Fluidizing Combustion

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Cover: Fluidized-bed combustion, captured in this photograph from U.K.'s Combustion Systems Ltd., tempts the electric utility industry with unique emissions control, improved boiler reliability, and fuel flexibility.

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FBC: New Technique for a New Era

Thomas Edison is remembered this year, the Centennial of Light, for inventing a practical light bulb and a system for powering it. He is less well remembered for his pioneering efforts in using pulverized coal for the manufacture of portland cement. Adopted in 1919 at a plant still operated by Wisconsin Electric Power Co., this method of firing coal gained acceptance and in just a few short years became *the* technology for burning coal in power plants.

This revolution in coal-burning technology 60 years ago was set in motion by a number of conditions that bear some resemblance to today. The then-existing coal-burning techniques, primarily the stoker furnace, had been developed for a different era's requirements. By the end of World War I the utilities needed vastly larger units, and extrapolating from the old designs was exceedingly difficult. Petroleum availability was declining and prices were escalating rapidly. Fuel conservation became more significant and utilities began to look at coal fines, which were then considered a waste product. And convincing arguments were made that pulverized-coal firing was an environmental boon because it could reduce smoke and ground level concentrations of particulate matter.

As we move into a new era with greatly expanded needs for coal-fired power generation, EPRI and its members are developing several important alternatives to pulverized-coal firing, including the fluidized-bed combustion boiler. The incentives for development are not unlike those of 60 years ago: The fluidized-bed boiler has found its initial application in burning the waste fuels of today—wood wastes and the tailings of coal washeries—and should find its most rapid deployment in the hard-to-grind and hard-to-burn fuels like lignites and subbituminous coals. Interest in coal use for industry is burgeoning as petroleum availability declines and its price climbs. The wide use of fluidized-bed combustion boilers of relatively small size by the nonutility sector (e.g., paper mills, chemical plants) is expected soon and will assist in the deployment of large, utility-scale units.

But the primary reason that may lead to the displacement of pulverized-coal boilers is that this process was invented at a time when all that was expected of a furnace was to burn out the carbon. Today, new requirements have been laid on coal boilers—the control of nitrogen and sulfur oxides and fly ash. Control of "NO_x and SO_x and rocks" by postcombustion devices adds substantially to the cost of current power plants and has adversely impacted plant reliability. Our experiments with fluidized-bed combustion confirm that it is possible to control NO_x and SO_x without a postfurnace cleanup device and that control of particulates should not be especially difficult.

Thus FBC represents a promising response to the new requirements of a new era. The results of recent design modifications are sufficiently encouraging that commercial systems are a distinct possibility within a decade. Yet the path is not completely clear. In today's highly politicized energy situation it is difficult to know if good engineering, sound economics, and reduced pollution are enough.

Shelton Ehrlich, Manager
Fluidized Combustion Program
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Authors and Articles

Options are plentiful on the energy scene—options in fuels, in the technologies and cycles for their conversion to electricity, in the materials and means for power delivery. But there is a countering array of constraints—costs, sites, materials, water resources, air quality standards, cycle efficiencies, equipment reliabilities, and even the load shapes that may favor one option over another.

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One key constraint on any energy option is the presence of another option for the same service. Thus two options for raw coal may well prove to be direct competitors. One is the familiar pulverized-coal combustion, the other is fluidized-bed combustion. By many indicators in its R&D, the latter will yield advances in efficiency, versatility, economy, and pollutant control.

Fluidized-Bed Boiler: Alchemy of Clean Combustion (page 6) explains the new process and tallies the developmental steps that should resolve its operation and bring it to commercial scale in less than 10 years. Nadine Lihach, *Journal* feature writer, is the author, basing her account on interviews with three project managers in EPRI's Coal Combustion Systems Division.

Terry Lund has managed EPRI research projects in fluidized-bed combustion since November 1975. He was formerly with Universal Oil Products Co., successively in process development and the design and startup of pilot and commercial plants. Lund is a 1970 chemical engineering graduate of the University of Washington.

William Howe joined EPRI in August 1978, having worked for Radian Corp. on the conceptual design of a 600-MW fluidized-bed boiler. He had earlier been with Pope, Evans & Robbins Inc. on fluidized-bed boiler tests at laboratory scale and as part of the startup team for a 30-MW AFBC demonstration at Rivesville, West Virginia. Howe is a 1975 marine engineering graduate from the U.S. Merchant Marine Academy at Kings Point, New York.

Callixtus Aulisio came to EPRI from Pope, Evans & Robbins Inc. in February 1978 with experience in the design and testing of fluidized-bed units. He held lead responsibility for startup of the 30-MW Rivesville demonstration. Aulisio is a 1972 chemical engineering graduate from the University of Maryland.

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Out of sight in cost as well as in fact, underground cables haven't been a clear option for power delivery. Now, however, overhead right-of-way and structure costs are altering the trade-offs, and so are the results of R&D on cable materials, construction, installation, and performance. These trade-offs are still highly site-specific, but several major trends add up to **Advancing Underground Technology** (page 14).

Jenny Hopkinson, *Journal* feature writer, was aided by Ralph Samm of EPRI's Electrical Systems Division. Samm's work at the Institute began in September 1974, and he was soon named to manage underground transmission research. He was previously with I-T-E Imperial Corp. for 16 years, becoming R&D manager for gas-insulated cable projects. Samm graduated from Johns Hopkins University in 1958 with a BS in electrical engineering. He later earned an MBA at the University of Pittsburgh.

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Even a single energy option often suggests subordinate options; for example, **Coal-Fired Power Plants: Efficient or Reliable?** (page 18). But such a trade-off is simplistic. Despite variables that arise during a 30–40-year plant life, it can and must be resolved by integrating overall design and operating criteria. The article was written by *Journal* feature editor Ralph Whitaker, with background from three utility operations managers and two EPRI research managers.

Dan Giovanni and John Dimmer came to the Coal Combustion Systems Division in 1977. Today they are teamed on advanced pulverized-coal plant design.

Dan Giovanni's early professional work was with KVB, Inc., consulting with electric utilities and power equipment manufacturers on fossil-fired plant performance improvement and emissions reduction. He then joined Kaiser Aluminum & Chemical Corp. to direct research in the energy efficiency of aluminum fabricating processes. Giovanni is a mechanical engineering graduate of the University of California at Berkeley, earning a BS in 1970 and an MS in 1971.

John Dimmer was with Detroit Edison Co. for 15 years. Among his assignments were cost reductions in fuel handling, installation of control instrumentation and programs, management of peak-generation units throughout the utility system, and organization of task forces to expedite the startup of new units and to increase the availability of existing plants. Dimmer is a 1962 electrical engineering graduate of the University of Detroit.

■

When a nuclear reactor core is brought up to operating power level, the speed and sequence of control rod withdrawal influence cost: the lifetime of fuel elements influenced by temperature and its gradient. They also influence revenue: the value of power generated along a 30–40-h startup curve.

PSMS: Simulating the Core (page 26), describes an EPRI-sponsored development for resolving these options.

Floyd Gelhaus, program manager in the Systems and Materials Department of EPRI's Nuclear Power Division, aided author Robert Vaile in preparing the article. Gelhaus has been with the Institute since April 1974, following six years with General Electric Co. and an earlier two years with RCA. At General Electric he worked extensively on thermionic power conversion and on breeder reactor fuel modeling. At EPRI his responsibilities cover fault analysis and modeling throughout reactor and steam cycle systems. Gelhaus is a 1961 electrical engineering graduate of the University of Wisconsin, with an MS in nuclear engineering from the same school. He earned a PhD in nuclear science and engineering at Cornell University in 1965.

■

Perhaps more than any other energy option, solar is a subject of mixed opinions. Indeed, the opinions go far beyond the data. But the data continue to build, and one index is the rising activity of electric utilities surveyed by EPRI in each of the last five years.

Utilities: A Growing Solar Program (page 28) reviews the 1979 findings and notes a few shifts in emphasis. Bruce Jackson wrote the article, drawing on data compiled by Gary Purcell, manager of several EPRI solar heating and cooling projects. Since August 1977 Purcell has specialized in instrumentation to control SHAC systems and collect data from their operation. He worked for 14 years in the design, test, and analysis of temperature control systems for Lockheed Missiles & Space Co., Inc. Purcell is a 1959 mechanical engineering graduate from Oklahoma State University.

