlorine for two hours once a day at the plant intake structure and to maintain a discharge residual of 0.15–0.2-ppm TRC.

Data acquisition is semiautomatic, with an operator recording the data from digital instruments. The accuracies of the devices measuring temperature, flow, and pressure are ±0.1°F (±0.06°C), ±2%, and ±0.1%, respectively. After each test series, biomass scrapings are being taken from the condenser tubes to establish biologic accumulation. Investigators are analyzing the water to determine turbidity, pH, salinity, ammonia, total organic carbon, chlorine demand expressed as both TRC and free available chlorine (FAC), total suspended solids, total bacterial count, and trihalomethanes. Comparing the heat-transfer coefficients, cleanliness factors, and chemical data versus time for both conventional and targeted treatment will determine their different effects on plant heat rate.

Thermal performance testing began in June 1987. A data base was obtained from

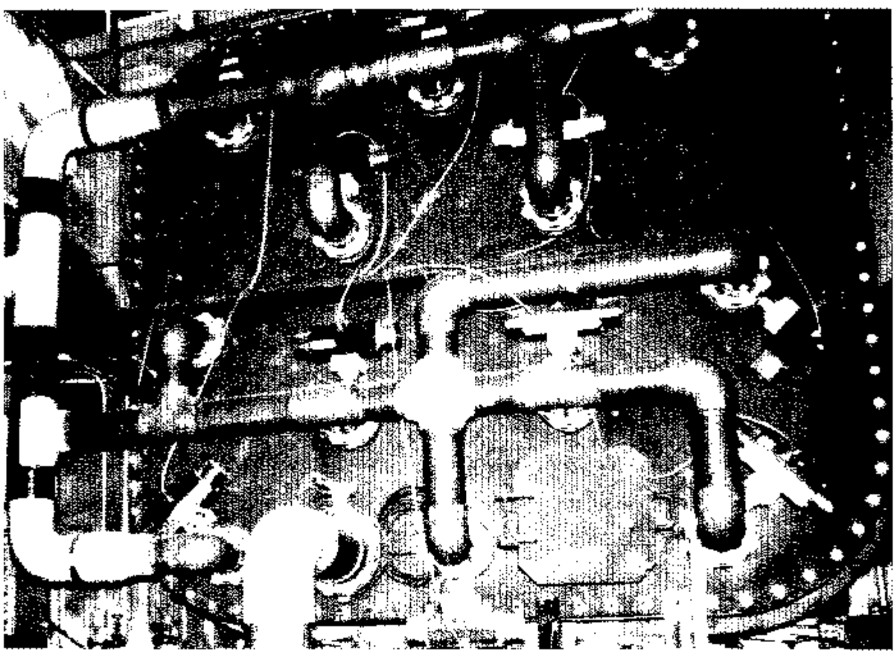
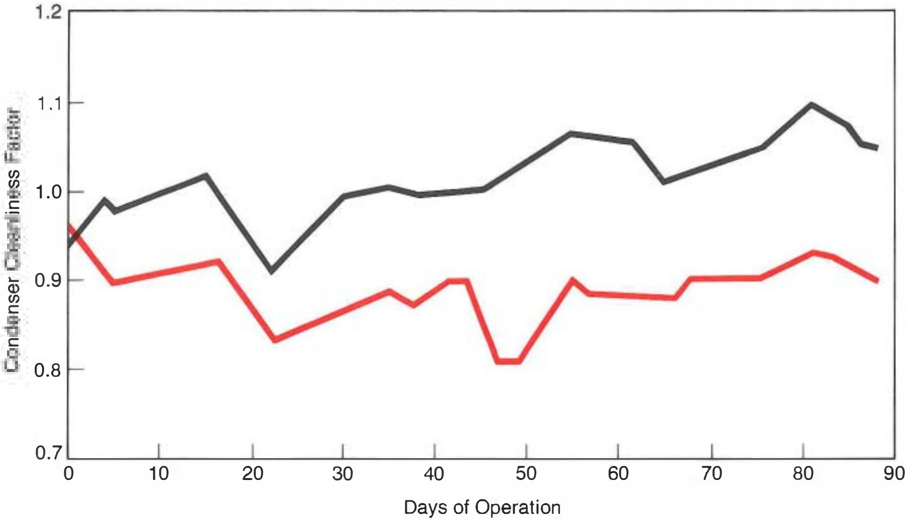


Figure 2 The targeted chlorination system as installed at the 250-MW(e) coal-fired Brayton Point Unit 2 condenser waterbox. During the initial test period, operator attention and maintenance of the mechanical equipment, electrical components, and related monitoring instruments have been minimal.

Figure 3 Since commencing the demonstration, the condenser shell employing targeted chlorination (black) has consistently out-performed the other one operating in parallel and treated by conventional chlorination (color). In fact, targeted chlorination has improved condenser performance to a level exceeding the design conditions specified by the condenser manufacturer.



both shells of the condenser for about one month without chlorination to define differences between the shells and to debug the instrumentation system. During the initial three months of targeted treatment, the tubes remained clean, while the condenser with conventional treatment began to foul. The resulting difference in cleanliness factors was 15% (Figure 3).