Dimmer Giovanni Samm

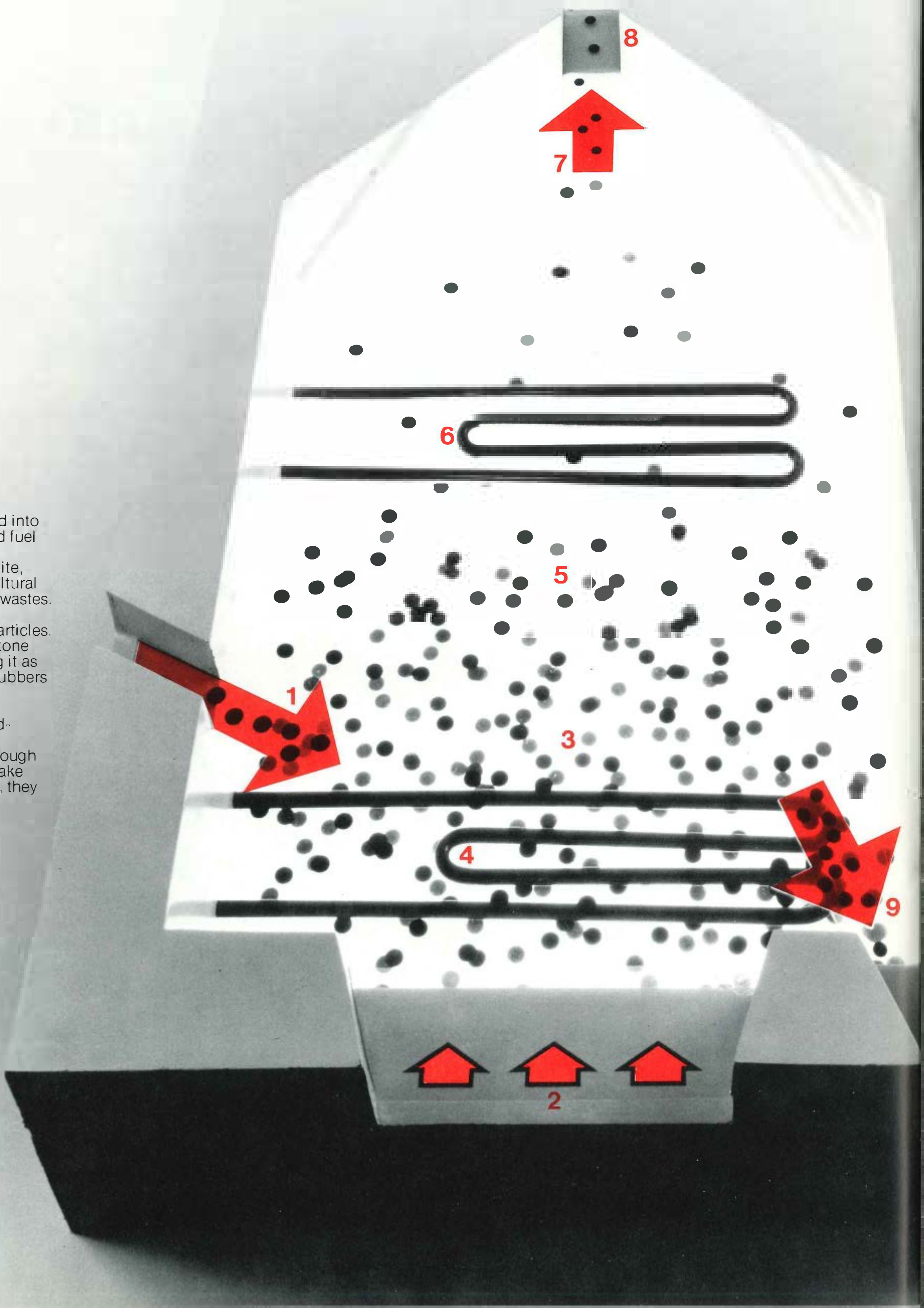
Aulisio Lund Howe

Fluidized-Bed Boiler: Alchemy of Clean Combustion

Imagine a black box that would solve many of the problems electric utilities wrestle with today. Coal is fed into the black box, but few sulfur or nitrogen oxides come out. No scrubbers are necessary to clean the sulfur from the flue gases. Nor does the black box melt coal ash into slag that fouls and corrodes equipment. Yet the omnivorous black box can burn any coal—from top-quality grades to those with high sulfur, high ash, or high moisture content.

The fluidized-bed boiler may be this marvelous black box, a greatly improved way of burning the coal the nation must rely on so heavily. And because of recent design innovations (and the promise of more to come) the new boiler could be commercially available to utilities in less than 10 years.

Inside the Boiler



Process and Attributes

1. Coal and limestone are fed into the bed. The boiler has broad fuel flexibility and can burn even low-grade fuels, such as lignite, coal-cleaning wastes, agricultural wastes, and municipal solid wastes.

2. Forced air fluidizes bed particles. As the coal burns, the limestone reacts with the SO_2, trapping it as calcium sulfate. Thus no scrubbers are necessary.

3. This atmospheric fluidized-bed combustor operates at atmospheric pressures. Although elevated pressures would make greater efficiencies possible, they would introduce additional technical difficulties.

A look inside the fluidized-bed boiler discloses the key differences between it and the conventional pulverized-coal boiler that utilities use to burn coal today.

In the conventional coal boiler, pulverized coal is blown out of jets and burned in midair. The waves of heat rush through the furnace past banks of tubing. Water within these tubes is boiled and the resultant steam powers electricity-generating turbines.

The fluidized-bed boiler does the same job, but with a special approach. Not only is combustion heat picked up from the gases by conventionally located tubing but some tubing is directly submerged in a bed of burning coal and heated limestone that is churned by air forced into the bed from below. Although the burning coal makes up less than 1% of the bed, all bed particles are quickly heated by this turbulent action. Hot solids and gases surround the bed boiler tubes, and the intimate contact with the solids makes heat transfer in the fluidized-bed boiler vastly more efficient than in the conventional boiler. Consequently, less boiler tubing surface is necessary to generate the same amount of steam as a conventional boiler, and capital costs are reduced.

The fluidized-bed boiler can also be fired with the lower grades of coal (such as high-moisture coal) that utilities would ordinarily shun. In fact, coal may not be the only fuel for a fluidized-bed boiler; municipal solid waste, coal-cleaning waste, agricultural waste, and peat are other possibilities.

The benefits don't stop there. Although many conventional boilers require scrubbers to remove the troublesome sulfur dioxide (SO_2) from flue gases, the calcium of the limestone within the fluidized bed reacts with this same SO_2, trapping it in a dry calcium-sulfate waste product. Scrubbers are thereby sidestepped, together with the capital, operating, and maintenance costs they entail.

The list of benefits goes on. Conventional boilers balk at the ash-forming minerals in coal; these noncombustible minerals (ash) melt under extremely high temperatures, forming a molten slag that fouls and corrodes boiler surfaces. Utilities pay to have ash removed from coal (with mixed results) or pay for boilers custom-designed to deal with the ash. However, because fluidized-bed boilers are more efficient heat exchangers than are standard boilers, they can be operated at comparatively low temperatures—1500–1600°F (815–870°C) versus ~3000°F (1650°C) for conventional boilers—so the coal ash never reaches its melting point. Cleaning to re-

4. Submerged boiler tubes pick up heat directly from bed solids, and because this heat transfer is so efficient, less boiler tubing surface is required. Bed temperatures can be kept relatively low, eliminating slagging problems and suppressing NO_x formation.

5. Freeboard gives unburned coal and unreacted limestone that have escaped the bed additional time to burn or react.

6. Convective boiler tubes pick up heat from flue gases. A conventional boiler relies solely on these tubes for heat transfer to superheaters.

7. Some unburned coal or unreacted limestone escapes the bed via flue gases.

8. It is possible for the stray fuel and limestone particles to be collected and recycled back into the main boiler.

9. Small amounts of bed material are continuously withdrawn from the bed to accommodate fresh coal and limestone.

move ash is therefore unnecessary, and boiler design standardization is possible. The lower operating temperatures of the fluidized-bed boiler extend yet another utility benefit: nitrogen oxide (NO_x) formation is suppressed, dramatically reducing these undesirable emissions.