In that same time, TRC at the condenser discharge was reduced to levels ranging from 0 to 0.05 ppm, well below the 0.2 ppm regulated threshold level with the conventional treatment. Accordingly, sodium hypochlorite consumption was also reduced by 80% from 150 lb/d (68 kg/d) for the conventional to 30 lb/d (14 kg/d) with the targeted treatment. The back-pressure improvements associated with the targeted treatment are estimated at 0.15 in of mercury (508 Pa), which corresponds to about $50,000 in savings for fuel and power costs. Not counting the chemical cost saving from reduced sodium hypochlorite use, this three-month fuel saving alone nearly covered the capital cost of the installed targeted chlorination system at Brayton Point.

The EPRI demonstration will continue through the fall of 1988. In the remaining time, researchers will evaluate the feasibility of other chlorination scenarios and the use of fewer nozzles. These additional tests will improve the current design bases and increase the likelihood of targeted chlorination's commercialization. Further information about the technology's commercial application is available in CS-5180.

Nuclear Component Reliability

NDE Benefits From Artificial Intelligence

by Michael Avioli, Nuclear Power Division

Artificial intelligence is often equated with expert systems (software that embodies the collective wisdom of a group of experts in a particular field). But artificial intelligence also encompasses pattern recognition (including scene analysis) and robotics. Techniques from these areas are now being used in applications related to nondestructive evaluation (NDE) of nuclear power plant components.

Pattern recognition is a sophisticated statistical data analysis technique that uses data bases to develop rules for classifying data into predefined categories. For instance, a collection of ultrasonic signals from pipe weld areas can be used to generate rules for discriminating between cracks and weld geometries. Scene analysis concerns the detection and identification of objects within an image or picture. (An example would be the use of a computer to detect a broken bone in an X ray.) Methods from these disciplines, together with robotics, are being used in concert to build systems that improve the reliability and credibility of NDE inspections.

Virtually all NDE involves a technician, an instrument, a procedure, and an analyst. The technician, equipped with all necessary inspection hardware, goes to the inspection site. If radiography is to be used, he will have the X-ray source with him, and he will follow established code procedures in making radiographs of the area of concern. The analyst then examines the radiographs and presents a disposition of the inspected area as determined by his analysis. Although this procedure is straightforward, it is far from simple when the inspection site is within a nuclear plant.

The nuclear plant site presents a number of complicating factors—for example, radiation, high temperatures, and noise. Less obvious but nonetheless important factors include the qualifications of the technician,

ABSTRACT *Advanced nondestructive evaluation systems that apply artificial intelligence principles are providing reliable results and increasing user confidence in NDE testing of nuclear power plant components. The new systems bring the techniques of pattern recognition, scene analysis, and robotics to bear on NDE problems associated with making component inspections under the severe environmental conditions that prevail in many plant areas. By relying on remote scanners and other computer-directed devices, NDE inspections can be performed more thoroughly and accurately than heretofore possible; personnel exposures to radiation, high temperatures, and other stress-inducing factors are reduced sharply.*

his psychologic disposition, the reliability of the procedure he uses and whether he uses it correctly, and the physical restraints to test-site accessibility. As a result, NDE procedures undertaken in a nuclear plant can be extremely stress- and fatigue-inducing, and stress and fatigue can quickly degrade job performance, reliability, and thoroughness. Reducing job-related stress, improving job performance, and ensuring strict adherence to proven procedures can improve the reliability of inspection results and thereby enhance user confidence in the inspection procedures.

To help relieve stress on inspection personnel, more and more of the data acquisition phases of NDE work are being turned over to remote scanners, tractors, pipe crawlers, and submersibles (submarines). The scanners are remotely controlled and can be programmed (through computer interfacing) to execute specific scanning patterns. Little time is required to set them up, and because they can be operated remotely, radiation exposure for test personnel is greatly reduced. Moreover, if the inspectors are removed from the immediate and stressful test environment, there is no pressure to hurry the inspection, as there may be during manual scans of components in, for example, areas of high radiation.

The incremental movements of remote scanners provide greater inspection coverage, and the digitization of signals by analog-to-digital converters provides for mass storage of an array of signals that can be used for off-line analysis, image generation, or both.

In its NDE program, EPRI is concentrating on combinations of techniques from pattern recognition, scene analysis, and signal processing. Both the EPRI base program and the BWR Owners Group are supporting work in these areas. Systems configured according to the postulates of these techniques are called advanced systems. They usually involve a mechanized scanner, a computer, and such storage devices as magnetic tape cartridges and floppy disks (Figure 1).

EPRI's initial developments began in 1978 with the ALN 4000 series adaptive learning network firmware (programmable hardware; NP-688). The ALN 4060 is a pattern recognition system that can be trained to discriminate between cracks and other types of reflectors. The training is accomplished by inputting an ensemble of ultrasonic signals from both cracked and uncracked samples. (Ultrasonic testing is used in the nuclear power industry primarily to detect, locate, and size cracks in piping and pressure vessels.) The ALN 4060 identifies the characteristics of the signals that are effective for differentiating reflectors.

These signal characteristics are then incorporated into an algorithm, or rule, that can be used to identify the presence of a crack. As more experience was gained with the ALN 4060, certain groups of characteristics or features were consistently selected for the discrimination task.

The ALN 4060 was based on statistical principles, not on physics, although at times, coincidentally, the statistical selection of characteristics would agree with the physics of the problem. During the period July through November 1982, the EPRI-sponsored ALN-Physics Review Committee examined feature selection by means of the physics involved in the scattering of ultrasonic waves from cracks. The results of that review identified physically based characteristics that could be used effectively for ultrasonic inspections (NP-3216). This technology, ahead of its time in 1978, lay dormant during the early 1980s.