This collection of unique benefits adds up to an impressive technology. "I think there's no other way we can achieve all the advantages that fluidized-bed combustion offers—reduced capital costs, fuel flexibility, self-contained emissions control, and a boiler design independent of coal ash properties," emphasizes Shelton Ehrlich, manager of EPRI's research in fluidized combustion.

Long haul ahead

Despite nearly a decade of R&D focused on utility applications, fluidized-bed combustion is still far from the point where the industry can use it. A marketable design for a commercial-scale plant has yet to be developed and proved. Without a demonstration of at least 100 MW (e), utilities are reluctant to take a chance on a new technology, however promising, points out Terry Lund, manager of EPRI's atmospheric fluidized-bed combustion (AFBC) research. Nor will the boiler manufacturers who design conventional systems switch to such a new technology. More R&D is needed to make utilities and manufacturers alike forsake conventional hardware for the new boilers.

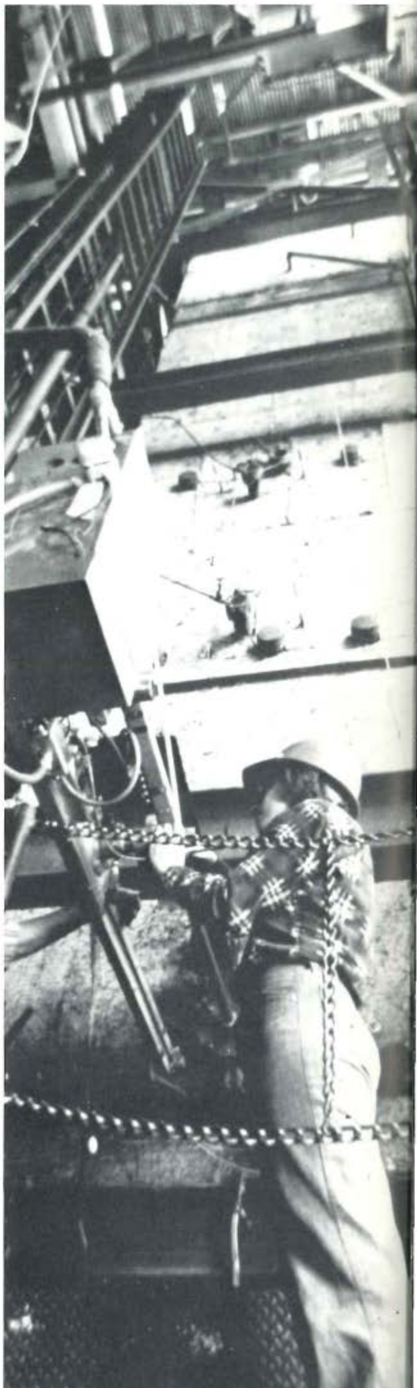
Fluidized beds may be unproved as far as utilities are concerned, but fluidized-bed processes are already widely used in other industries. There are hundreds of fluidized-bed processes in operation worldwide, primarily at mines, chemical plants, and oil refineries. However, the use of coal in such beds to produce steam is limited to a few small industrial facilities. And a utility boiler must meet a different set of cost and performance objectives than the process industry's beds.

A pioneering attempt to apply AFBC to steam-electric power generation was a 30-MW (e) demonstration installed in 1976 by DOE in an existing power plant at Rivesville, West Virginia. The boiler was designed by Pope, Evans & Robbins Inc. and built by Foster Wheeler Energy Corp. after the former studied the fluidized-bed concept on a 0.5-MW (e) test facility at Alexandria, Virginia. According to Lund, however, the Rivesville facility does not accurately represent the design of a commercial fluidized-bed boiler.

One significant shortfall is that Rivesville's freeboard (the space between the top of the fluidized bed and the convective boiler tubes immediately overhead) is only 3–4 ft (0.9–1.2 m). Additional freeboard would allow carbon and limestone particles escaping the bed via flue gases extra residence time to burn or react, thereby increasing efficiency, explains William Howe, EPRI project manager and formerly a startup engineer at Rivesville.

The Rivesville facility also relies on a supplementary fluidized bed to burn whatever carbon escapes the primary fluidized bed. To ensure that all carbon is consumed in this carbon burnup bed, temperatures are necessarily higher than those in the primary bed. These higher temperatures allow additional NO_x to form and also reduce SO_2 retention, according to Callixtus Aulisio, another EPRI project manager and also a former Rivesville startup engineer.

Finally, the Rivesville facility was a demonstration rather than a pilot plant. It was designed to—and did—produce electricity but was not equipped for evolving better designs. Because the boiler was built into an existing plant, there was little room to experiment with new designs. For instance, there was insufficient overhead space to expand boiler freeboard, according to Howe. Nor was Rivesville designed for extensive data collection. Aulisio cites one example: The flues of the facility's three fluidized beds converge into a common flue, precluding individual gas-flow measurements and emissions analysis.



A look around EPRI's 6-by-6-ft AFBC pilot plant at Babcock & Wilcox's Alliance (Ohio) Research Center. Notable design features include an 18-ft boiler freeboard and the

ability to recycle unburned coal and unreacted limestone back into the fluidized bed. The fully instrumented pilot has been providing researchers with a volume of useful data.

Enter EPRI

While the Rivesville facility was moving toward completion in 1976, EPRI reviewed a recently completed feasibility study by Babcock & Wilcox Co. These fresh results confirmed that an R&D pilot plant, rather than a demonstration facility, was needed to advance AFBC to commercial status. Specific requirements were the flexibility to test new designs and the data-gathering ability to determine which designs worked best. That year EPRI opted to fund construction of a $2 million, 2-MW (e), 6-by-6-ft pilot plant at B&W's Alliance (Ohio) Research Center. The plant's first 300-h continuous test was run in April 1978, and the facility has been fully operational since, supplying a volume of useful data.

While small compared with Rivesville's 30-MW (e) capacity, this plant offers the crucial flexibility to change designs as research progresses, comments Aulisio, who manages this project. Moreover, the 6-by-6-ft pilot is fully instrumented with about 400 individual data channels. The instrumentation can do everything from measure spot temperature and pressure to perform online gas analyses. A computerized data acquisition system monitors all channels for the information so necessary to design the fluidized beds of the future.

The pilot plant also incorporates a number of innovative designs calculated to increase plant efficiency. Boiler freeboard was expanded to 18 ft, a hefty increase over the freeboard at Rivesville. This expansion promotes better combustion efficiencies and sulfur capture.

The pilot plant is further equipped to recycle unburned carbon and unreacted limestone back into the fluidized bed, rather than discard it or send it to a carbon burnup bed. Recycling has resulted in a 98% combustion efficiency at the EPRI 6-by-6-ft pilot and has cut SO_2 emissions to about 200 ppm, a removal efficiency greater than 90%. The pilot has also demonstrated that fewer underbed coal and limestone feedpoints are necessary than engineers previously believed. Originally equipped with four underbed feedpoints—one for every 9 ft^2 of bed area—the pilot plant was able to operate efficiently with only one feedpoint. The cost benefits of fewer feedpoints are multiplied in a full-size facility, which may have a bed area of tens of thousands of square feet.

A battery of other EPRI studies supports the work at the 6-by-6-ft pilot. These studies enhance the pilot's effectiveness without unnecessarily taking up test time and money at the actual pilot plant. A "cold model" test rig at Oregon State University, for instance, uses such materials as sand or glass pellets within a plastic fluidized-bed model to simulate the activity of coal and limestone in a real fluidized bed. Mechanical effects can thereby be studied at a fraction of the cost of a "hot" test.

Other support studies are under way to determine the most efficient means of removing the SO_2 produced by coal combustion. Researchers discovered that when the calcium in the crushed limestone reacts with SO_2, the outer layer of the limestone may become impregnated with the calcium sulfate by-product, making further reactions impossible. The penalty is increased limestone requirements. At Westinghouse Electric Corp., a thermogravimetric analyzer is being used to study exactly how this reaction proceeds. At the University of Maryland, the use of chemical additives to modify limestone porosity is being explored.

Because the materials used to construct fluidized beds may be subject to unusual combustion conditions, EPRI has also undertaken a series of materials studies. Different metals, as well as operating conditions, are now being evaluated.

Bigger and better

As EPRI was preparing its pilot plant for startup, the results of a number of preliminary design studies for demonstration- and commercial-scale AFBC facilities began to emerge. These studies,

Commercialization of AFBC for utility industry applications is possible within 10 years. Units of 600–800 MW (e) are the target.