Ultrasonic imaging, however, was progressing. Several systems were developed at that time to address the pressurized thermal shock (PTS) issue in pressure vessels and cracking in boiling water reactor (BWR) pipes. Two systems of note are Intraspect (T301-1) and UDRPS (RP2165-3).

Intraspect is an imaging system that color-codes an ensemble of ultrasonic signals and creates an image that represents the spatial variation of ultrasonic energy within a pipe weld area. UDRPS performs essentially the same function as Intraspect but is more sophisticated. It can compensate for characteristics of the ultrasonic transducer that cause signal artifacts that can be misinterpreted; several views of the ultrasonic data are available, including three-dimensional isometric plots. Other capabilities of the UDRPS include signal processing, signal-to-noise ratio enhancement, and target tracking.

Intraspect has been further improved through work sponsored by the Tennessee Valley Authority. System modifications include synthetic aperture processing and various perspective views of the data.

While EPRI was exploring the areas of signal processing, pattern recognition, and imaging in the late 1970s and early 1980s, a revolution was taking place in the availability of inexpensive computing power. Before the advent of the personal computer, the key item (and the most costly and bulky one) in advanced NDE systems was the computer. In fact, progress in NDE was impeded by the size and cost of the computers then available. In addition, for NDE applications, computers had to be portable and able to withstand the harsh environment of a nuclear power plant.

With the development of personal computers, however, advanced NDE systems proliferated. The utility NDE manager faces an overwhelming selection of computerized systems with remotely controlled scanners. The manufacturers have taken full advantage of the large-scale circuitry manufacturing processes and are producing systems that are fast and cost-effective. In addition, they possess an abundance of memory and computing power. EPRI contracted with Vintek, Inc., to survey utility and service/vendor users of advanced systems and to compile a guide to advanced systems that enables a utility NDE manager to select the proper system for his particular needs (NP-5086)

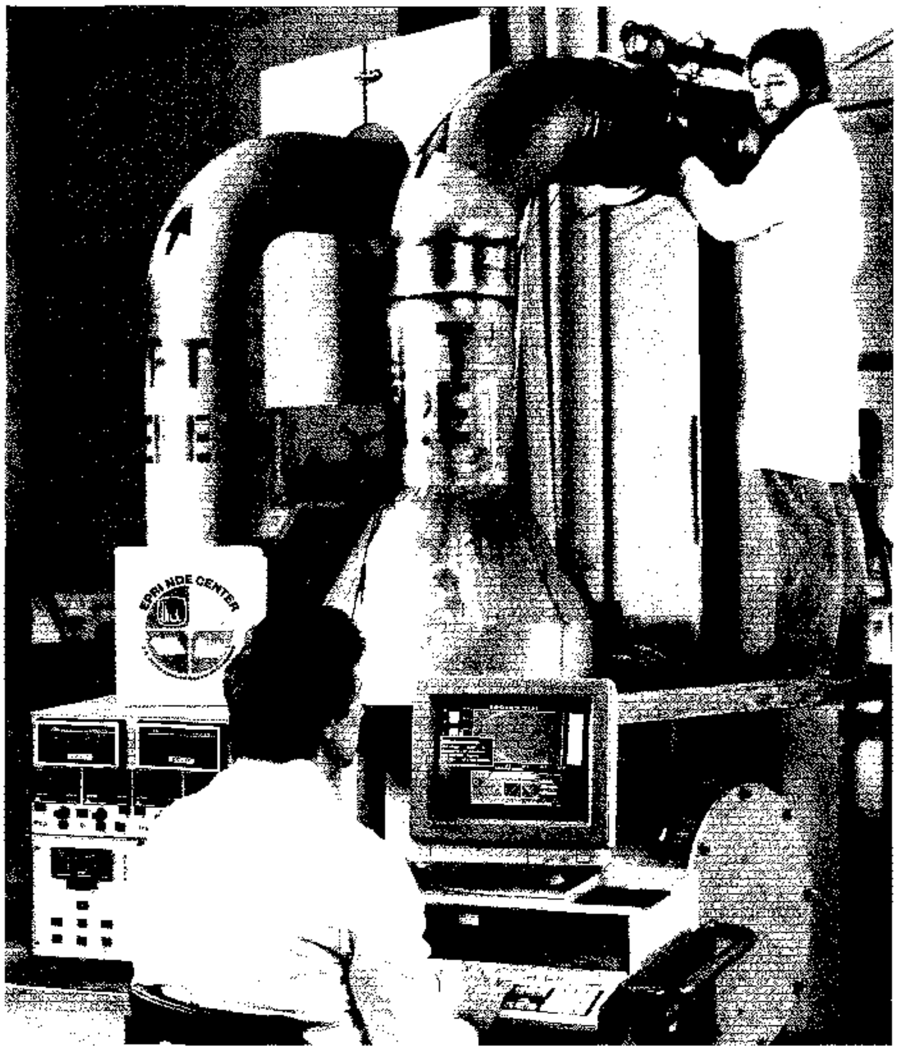


Figure 1 A feature-enhanced imaging system is evaluated at EPRI's NDE Center. An ultrasonic transducer mounted on the scanner provides data for the host computer's pattern recognition software (right). The scanner controller (left) determines the scanner's position.

The trend in advanced systems is rather one-sided in favor of imaging systems; pattern recognition, or so-called feature-based systems, are less in demand. Looking ahead, we anticipate feature-enhanced imaging systems, the synergistic result of combining feature-based systems with imaging or scene analysis systems. Several contracts have been initiated to interface Testpro pattern recognition software (Infometrics/Structural Integrity Associates) with various widely used imaging systems.