A 200-MW (e) demonstration plant should convince both utilities and boiler manufacturers that AFBC technology is ready for scale-up to commercial sizes. Such a plant could be on-line by 1987.

TVA's 20-MW (e) pilot should be ready for startup by 1982. Larger than the 6-by-6-ft pilot, it will give utilities the opportunity to test full-size hardware and process designs.

The EPRI 6-by-6-ft pilot at Babcock & Wilcox's Alliance (Ohio) Research Center, started up in early 1978, is the principal test facility for the development of AFBC for utility applications. Ongoing **support studies** screen process alternatives.

DOE's industrial demonstration program is expected to provide useful information on AFBC boiler life and operability, even though industrial boilers have different cost and performance objectives than utility boilers.

Design studies for 200- and 600-MW (e) AFBC plants are being carried out by TVA and by EPRI. These studies, essentially revisions of earlier studies, incorporate new design developments and data from the EPRI 6-by-6-ft pilot.

High-efficiency designs are necessary to ensure the AFBC boiler a place in the utility market. Accordingly, EPRI is exploring design innovations such as higher fluidizing-air velocities, deeper beds, and circulating beds.

commissioned by DOE and by TVA, constituted the first total systems analyses of AFBC for large-scale utility applications and were carried out by U.S. boiler manufacturers and architect-engineering teams. The design studies, which had been completed before substantial pilot plant data were developed, revealed that the level of AFBC technology was probably insufficient to satisfy the economic and environmental requirements of the utility industry.

These results provided a greater impetus to the 6-by-6-ft pilot plant project, Lund points out. However, it also became apparent that there were major technical uncertainties concerning AFBC that the small pilot, successful as it was, could not resolve. A larger pilot plant would be necessary on which to test hardware that could be scaled up to demonstration proportions of about 200 MW (e), and later to commercial proportions of 600–800 MW (e).

One major uncertainty was solids feeding. A complex arrangement of weigh feeders, feed pipes, and flow distributors could be required to deliver coal and limestone efficiently and reliably throughout the bed. A full-size commercial facility would have to supply coal and limestone to thousands of square feet of bed, comments Howe, whereas the EPRI pilot only had to distribute solids over a bed area of 36 ft^2. So design engineers would need a much larger bed to work with before they could arrive at an optimal feeding system.

An expanded convection surface was also needed to simulate flow and solids loading conditions in larger AFBC units. Similarly, larger freeboard and gas-pass areas than the 6-by-6-ft pilot offered were necessary to study the effects of flue temperature and turbulence on carbon and limestone utilization in larger facilities.

A commercial AFBC unit must respond to changes in electricity demand, so a well-defined load-following technique had to be developed; again, a larger pilot plant with an integrated system design was a prerequisite. Automatic startup, shutdown, and safety systems also needed development on a more true-to-life scale.

The argument for a larger pilot plant was a persuasive one, and in September 1979 TVA made a formal commitment to push ahead with a 10–20 MW (e) pilot on a utility site. This facility will be an actual prototype, a single-bed unit that can be multiplied, unit by unit, up to a full-size demonstration facility of approximately 200 MW (e).

Specifications for the TVA pilot ensure that it can tackle commercial-size problems. The bed will be expanded from the EPRI pilot's 6-by-6-ft dimensions and 36-ft^2 area to about 9 by 24 ft, or 216 ft^2. The freeboard will be increased to achieve combustion efficiencies and SO_2 retention typical of larger AFBC designs. A test electrostatic precipitator will operate on a slipstream to the main gas flow; a baghouse will be used as the routine means of particulate collection. Although not actually connected to the power grid, the plant will be able to simulate utility load demand by routing steam through a surface condenser.

The TVA facility will have other assets as well. It will be self-sufficient, relying on an existing power plant for only electricity and raw water. A complete data acquisition system and computer system for on-line data analysis and storage will be included. And the plant will be highly flexible and able to run under a wide range of operating conditions.

EPRI, keenly interested in the outcome of the TVA pilot, is presently providing TVA with technical assistance in its design and test planning processes. Financial assistance is also a possibility, according to Howe, who manages EPRI's TVA-related AFBC work. The pilot, to be designed and constructed by B&W, is scheduled for startup in early 1982; investigations of feeding, solids recycling, turndown, and load-following concepts will follow.

Meanwhile, DOE is moving ahead with an AFBC industrial demonstration program. Under this effort, a 100,000-lb/h industrial boiler began operation at Georgetown University in Washington, D.C. A second unit, 50,000 lb/h, is being designed for the Great Lakes Naval Training Center near Chicago, Illinois.

High-efficiency designs

In addition to the effort at the TVA pilot, EPRI is continuing its R&D to improve boiler efficiencies. Early economic comparisons showed that the cost of electricity generated by AFBC had but a marginal advantage over that generated by conventional boilers equipped with scrubbers. And although Lund emphasizes that these cost figures were based on conservative assumptions and experimental data, he comments that sizable cost advantages are necessary to ensure the fluidized-bed boiler a place in the utility market. Accordingly, EPRI is trying hard to top AFBC's already good efficiencies.

One contender is a high-velocity bed design from General Electric Co. This system relies on air velocities of 15–25 ft/s (air velocities in standard AFBC designs are only 4–12 ft/s) and a deeper bed than usual to achieve greater mixing of coal and limestone. Increased combustion efficiency and sulfur capture are the result. This design is being tested at a 2-by-2-ft (~0.2 MW [e]) facility owned by General Electric and operated under EPRI contract.

The most promising high-efficiency system, however, may be a circulating fluidized-bed boiler such as the one designed by West Germany's Lurgi. This design, which operates with higher air velocities and much finer coal and limestone particles than do conventional systems, entrains and recirculates bed solids through a heat exchanger. Boiler tubes are removed from the combustion bed. According to Lund, a small (~0.01 MW [e]) Lurgi test unit has produced high combustion efficiencies as well as high limestone efficiencies for 90–95% SO_2 removal. Furthermore, this system is capable of reducing NO_x emissions to less than 100 ppm.

The case for AFBC

A 200-MW (e) demonstration plant is the last stage before AFBC commercialization. At this scale, boiler manufacturers and utilities can be convinced that the technology is mature. TVA intends to proceed with a 200-MW (e) demonstration design, Lund indicates, and it is likely that EPRI will provide technical, and possibly financial, support.

Information from the EPRI and TVA pilot plants, the high-efficiency studies, and DOE's AFBC industrial demonstration program will be funneled into the design effort, and construction could begin by 1984. The demonstration plant could be operating by 1987. If boiler manufacturers and utilities are satisfied, orders for AFBC plants could be placed by the end of the 1980s.

Utilities, whether they burn eastern or western coal, will provide a large potential market for AFBC boilers, asserts Ehrlich. Utilities that burn high-sulfur eastern coal must now use scrubbers to desulfurize flue gases. AFBC's innate ability to trap SO_2 with bed limestone should provide sizable capital incentives to use the new boilers.

AFBC's dry calcium sulfate by-product also compares favorably with the unwieldy sludge that conventional scrubbers produce. EPA regulations stemming from the Resource Conservation and Recovery Act of 1976, which mandates environmentally acceptable disposal of power plant by-products, may complicate disposal of this waste, but Lund maintains AFBC's dry calcium sulfate by-product is no more likely to merit special disposal requirements than is scrubber sludge. It will certainly be easier to handle. (EPRI is presently supplying EPA with AFBC by-products for field-testing to determine their environmental effects.) And as limestone utilization efficiencies increase, the amount of AFBC by-products will decrease.

Utilities that burn western coal are a large potential AFBC market for different reasons. Many western coals are relatively high in ash and moisture. Because relatively low AFBC operating temperatures eliminate ash slagging problems, boiler reliability can be expected to improve significantly. With AFBC's excellent combustion characteristics, high moisture content does not adversely affect performance. As a final incentive, some western coals contain sizable amounts of calcium and sodium; these natural sorbents could eliminate or reduce the need for limestone in the bed.

Most AFBC research so far has focused on eastern coal; EPRI has now undertaken a special study of western coal. A recently completed study by Burns and Roe, Inc., indicates that the savings in cost of electricity with AFBC will be even greater for western coals than for eastern coals.

Ten-year timetable

Within 10 years the loose ends of AFBC should be gathered up: combustion efficiencies increased, limestone consumption reduced, and an integrated system developed that will win the confidence of boiler manufacturers and electric utilities. Encouraged by recent progress, Terry Lund concludes, "A 10-year timetable for commercialization seems very real. We now have the insight and the hardware to do it." ■

Overhead transmission systems have been the overwhelming favorite until recently. Compared with underground systems, they save on insulation because they are surrounded by air, and they are comparatively easy to construct and maintain. Faults, too, are generally a routine matter to detect and repair. In most cases, therefore, utilities choose overhead systems for transmission unless this option is barred by topography, by law, or by cost, that is, prohibited by either a nonexistent or an extremely expensive right-of-way.

Cost is becoming an increasingly strong reason to think twice about construction overhead when planning transmission expansion. As demand for electricity grows, greater amounts of power flow from generator to consumer, and from an economic standpoint, the best way to push more power over long distances is to use high voltage. Because there are esthetic as well as other objections to transmitting high-voltage power via overhead lines, some utilities and researchers are planning to increase the very small percentage of underground lines instead of constructing additional overhead lines.

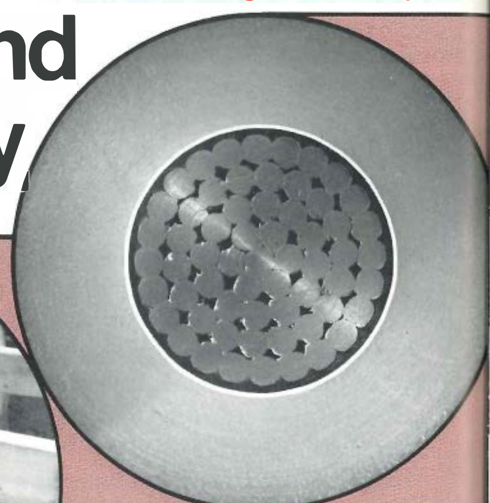
To support this move, EPRI is sponsoring research into new cables and improved underground installation methods that will bring down costs and, at the same time, produce systems that will respond reliably to greater loads.

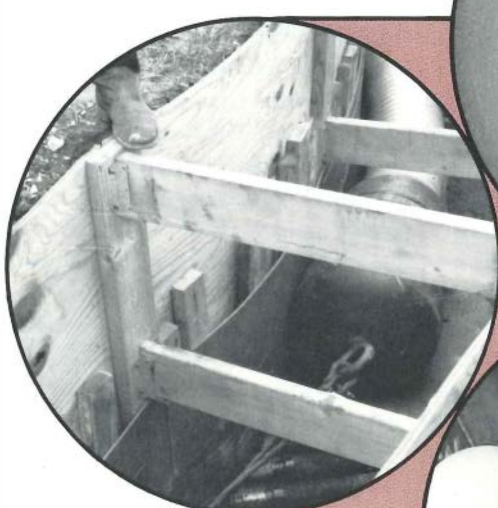
Leveling the differences

Until recently it was generally believed that the ratio of installed costs, underground to overhead, ranged between 10:1 and 20:1. But studies show no general comparison can be made between system costs because each new circuit is characterized by widely different attributes, such as price and availability of land, local population distribution, type of terrain, length of circuit, size of load, and prevailing regulations. In choosing a system that is particularly appropriate for it, a utility cannot just decide on installing the least expensive one; local attributes influence the decision, too. Illustrating the dilemma is a statement in a recent EPRI report, *Cost Components of*

Underground systems for transmitting power are becoming more competitiv

Advancing Underground Technology





High-Capacity Transmission Options, which runs: "One of the dangers in presenting these cost figures is that one might be tempted to compare one technology against another."

Although the interrelationship of three elements—cost, reliability, and environmental adequacy—varies with each installed transmission system, cost still is a heavy disadvantage of going underground. For instance, in cities, where underground lines are often mandatory, about half the total installed cost of an underground cable circuit is incurred in cutting the trench, pulling the cable through it, refilling the trench, and resurfacing the street. But each one of these processes is under scrutiny. Researchers are looking for ways to shorten installation schedules, reduce manpower required, and economize on materials and equipment.

On the other hand, costs of overhead construction are rising, particularly in terms of land purchased as rights-of-way and the additional equipment needed for higher-voltage lines. Utilities are transmitting power through overhead lines at ever-greater voltages to match heavier loads, and voltage determines such cost-related factors as the horizontal spacing between aerial lines and the length of the string of insulators from which the lines are suspended. These factors present not only a costlier project but a more cluttered and maybe more unsightly construction than lower-voltage lines.

In addition, higher-voltage overhead lines bring such problems as audible noise, interference with radio and television receivers, and corona (a halolike glow around the line), which discharges electrical energy from the conductor into the atmosphere, causing a loss of power.

Overhead lines are also prey to damage by the weather—ice, lightning, wind, and rain. Vandals are sometimes a problem, too, as are accidental tangles with falling trees or stray kites.

But despite these drawbacks, overhead lines still represent 99% of all U.S. transmission of electric power. For that percentage to change, new and improved methods of underground transmission

ith overhead systems as research brings advances in materials and methods.

will have to emerge from the research and demonstration stages to full-fledged commercial availability.

Advanced cables

Most of the 1% of transmission systems that are installed underground are fitted with cables that are insulated with layers of oil-impregnated kraft paper. The most commonly used system is the pipe-type cable, which comprises three conductors individually wrapped with paper tape, saturated with a dielectric fluid, and enclosed in a steel pipe that is filled with an insulating oil and pressurized. This high-pressure, oil-filled (HPOF) cable has been installed at voltages up to 345 kV, and designs rated up to 500 kV have been successfully tested at EPRI's Waltz Mill Underground Cable Test Facility.

But HPOF cables have limitations, among them a dangerous rise in temperature with severe overloads, high losses in the insulation, and excessive charging currents with increased voltages and distances. Although researchers are testing new semisynthetic insulation materials and forced-cooling techniques to mitigate these limitations, upgrading the voltage and capacity of HPOF cables may take time.

Meanwhile, work continues to perfect other concepts in underground power transmission: compressed-gas-insulated cables and extruded-polyethylene-insulated cables. In addition, resistive cryogenic cables and superconducting systems may have promise for the long term.

Researchers have developed both rigid and flexible gas-insulated cables. Rigid cables are capable of transmitting large quantities of power, but are only economical for very short lengths. To overcome this problem, researchers have developed a gas-insulated pipe that carries three conductors. This method should permit a 10–15% reduction in cost.

The flexible gas-insulated cable, made from corrugated tubing, can be fabricated in long sections and dispensed from reels. Installation is therefore easier and more efficient, because splicing and field welding are reduced considerably. These methods of manufacturing and installing underground cable are expected to result in at least a 25% saving compared with rigid gas cables.

Extruded polyethylene cables, in which a solid insulation of synthetic materials surrounds the conductor, are easier to handle because no fluid is involved. They should cost relatively less than HPOF cables to produce, install, and operate because the oil-pressurizing equipment and some of the system maintenance of HPOF cables are eliminated. However, the reliability of these cables depends to a large extent on the purity of the polyethylene; contaminants can cause electrical discharges that burn through insulation. EPRI and Reynolds Metals Co. have developed a way to combat these contaminants, thereby enhancing cable reliability, with a prototype of an optical detector, which rejects contaminated pellets of the polyethylene feedstock before they enter the extruder.

Cooling of cables also enhances reliable transmission of electric power. In fact, extreme cooling lowers or eliminates the resistivity of cables to electricity, creating an unimpeded and therefore very efficient flow of electric current. For example, cryoresistive cables, cooled by liquid nitrogen, are kept at a temperature of 77 K (−196°C), which reduces the resistivity of the two conductor metals, copper and aluminum, by a factor of 10. In superconducting cables, liquid helium lowers cable temperature to between 5 and 15 K, reducing resistivity almost to zero.

For overall efficiency, reductions in resistance have to generate savings that match the cost of refrigeration. In the cryoresistive range, it does not appear that costs break even; in the superconducting range, however, there is a net gain. Superconducting systems also have higher power-transmitting capability, and further research is likely to be a worthwhile investment.

Improvements in trenching

An immediate saving in land purchase for underground cables is provided by the relatively narrow rights-of-way they require. Right-of-way widths for overhead lines can range up to 300 ft; in contrast, underground lines need only a few feet, plus an access easement.