T301-20 provided for the interfacing of Testpro with Intraspect and I/98 imaging systems; this software was integrated with the UltraImage III imaging system (Science Applications, Inc.; RP2405-21).

With the cooperation of General Electric (T301-24) and several utilities (Northern States Power, Carolina Power & Light, and Philadelphia Electric), feature-enhanced imaging is being refined and field-tested in preparation for its eventual transfer to the utility industry as an advanced NDE tool.

Feature-enhanced imaging takes advantage of the visually and spatially oriented information that is supplied by image and scene data and combines it with the quantitative decision-oriented information available from pattern recognition systems.

The use of this ancillary information by analysts should greatly improve NDE in general and NDE reliability in particular. Reducing nuclear plant environmental effects on inspection personnel and reducing the stress encountered during inspections make this type of system a must for the future.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Advanced Power Systems		
Dual Catalysis and Modeling of Liquid-Entrained Reactor (RP317-06)	$150,619 13 months	University of Arkansas/ *C. Kulik*
Evaluation of Small-System Performance Under High-Wind-Form Penetration (RP1590-13)	$60,508 10 months	Power Technologies, Inc./ *J. Schaefer*
STAR Center Operations (RP1607-12)	$191,810 19 months	Allegheny Power System, Inc./*J. Schaefer*
Hydrogen Sulfide Abatement for Geothermal Steam Power Plants (RP1991-04)	$116,000 19 months	Pacific Gas and Electric Co./*E. Hughes*
GATE-STRAP Software Review (RP2052-08)	$66,850 11 months	Professionals Computer Management Consultants, Inc./*A. Cohn*
Conceptual Design of a Coal-Fired MHD Retrofit (RP2466-11)	$50,000 16 months	MHD Development Corp./ *A. Cohn*
Detailed Characterization of Cavitation Damage in Hydraulic Machinery (RP2866-01)	$93,328 19 months	Daedalus Associates, Inc./*C. Sullivan*
Support for High-Concentration Photovoltaic Performance Evaluation (RP2948-03)	$70,708 14 months	Georgia Power Co./ *J. Bigger*
Testing of EPRI Point-Contact Photovoltaic Modules (RP2948-05)	$60,936 26 months	Arizona Public Service Co./*J. Bigger*
High-Concentration Photovoltaic Array Design, Construction, and Deployment (RP2948-08)	$177,607 5 months	Scientific Analysis, Inc./ *F. Dostalek*
Coal Combustion Systems		
Evaluation of Heat Pipe Air Preheater Technology for Gas-/Oil-Fired Power Plants (RP1403-37)	$55,931 7 months	Pacific Gas and Electric Co./*J. Bartz*
Coordination of Heat Rate Improvement Conference (RP1711-06)	$30,900 13 months	Sargent & Lundy Engineers/*R. Leyse*
Continuous Turbine Heat Rate Monitoring System (RP1711-07)	$205,000 23 months	Pacific Gas and Electric Co./*G. Poe*
NO_x and Particulate Emission Reduction Project at Kahe Unit 6 (RP2869-06)	$203,755 14 months	Hawaiian Electric Co./ *M. McElroy*
Engineering and Cost Estimating SO_2 and NO_x Control by Combination of Multiproduct Coal Cleaning and FBC (RP2924-01)	$210,334 1 year	Bechtel Group, Inc./ *D. O'Connor*
Electrical Systems		
Evaluation of PCDF Analytic Methodologies (RP2028-21)	$39,539 10 months	Twin Cities Testing Corp./ *G. Addis*
Cross-Bonding Hardware (RP7801-22)	$68,816 10 months	Pirelli Cable Corp./ *F. Garcia*
Demonstration of PPP Cable Systems (RP7880-04)	$500,000 49 months	Public Service Electric & Gas Co./*J. Shimshock*
Impulse Waveshape Measurements—Digital Analysis and Correction (RP7899-24)	$32,452 8 months	Mississippi State University/*F. Garcia*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Energy Management and Utilization		
Experimental Testing Radiant Barriers Under Moisture Condensing Conditions (RP2034-24)	$30,000 9 months	Martin Marietta Energy Systems, Inc./ *J. Kesselring*
Transition From Internal to External Oxidation of Alloys (RP2278-08)	$117,358 35 months	University of Manchester Science and Technology/ *J. Stringer*
Post Occupancy Evaluation: Second Level Analysis (RP2418-08)	$70,000 7 months	Lighting Research Institute/*K. Johnson*
NiAl Alloys for Elevated Temperature, Shape Memory Applications (RP2426-15)	$181,097 33 months	University of Illinois/ *J. Stringer*
Oxide Dispersions Produced by Plasma Preoxidation (RP2426-16)	$199,970 22 months	SRI International/ *J. Stringer*
Development and Demonstration: Extended-Range Electric Vehicle (RP2664-05)	$92,267 9 months	Chloride EV Systems, Ltd./ *G. Purcell*
Environment		
Diffusion Scrubber-Coupled Ion Chromatography for the Measurement of Trace Atmospheric Gases (RP1630-55)	$200,521 35 months	Texas Tech University/ *D. Hansen*
Sensitivity and Uncertainty Analysis of a Selenium Speciation Model (RP2020-08)	$59,718 10 months	Martin Marietta Energy Systems, Inc./*D. Porcella*
Technical Coordination of Desk Reference (RP2414-23)	$79,635 13 months	Evergreen Innovations, Inc./*P. Robinson*
Field Measurements for Validation of Geochemical Models (RP2485-09)	$2,002,844 23 months	Radian Corp./*I. Murarka*
Engineering Characterization of Small-Magnitude Earthquake (RP2556-48)	$159,448 14 months	Woodward-Clyde Consultants, Inc./*J. Schneider*
Nuclear Plant Life Extension Operational Evaluation Sources (RP2643-22)	$85,282 1 year	Electricité de France/ *M. Lapides*
Millstone-1 Zinc Injection Evaluation (RP2758-04)	$100,000 1 year	Northeast Utilities Service Co./*C. Wood*
Evaluation of Reactor Physics Methods (RP2803-07)	$37,961 10 months	Erin Engineering and Research, Inc./*B. Breen*
Treatment, Packaging, and Storage of Bundle Scrap Hardware (RP2813-13)	$90,000 10 months	Rochester Gas & Electric Corp./*R. Lambert*
Pathophysiology of Electrical Injuries (RP2914-02)	$274,901 33 months	Canadian Electrical Association/*W. Weyzen*
Alternative Hypothesis for Association Between Distribution Wiring Configurations and Cancer (RP2966-02)	$49,985 6 months	Environmental Research Information, Inc./ *S. Sussman*
Analysis Support of EPRI Erosion-Corrosion Program (RP3000-18)	$99,778 11 months	S. Levy, Inc./*V. Chexal*
NUMARC–MAAP Independent V&V Program (RP3000-21)	$190,193 10 months	Jaycor, Inc./*R. Ritzman*
Planning and Evaluation		
Valuing Fuel Contracting Options (RP2314-05)	$30,341 11 months	Teisberg Associates/ *S. Chapel*

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ADVANCED POWER SYSTEMS

Heber Binary-Cycle Geothermal Demonstration Power Plant: Startup and Low-Power Testing
AP-5240-SR Special Report; $40
EPRI Project Manager: V. Roberts

Production Costing: Combined-Cycle and Gasification–Combined-Cycle Plants
AP-5448 (RP2029-16, RP2699-5); $32.50
Contractor: Potomac Electric Power Co.
EPRI Project Manager: A. Lewis

Economics of Phased Gasification–Combined-Cycle Plants: Utility Results
AP-5466-SR Special Report; $32.50
EPRI Project Managers: A. Lewis, M. Gluckman

Turbine-Related Fish Mortality: Review and Evaluation of Studies
AP-5480 Final Report (RP2694-4); $32.50
Contractor: Eicher Associates, Inc.
EPRI Project Manager: C. Sullivan

Hydraulic Model Evaluation of the Eicher Passive Pressure Screen Fish Bypass System
AP-5492 Final Report (RP1745-18); $32.50
Contractor: Eicher Associates, Inc.
EPRI Project Manager: C. Sullivan

Combustion Turbine Repowering
AP-5493 Final Report (RP2565-1); $32.50
Contractor: Public Service Electric & Gas Co.
EPRI Project Manager: H. Schreiber

Process Screening Study of Alternative Gas Treating and Sulfur Removal Systems for IGCC Power Plant Applications
AP-5505 Final Report (RP2221-13); $25
Contractor: SFA Pacific, Inc.
EPRI Project Manager: N. Hertz

Stability and Compatibility of Residual Fuel Oils
AP-5506 Interim Report (RP2527-1); $47.50
Contractor: National Institute for Petroleum and Energy Research
EPRI Project Manager: W. Rovesti

Once-Through Methanol Project Support Study
AP-5508 Final Report (RP2563-3); $32.50
Contractor: Tennessee Valley Authority
EPRI Project Manager: W. Weber

Thermal-Cycling Tests for a Compressed-Air Energy Storage Recuperator
AP-5548 Final Report (RP2488-4); $32.50
Contractor: Encotech, Inc.
EPRI Project Manager: B. Mehta

DYNASTORE—A Computer Model for Quantifying Dynamic Energy Storage Benefits
AP-5550 Interim Report (RP1084-22); $32.50
Contractor: Electric Power Consulting, Inc.
EPRI Project Manager: B. Louks

COAL COMBUSTION SYSTEMS

Power Plant Performance Monitoring and Improvement, Vols. 4–6
CS/EL-4415 Interim Report (RP1681, RP2153); Vol. 4, $1000; Vol. 5, $1000
Contractor: Potomac Electric Power Co.
EPRI Project Managers: R. Leyse, N. Balu

Coal Quality Information Book
CS-5421 Interim Report (RP1400-6, -11); $500
Contractors: Kaiser Engineers, Inc.; Science Applications International Corp.
EPRI Project Managers: C. Harrison, J. Hervol

Cleaning Kentucky No. 9 Seam Coal for SO_2 Compliance and Using Fly Ash–Derived Magnetite for Coal Cleaning
CS-5422 Interim Report (RP1400-6, -11); $200
Contractors: Kaiser Engineers, Inc.; Science Applications International Corp.
EPRI Project Managers: C. Harrison, J. Hervol

Recovering Clean Coal From Anthracite Culm
CS-5423 Interim Report (RP1400-6, -11); $200
Contractors: Kaiser Engineers, Inc.; Science Applications International Corp.
EPRI Project Managers: C Harrison, J. Hervol