Counteracting this saving are the expenses involved in trenching for underground lines. Necessary operations include detecting obstacles when mapping the route, cutting pavement or rural land, shoring the sidewalls of trenches, installing cable, and refilling the trench. Researchers are already improving these operations.

A cable installation starts with a detailed plan, part of which is laying out the route. In an EPRI-sponsored project, Ohio State University is developing a fast, accurate radarlike device for detecting, identifying, locating, and mapping underground obstacles. A minicomputer is employed on the field-scanning device that enables operators to process and plot data rapidly for efficient mapping.

After mapping the route, the next step is likely to be the removal of a paved surface prior to cable installation. Pneumatic hammers traditionally perform this time-consuming, noisy task. But EPRI and Flow Industries, Inc., have developed a water-jet concrete-cutting vehicle that is expected to outpace the hammer. Four utilities in turn are to try the concrete cutter for six months each in a program to train utility people in using the vehicle and to collect enough data to project future operating costs.

Whether cables are laid in pipes, ducts, or directly in the ground, trench sidewalls have to be propped up to prevent fall-in of earth. Unitized sidewall shoring is another innovation that is expected to lessen trenching costs.

Maintaining reliability

If cables are buried directly in the ground, they must be packed with soft, sandy backfill to prevent damage from stones or other rough material. But an even more important role for the sandy fill is as a heat dissipator to prevent overheating and failure of the cables. At the University of California at Berkeley, researchers working on an EPRI-sponsored study of backfill materials experimented with various additives that when mixed with soils, could vastly improve their thermal conductivity. They found the most effective additive was slack wax, a cheap by-product of the petroleum refining industry. This is an example of the research results that can ensure improved reliability in underground transmission.

Malfunction or failure in underground power-carrying cables occurs infrequently compared with overhead circuits. However, detection and repair of the faults that do occur are time-consuming and costly processes. Because of the need for a fast, accurate method of locating faults, EPRI is sponsoring research into the problems. In one project, Power Technologies, Inc. (PTI) is developing and testing an advanced system for locating leaks of both cable oil and cable gas. After reviewing advantages of traditional methods of leak location, PTI will assess other methods, such as those employing flow metering, acoustic signal injection, tracer gases, stable isotopes, infrared surveying, and possibly ground-penetrating radar. The final system will operate in two stages. The first will define the general location of the leak (e.g., in an area between specific manholes), and the second will pinpoint the leak.

In another project, Hughes Research Laboratories is developing a fault location system for paper-oil-insulated, pipe-type cables and extruded polyethylene cables. The measuring technique developed will be based on the time required for a spark-gap impulse wave to travel from the failed section to a terminal.

Resolving the problems in underground fault location is a matter of urgency, particularly as the industry is increasing the use of underground cable in urban areas, where dense loading makes reliability a critical factor.

Changes ahead

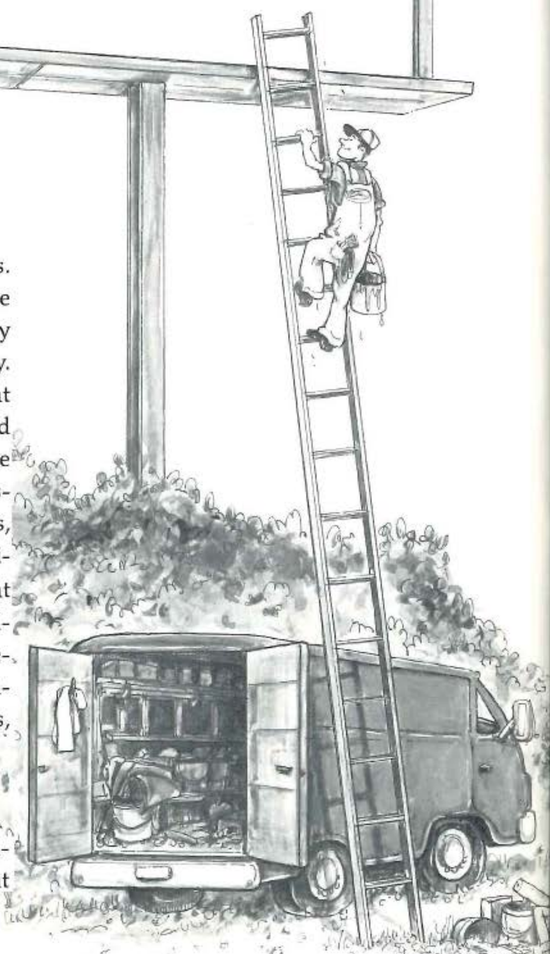
With changes expected at the generating end of power production and the likelihood of new consumer patterns, transmission methods will be under pressure to adapt. Present research and development are already yielding materials and methods designed to save time, cut costs, and respond to growing demand with minimal disruption of the environment.

In some installations, either overhead or underground lines are mandatory. In mountainous terrain, for instance, overhead lines, workers, and machinery often have to be dropped by helicopter. Correspondingly, underground or underwater installations are mandatory at sea. In fact, the term *underground* is sometimes appropriate for sea installations, because in one instance at least, cable will be buried in a 5-ft-deep trench cut in the seabed of the English Channel by an undersea trenching tractor. This is part of a plan to connect the grids of the U.K. Central Electricity Generating Board and Electricité de France. The proposed 95% availability of the cable depends on the certainty that it will not be fouled by ships' anchors and trawls.

Apart from obvious instances where one or the other system must be installed, there will increasingly be situations where a choice has to be made. To evaluate many of the bulk power underground transmission systems that may be available in the 1990s, DOE and the Philadelphia Electric Co. made the theoretical supposition that the Pennsylvania–New Jersey–Maryland (PJM) Interconnection was to be expanded to about three times its present size by increasing underground installations. A hypothetical 10,000-MW generation park was added to the base system at a location remote from principal load centers. The theoretical transmission route corresponded to an existing aerial right-of-way, which crossed a wide range of terrain from rural farmland near the generation park, through suburbs, and finally to a densely populated urban area. The cost of the right-of-way was included in the study as if it had to be purchased. Fifteen transmission systems were costed, all of which were underground systems, except for one part-underground, part-overhead system. It was apparent from the results that the hybrid system was the least costly, that is, between one-third and one-fourth the cost of the underground systems. Even so, the cost ratio of underground to hybrid never reached the 10:1 to 20:1 range that is generally accepted. In fact, a recent comparison of current underground technology with overhead for a rural installation came close to a 5:1 ratio. Future technologies, such as superconductivity, have the potential of reducing this ratio even further.

The results of the PJM costing study are an example of the opportunities to be gained by continuing research. As Ralph Samm, manager of EPRI's Underground Transmission Program, states, "The expected increase in demand for underground transmission systems can be successfully met only if viable alternatives are made available to provide more economical systems, more reliable systems, higher-capacity systems. EPRI's R&D programs are carefully structured to meet those needs. The near-term alternatives are compressed-gas and extruded dielectric cables. And these newer transmission technologies are not expected to detract significantly from the quantity of HPOF cable presently being installed in urban areas. Rather, these newer technologies are expected to expand the use of underground cables to suburban applications, special applications, such as substation get-a-ways or highway crossings, and possibly even rural applications where the cost differential can be justified." ■

Traditional opinion holds that power plant efficiency and reliability are a trade-off. But some utilities are attaining both. Building on their success calls for attention to operating practices, R&D troubleshooting, and integrated design of new plant systems.



Coal will evidently be the dominant utility fuel for the next 25 years or so, and direct firing for steam-electric power generation is the most familiar way to use it. The technology is thoroughly established and well documented.

If coal is to be used, especially on a startlingly larger scale, it must perform well. The price of coal (despite uneven quality) demands it. So does the cost of emission control systems to scrub, filter, and precipitate air pollutants, as well as systems to handle residual sludge and fly ash. And so does the inflation of plant capital and operating costs.

Despite mature technology, documentation of coal-fired plant performance is ambiguous. By one conventional reliability measure—availability—there is a mixed record of successes and failures. Moreover, there is mixed opinion on the connection between a plant's availability and its design level of thermal efficiency.

Some utility people say flatly that availability is the only ultimately valid measure of a plant's worth. They note that it has slipped in recent years, especially for newer plants, larger plants, and plants designed for higher theoretical efficiencies. Others insistently point to a cause-and-effect relationship. Availability has dropped, they say, because designs have been pushed beyond reasonably operable, reliable limits of materials, complexity, and equipment size.