Improving the Quality of Lower Freeport Seam Coal to Reduce Electricity Costs
CS-5477 Interim Report (RP1400-6, -11); $200
Contractors: Kaiser Engineers, Inc.; Science Applications International Corp.
EPRI Project Managers: C. Harrison, J. Hervol

Guide for the Use of Corrosion-Resistant Coatings on Steam Turbine Blades
CS-5481 Final Report (RP1408-1); $800
Contractor: Southern California Edison Co.
EPRI Project Managers: B. Syrett, T. McCloskey

PFBC Turbocharged Boiler Design and Economic Study, Vol. 1
CS-5487 Final Report (RP2428-1, RP2428-2); $500
Contractors: BBC Brown Boveri; Combustion Engineering, Inc.; Decision Focus, Inc.; Fluor Engineers, Inc.; Foster Wheeler Development Corp.; Hoy Associates; Lurgi Corp.; Research Cottrell, Inc.
EPRI Project Manager: S. Drenker

Microbial Corrosion in Fossil-[Fuel-] Fired Power Plants
CS-5495 Final Report (RP2300-12); $200
Contractor: Rensselaer Polytechnic Institute
EPRI Project Manager: J. Bartz

AFBC Conversion at Northern States Power Co., Vol. 1: Project Origins
CS-5501 Final Report (RP2628-3); $250
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: S. Tavoulareas

UNSAT1D Groundwater Computer Code Manual: IBM PC Version
CS-5512-CCML Computer Code Manual (RP2708-1)
Contractor: ICF Northwest
EPRI Project Manager: D. Golden

Trends in State and Local Underground Storage Tank Regulations
CS-5520 Final Report (RP2795-1); $150
Contractor: Roy F. Weston, Inc.
EPRI Project Managers: M. McLearn, M. Miller

Slagging and Fouling in Pulverized-Coal-Fired Utility Boilers, Vols. 1 and 2
CS-5523 Final Report (RP1891-1); Vol. 1. $200; Vol. 2, $200
Contractor: Battelle, Columbus Division
EPRI Project Manager: A. Mehta

Operations Guide for the Use of Combustion Additives in Utility Boilers
CS-5527 Final Report (RP1839-3); $400
Contractor: EnerChem Inc.
EPRI Project Manager: A. Mehta

Specification Guidelines for Flue Gas Desulfurization Rubber
CS-5528 Final Report (RP1871-12); $500
Contractors: Radian Corp.; Texas Research Institute
EPRI Project Manager: C. Dene

ELECTRICAL SYSTEMS

Power Plant Performance Monitoring and Improvement, Vols. 4–6
CS/EL-4415 Interim Report (RP1681, RP2153); Vol. 4, $1000; Vol. 5, $1000
Contractor: Potomac Electric Power Co.
EPRI Project Managers: R. Leyse, N. Balu

TLWorkstation Code: Version 1.1, Vol. 4: GATL User's Manual
EL-4540-CCM Computer Code Manual (RP1494-7); $32.50
Contractor: Safe Engineering Services & Technologies, Ltd.
EPRI Project Manager: R. Kennon

TLWorkstation Code: Version 1.1, Vol. 16: CUFAD Manual
EL-4540-CCM Computer Code Manual (RP1493-6); $32.50
Contractor: Cornell University
EPRI Project Manager: R. Kennon

Composite-System Reliability Evaluation: Phase 1—Scoping Study
EL-5290 Final Report (RP2581-1); $32.50
Contractor: Public Service Electric and Gas Co.
EPRI Project Manager: N. Balu

Electrohydrodynamic Pumping in Distribution Transformers
EL-5383 Final Report (RP2589-1); $25
Contractor: General Electric Co.
EPRI Project Manager: J. Porter

Distribution Transformers Not Subject to Destructive Failure
EL-5442 Final Report (RP1143-3); $25
Contractor: McGraw-Edison Co.
EPRI Project Manager: J. Porter

Power Line Fault Current Coupling to Nearby Natural Gas Pipelines, Vols. 1–3
EL-5472 Final Report; EL-5472-CCM Computer Code Manual (RP742); Vol. 1, $32.50; Vol. 2, $32.50
Contractor: Safe Engineering Services & Technologies, Ltd.
EPRI Project Manager: R. Kennon

Shield Losses in Medium-Voltage Cables
EL-5478 Final Report (RP2839-1); $32.50
Contractor: David A. Silver & Associates, Inc.
EPRI Project Managers: H. Songster, J. Mitsche

Structural Development Studies at the EPRI Transmission Line Mechanical Research Center
EL-5488 Interim Report (RP2016-3); $240
Contractor: Sverdrup Technology, Inc.
EPRI Project Manager: P Lyons

ENVIRONMENT DIVISION

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

A Review of the State-Level Advanced Utility Simulation Model
EA-5499 Interim Report (RP1484-1); $40
Contractor: Massachusetts Institute of Technology
EPRI Project Manager: T. Wilson

ENERGY MANAGEMENT AND UTILIZATION

Seminar Proceedings: Commercial Cool Storage
EM-5454-SR Special Report; $32.50
EPRI Project Manager R. Wendland

Workshop Proceedings: Opportunities to Improve Indoor Environments of Commercial Buildings
EM-5530 Proceedings (RP2034-21); $25
Contractor: W. I. Whiddon & Associates, Inc.; Hart, McMurphy, & Parks, Inc.
EPRI Project Manager: M. Blatt

Water Treatment Technologies for Thermal Storage Systems
EM-5545 Final Report (RP2732-7); $25
Contractor: Ahlgren Associates
EPRI Project Manager: R. Wendland