Duke: efficiency from operation

There are other views, and other experience, on availability. These suggest that the cause-and-effect linkage can be broken. Joseph Davis, manager of system results for the steam production department of Duke Power Co., has this to say: "Our plant people continually monitor the major operating variables, like main steam temperature, pressure drop in the turbine cycle, flue gas temperature, excess air in the boiler. Others, too. Each variable has a controllable range that represents just 1/10 of 1% fluctuation in plant heat rate. If one of them deviates by this amount, the shift crew is responsible for immediate corrective action, and the plant maintenance and technical services groups back them up."

What the Duke operators monitor are, in fact, measures of plant efficiency. But what they also want, and get, is high availability.

Julian D'Amico, Jr., manages the fossil production division that comprises Duke's 30 units at 7 coal-fired plants. He adds, "We send monthly reports back to every plant, detailing the control variables that affect unit heat rate and showing the dollar value of lost revenue for each one. The plant people understand dollars, and at monthly meetings conducted by the plant technical services superintendent, they all have the opportunity to suggest and share solutions. That dollar picture really makes them a team."

Duke's methodical record of efficiency and availability has even broader applicability: corrective action at regular meetings of plant and central office engineers; feedback to design engineering teams on new plants; and advance planning of major maintenance, rehabilitation, and equipment modification. The latter effort focuses on unit problems for which systemwide company data show adverse effects on efficiency or reliability.

AEP: efficiency from design

Then there is David Williams, senior vice president for operations of American Electric Power Service Corp. He works on behalf of four generating utilities (Ohio Power Co., Appalachian Power Co., Indiana & Michigan Power Co., and Kentucky Power Co.) that total 37 units at 13 coal-fired plants. "We do each of our designs as a series—replicate a unit three, six, even nine times, fine-tuning each successive unit for better efficiency until that size doesn't seem to be economic. The average is maybe 6 units in a series. But the technology for each size is built on the previous one, including what we learned from running it. When we go up, it's also to achieve new goals of both thermal efficiency and availability."

Right now AEP is working with six 1300-MW units, all designed for supercritical steam conditions of 3500 psi (24 MPa). Williams cites the 1979 availabilities, through June, for the three already in service: "Amos, 92.2%; Gavin-1, 76.1% (we took an outage on that one early in the year); and Gavin-2, 94.1%. All in all, we've got 15 unit-years of experience with those three, at an average availability of 86%."

Williams also points to the system's rolling five-year maintenance program, which includes projections by each plant manager for maintenance, capital improvements, and the personnel to do the work. "The plan is updated each year, reviewed by our plant engineering and maintenance groups, and then the maintenance people meet for a whole day with each plant manager to go over what's proposed for next year. Together, they come up with the work to be done, the time required, the outside services needed, and the plant's preference for scheduling.

"In July the next year's plan is reviewed against our system forecast, and we lay out a maintenance schedule, unit by unit. We have a computer program for making trial balances of capacity versus load, reserve requirement, and so forth. There has to be some juggling, of course."

That isn't all. AEP's maintenance plan is reviewed by corporate management, then costed. "This is likely to change a few priorities," says Williams, "but by the end of October each plant manager has a firm plan—when he'll be out, what's to be done, and his budget. He's accountable for all three.

"You know," Williams adds, "we're putting much more emphasis now on our plant managers' being business managers, and they're responding to it. Given the time and task definitions for each year's planned outages, they're still aiming for the highest possible availability."

TVA: efficiency from maintenance

Still another approach is recounted by Clem Schonhoff, assistant director for engineering and maintenance in the division of fossil and hydro production of the Tennessee Valley Authority. His utility became caught between its nuclear plant delays and a 2000-MW power exchange agreement that ties up its coal-fired plants during what would be the season for annual maintenance outages.

"We had a problem of generation to meet demand, so we continually deferred and shortened our planned outages; and the result was forced outages that made availability worse." The situation was severe, Schonhoff points out, "older units just plain wearing out, others having to cycle and experiencing thermal stress fatigue in turbine rotors. And we were always playing catchup."

But in 1977 that began to change. Says Schonhoff, "We did an analysis of deratings and forced outages and their costs for all 63 units at our 12 plants. This gave us priorities for a systematic program, and it justified creating the outage time we needed by spot purchases of replacement power or by more use of our own gas turbines.

"At Bull Run, for instance, we had a 20% forced-outage rate just from furnace tube failures—corrosion caused by a reducing atmosphere on the fire side. Without our new plan, we might have endured it. But with the plan, we could see what it was costing us and could weigh that against the cost of replacement power for the needed repair time, which is about 12 weeks, whereas a normal yearly outage is planned for about 6 weeks."

The work at Bull Run was eventually scheduled in two stages, 1977 and 1979, with the expectation of cutting tube-leak outages to about 2% and bringing the plant up to an availability of 84%. With steps like that, the overall availability of TVA's coal-fired plants is being reestablished, and efficiency is on the rise, too. Bull Run, in fact, led the nation's coal-fired plants in 1978, posting a heat rate record for the year of only 8810 Btu/kWh.

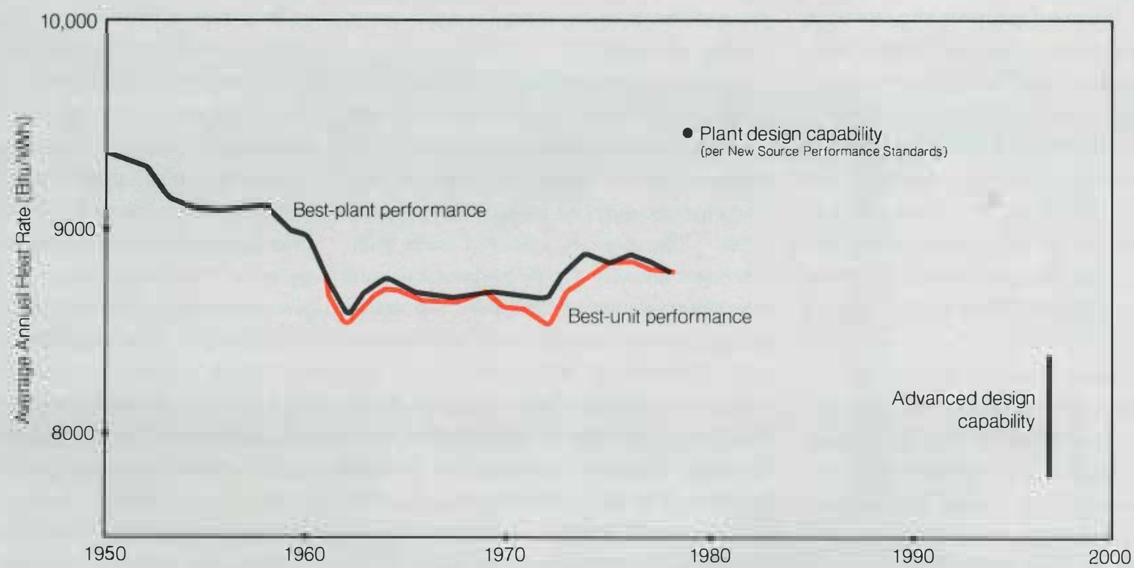
These three utilities—Duke, AEP, and TVA—have different approaches to efficiency and reliability, reflecting, in part, their corporate, regional, and service circumstances. But they have long been leaders in designing coal-fired power plants for better performance. They also share the conviction and the records that such plants can operate at high availability.

Defining the difference

Efficiency and reliability. Not one or the other, but both. What do the words really mean? Why or how do they contrast in any practical sense?

Efficiency is an overall index for the thermodynamic performance of a power plant, measured at any moment or averaged over the course of a year. Although efficiency is formally defined as a pure ratio (output energy divided by input energy, both measured in the same unit),

Historic performance of coal-fired plants is revealing: average annual heat rate downward in the 1950s with better plant designs; level in the 1960s when coal was cheap and oil-fired and nuclear plants were favored; upward in the 1970s because of the performance penalties of emission controls and poor fuel quality. The cost of coal today demands renewed emphasis on heat rate. Can we improve on today's design capability?



utility convention gives us an inverse ratio called heat rate, which is the amount of fuel energy (Btu) required per unit of generated electricity (kWh). Thus, the lower the heat rate, the better the plant efficiency.