Evaluation of Near-Term Electric Vehicle Battery Systems Through In-Vehicle Testing
EM-5553 Final Report (RP1136-27); $40
Contractor: Tennessee Valley Authority
EPRI Project Managers: G. Purcell, D Douglas, L. O'Connell

A Compendium of Utility-Sponsored Energy Efficiency Rebate Programs
EM-5579 Final Report (RP2884-9); $40
Contractors: Consumer Energy Council of America Research Foundation; American Council for an Energy-Efficient Economy
EPRI Project Managers: W. Smith, T. Oldberg

NUCLEAR POWER

RETRAN-02—A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems, Vol. 5: Modeling Guidelines
NP-1850-CCM Computer Code Manual (RP889-3); $62.50
Contractor: EI Services
EPRI Project Manager: L. Agee

PICEP: Pipe Crack Evaluation Program (Rev. 1)
NP-3596-SR Rev. 1, Special Report; $32.50
EPRI Project Managers: D. Norris, B. Chexal

ARMP-02 Documentation Part II, Ch. 13, Vols. 1–3: NORGE–P Computer Code Manual
NP-4574-CCM Part II, Ch. 13, Computer Code Manual (RP976-3, -9); Vol. 1, $25; Vol. 2, $32.50; Vol. 3, $32.50
Contractor: Science Applications International Corp.
EPRI Project Manager: O. Ozer

Evaluation of Intergranular Attack on Alloy 600, Vol. 2: Effectiveness of Boric Acid
NP-4978 Vol. 2 Final Report (RPS302-13); $40
Contractor: Westinghouse Electric Corp.
EPRI Project Managers: J. Paine, R. Pathania

Load-Following Experience in Commercial PWRs
NP-5303M Final Report (RP2630-3); $25;
NP-5303SP Final Report (RP2630-3); $10,000
Contractor: The S. M. Stoller Corp.
EPRI Project Manager: J. Santucci

Materials Failure Trends in LWRs
NP-5438 Final Report (RP1166-7); $25
Contractor: The S. M. Stoller Corp.
EPRI Project Manager: R. Jones

Identification and Classification of Technical Specification Problems
NP-5475 Final Report (RP2142-2); $25
Contractor: IT-Delian Corp.
EPRI Project Manager: J. Gaertner

In Situ Heat Treatment of U-Bends
NP-5496 Final Report (RPS303-11); $32.50
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: A. McIlree

Advanced Radioactive Waste Assay Methods
NP-5497 Final Report (RP2412-2); $40
Contractor: Science Applications International Corp.
EPRI Project Manager: C. Welty

Proceedings: 1983 Workshop on Primary-Side Stress Corrosion Cracking of PWR Steam Generator Tubing
NP-5498 Proceedings (RPS303-5); $55
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: A. McIlree

Requirement and Design Specifications of a BWR Digital Feedwater Control System
NP-5502 Final Report (RP2448-3); $40
Contractor: Science Applications International Corp.
EPRI Project Managers: M. Divakaruni; B. Sun

Simulator Qualification Plan, Vols. 1 and 2
NP-5504 Vols. 1 and 2 Final Report (RP2054-2); Vol. 1, $25,000; Vol. 2, $25,000
Contractor: General Physics Corp.
EPRI Project Manager: R. Colley

SIMTRAN–E: A SIMULATE-E to RETRAN-02 Datalink
NP-5509-CCM Computer Code Manual (RP1761-14, -17); $40
Contractor: EI International, Inc.
EPRI Project Manager: L. Agee

Proceedings: 1986 Seminar on Emergency Response Facilities and Implementation of Safety Parameter Display Systems
NP-5510-SR Proceedings; $70
EPRI Project Managers: M. Divakaruni; B. Sun

Fracture Toughness Characterization of Type 410 Stainless Steel
NP-5511 Final Report (RP2455-15); $25
Contractor: Materials Engineering Associates, Inc.
EPRI Project Manager: T. Griesbach

Large-Scale Soil-Structure Interaction
NP-5513-SR Special Report; $32.50
EPRI Project Manager: H. Tang

Failed-Fuel Action Plan Guidelines
NP-5521-SR Special Report; $25
EPRI Project Manager: J. Santucci

LOMI Decontamination Reagents and Related Preoxidation Processes
NP-5522M Final Report (RP1329-1); $25
NP-5522SP Final Report (RP1329-1); $10,000
Contractor: Central Electricity Generating Board
EPRI Project Manager: C. Wood

Testing and Installation of a BWR Digital Feedwater Control System
NP-5524 Final Report (RP2448-5); $40.00
Contractor: Atomic Energy of Canada, Ltd.
EPRI Project Manager: B. Sun

Robotic Task Planning
NP-5525 Final Report (RP2515-1); $32.50
Contractor: Carnegie-Mellon University
EPRI Project Manager: F. Gelhaus

An Analytic Model for Pump Performance in Condensable Two-Phase Flows
NP-5529M Final Report (RP2290-1); $25;
NP-5529SP Final Report (RP2290-1); $15,000
Contractor: Tetra Tech, Inc.
EPRI Project Manager: J. Kim

Risk-Significant Functional Dependencies in PWRs
NP-5536 Final Report (RP2169-4); $32.50
Contractor: Pickard, Lowe and Garrick, Inc.
EPRI Project Manager: D. Worledge

Nuclear Unit Operating Experience: 1985–1986 Update
NP-5544 Final Report (RP2490-3); $47.50
Contractor: The S. M. Stoller Corp.
EPRI Project Manager: N. Hirota

Benchmark of Systematic Human Action Reliability Procedure (SHARP)
NP-5546 Final Report (RP2682-1); $32.50
Contractor: NUS Corp.
EPRI Project Manager: D. Worledge

Plant Expert System (PLEXSYS): Prototype Description Version 1.0
NP-5554 Interim Report (RP2582-3); $32.50
Contractor: Intellicorp
EPRI Project Manager: D. Cain

Boric Acid Application Guidelines for Intergranular Corrosion Inhibition
NP-5558 Topical Report (RPS302-13); $32.50
Contractor: Westinghouse Electric Corp.
EPRI Project Managers: J. Paine, R. Pathania

Analysis of Anticipated Transients Without Scram in Severe BWR Accidents
NP-5562 Final Report (RP2761-1); $25
Contractor: General Electric Co.
EPRI Project Manager: B. Sehgal

Chromate Substitutes for Corrosion Inhibitors in Cooling Systems
NP-5569 Final Report (RP825-9); $25
Contractor: Gebco Engineering
EPRI Project Manager: T. Passell

Thermal Analysis of Core Barrel Heating and Coolant Recirculation During Core Uncovery in PWR Accidents
NP-5586 Final Report (RP1760-3); $32.50
Contractor: Purdue University
EPRI Project Manager: J. Kim

PLANNING AND EVALUATION

Coal Markets and Utilities' Compliance Decisions
P-5444 Final Report (RP2369-53); $47.50
Contractor: Energy Ventures Analysis, Inc.
EPRI Project Manager: J. Platt

CALENDAR

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

MAY

23–26
International Conference: Validation of Flow and Transport Models for the Unsaturated Zone
Ruidoso, New Mexico
Contact: Ishwar Murarka (415) 855-2150

JUNE

6–10
Symposium: Feedwater Heater Technology
Winston-Salem, North Carolina
Contact: John Tsou (415) 855-2220

13–15
Life Extension and Assessment of Fossil Fuel Plants
The Hague, Holland
Contact: Barry Dooley (415) 855-2658

14–16
Acoustic Leak Detection Instruction
Philadelphia, Pennsylvania
Contact: Richard Colsher (415) 855-2843

AUGUST

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

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

SEPTEMBER

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

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

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

OCTOBER

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

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

17–20
8th Annual Coal Gasification Conference
Palo Alto, California
Contact: Neville Holt (415) 855-2503

18–19
Workshop: Upgrading Low-Rank Coals
Denver, Colorado
Contact: Clark Harrison (412) 479-3505

25–28
Symposium: FGD and Dry SO_2 Control
Saint Louis, Missouri
Contact: Paul Radcliffe (415) 855-2720

NOVEMBER

15–16
9th Annual EPRI NDE Information Meeting
Charlotte, North Carolina
Contact: Soung-Nan Liu (415) 855-2480

29–December 1
2d EPRI Conference: Fossil Fuel Plant Inspection
San Antonio, Texas
Contact: Stephen Gehl (415) 855-2770

Authors and Articles


Dolbec


Spencer


Jeffress


Bilanin

Utility Turbopower for the 1990s (page 4) was written by Taylor Moore, senior *Journal* feature writer, aided by two research managers of EPRI's Advanced Power Systems Division.

Al Dolbec has headed the division's research in power generation machinery since 1978, a year after he came to EPRI as a project manager for combustion turbine control systems. He formerly was with General Electric for nearly 26 years, becoming manager of engineering for gas turbine and combined-cycle plant controls. Dolbec graduated in electrical engineering from Manhattan College.

Dwain Spencer, an EPRI vice president, has been director of the Advanced Power Systems Division since 1979. He came to EPRI in 1974 as a project manager for solar and geothermal energy R&D. Spencer was formerly with Caltech's Jet Propulsion Laboratory for 16 years, including 2 years on loan to the National Science Foundation. He is a chemical engineering graduate of Notre Dame, with a master's in engineering from Purdue. ■

The Rise of Electric Steelmaking (page 14) was written by John Douglas, science writer, with technical input from **Robert Jeffress** of EPRI's Energy Management and Utilization Division. Jeffress is a project manager for research in metals production and fabrication; he came to EPRI in November 1986 after 13 years with the American Iron and Steel Institute, including 5 years as its director of technology. Jeffress earlier worked for 10 years in metallurgy and quality control at Armco Steel Corp. He has a BS in metallurgical engineering from Purdue. ■

Walter Baer: Technology and the Business of Information (page 22) draws on the career and views of a 20-year expert in telecommunications technology whose most recent 7 years, with Times Mirror Co., reveal important parallels between the information business and the electricity business. A member of EPRI's Advisory Council, Baer was interviewed by Ralph Whitaker, *Journal* feature editor. ■

Off the Shelf Parts for Nuclear Plants (page 28) was written by Jon Cohen, science writer, with the cooperation of **Warren Bilanin,** a program manager in EPRI's Nuclear Power Division. Associated with the Quality Engineering and Construction Program for the past two years, Bilanin is also program manager for the Nuclear Construction Issues Group, a plant owners group to develop guidelines for common construction and repair problems. He has worked with several special-purpose programs since he came to EPRI as a project manager in 1979, following eight years with General Electric. Bilanin has BS and MS degrees in mechanical engineering from the Northrop Institute of Technology. ■

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