All the incremental steps of energy conversion and transfer in a power plant —chemical to thermal to mechanical to electrical—can be evaluated in terms of equivalent Btu/kWh loss from beginning to end, including exhaust gas up the stack and exhaust steam into the condenser. A complete heat balance measures these incremental efficiencies, or heat rates, and pinpoints principal sources and causes of loss, thus defining those processes and subsystems where design or operating improvements may produce the best payoff.

Reliability is harder to pinpoint. Broadly, it refers to the certainty that a plant can operate when needed. Utility convention therefore measures the percentage of time (usually on an annual basis) that a plant is ready (available) to generate power. Availability thus reflects the plant outage time that is planned and scheduled for inspections, maintenance, and overhauls. It also reflects, historically, the forced-outage time occasioned by equipment failures.

Availability isn't really a precise measure of reliability. For example, when system demand is low and a plant is in reserve, it may undergo a leisurely maintenance routine that could have been done faster, or even deferred. The result is a distinct drop in its availability but also a more dependable plant when it goes back into service.

Tracing the history

Why efficiency and reliability often seem to conflict is seen in the record of the last 20 years in the evolution of coal-fired power plants. The record is a composite of many factors, some well documented, others intuitively evident, and still others merely conjectural. Involved are trends in size, steam pressure and temperature (efficiency), availability factor, emission control, coal quality, and the cost of everything.

During the 1960s and early 1970s, coal-fired plant designs were steadily increasing in unit size, all in all about threefold, from 400 to 1200 MW. Peak-load growth rates for utilities called for the capacity involved, and economies of scale clearly justified the unit size trend. Together with decreasing coal cost, this evolution furthered a longtime downward trend in electricity cost at the busbar and delivered to customers.

During much of the same period, design steam conditions also rose, inlet pressures going from 1800 to 2400 to 3500 psi (12.5, 16.5, 24.0 MPa), and in a very few instances of smaller, prototypical units, to 5000 psi (34.5 MPa). Steam reheat loops of increasing temperature were added, recycling steam to the convection heating portion of the boiler as many as three times during its progress through the tandem high-, intermediate-, and low-pressure turbines of a single unit. However, by the early 1970s, units designed for 3500 psi (24 MPa) and double reheat appeared less frequently; by 1975 the same became true for 3500-psi (24-MPa) single-reheat units; and units installed subsequently have predominantly been 2400-psi (16.5-MPa) designs with a single reheat loop.

Because of the lead time in utility procurement, it is clear that this retrenchment in size and steam conditions originated much earlier than the installation dates. Two technological constraints apparently contributed to the leveling off in size: allowable stress levels in critical components and physical size limitations for some forgings and castings.

Assessing performance

But why the retreat in steam conditions? Here is where utility operating experience with heat rate and availability comes in. The average heat rate for all coal-fired plants fell steadily from long before the 1960s until about 1965 and then leveled off at about 10,400 Btu/kWh. Similarly, the annual heat rate for the best individual unit leveled off at about 8700 Btu/kWh. Then, in the early 1970s, both records began to rise—the result of another set of circumstances. In retrospect, the leveling of heat rate doubtless caused some concern, but the drop in availability that accompanied each increase in unit size must have been profoundly disturbing. (This conclusion is drawn from data compiled by Westinghouse Electric Corp., the EEI Prime Movers Committee, and others, and only recently analyzed. It is a composite rationale for many decisions, motivated in subtly different ways, that were made by individual utilities.)

The drop in availability was evidently seen as a function of higher steam conditions, and it also slowed the pace of unit size increase. In fact, the decline in availability was also a result of the immaturity of so many units. Both steam conditions and size influence plant complexity, and there was logically an impact on utility operating and maintenance capabilities—at the very least, a learning curve difficulty.

Cost experience doubtless also influenced unit size, heat rate, and availability trends. Well into the 1960s electricity costs and rates were falling, and capital investment was devoted to conservative design margins in the new, larger units of that time. As costs leveled and then as they began to inch upward, design margins were shaved. Hindsight tells us that technical certainty was compromised and reliability was sacrificed.

EEI figures for the industry between 1967 and 1976 support these observations. For units of less than 200-MW capacity (generally, the oldest ones), the average availability was a respectable 86.8%; for 200–400-MW units, 80.1%; for 400–600-MW units, 77.9%; and for 600–800-MW units, only 73.5%. The biggest (and frequently, the newest) units, 800 MW and above, posted an average availability record of only 74.0%.

It should be noted that a Westinghouse analysis of the EEI data shows a different trend for a specific group of units (several of them on the AEP system), all characterized by supercritical steam conditions. For units between 600 and 800 MW, availabilities increased from about 70 to 75% for those with one reheat loop, and from about 77 to 79% for those with two reheat loops.

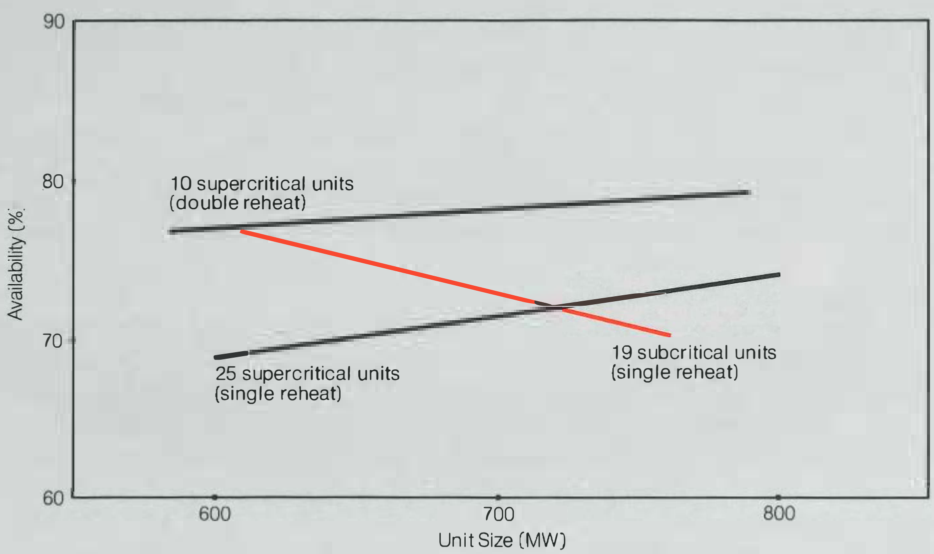
Dealing with new conditions

In the early 1970s, yet additional circumstances intruded. The first was the advent of flue gas desulfurization systems—sulfur dioxide scrubbers that were unfamiliar, unreliable, and inevitably parasitic in their energy requirements. These add-on systems began pushing heat rates upward.

The second was a severe decline in coal quality and its consistency. Lower Btu content and higher ash content meant greater fuel volume to produce the same furnace heat. This imposed new loads on coal pulverizers and new loads on the electrostatic precipitators that remove fly ash. Inconsistent coal has been an even worse problem. Plants designed for one quality can be modified (more pulverizers, for example) to handle another, but they cannot be infinitely adjusted in operation to deal with variations from one coal shipment to the next. Furnace-fouling and pulverizer capacity problems followed, and both efficiency and reliability suffered further.

The third factor in the 1970s was the successive energy crises that have seen

Availability of coal-fired units does not consistently fall off with increasing size. Steam conditions are also influential. According to a Westinghouse analysis of EEI data from 54 units, the larger supercritical units exhibit slightly better availability.



all utility fuels escalate, coal perhaps the least (only double since 1973). Concurrent inflation and recession drastically changed the capital and operating cost picture for electric utilities, so the actual cost of delivered electricity has now been on the rise for six or seven years. The premium on efficiency, lower heat rate, has thus been renewed.

Finally (perhaps), rising electricity prices have motivated widely divergent projections of future electricity demand, creating great uncertainty for utility planners and regulatory agencies. Because plants cost so much to build and utilities are limited in their capital resources, new capacity is subject to deferment or to scaling down in size. The traditional value of plant availability has therefore taken on renewed importance, too. Small wonder that a utility representative on one of EPRI's advisory committees spoke his preference with the laconic statement that "a heat rate of 9000 and running is better than 8000 and not running."

Evaluating R&D needs

How can both better performance and better availability be ensured for the future? Beyond utility practices themselves, but building on them, are two efforts of EPRI's Coal Combustion Systems Division, headed by Kurt Yeager. One is an established research program to improve the performance and reliability of today's plant designs, the ones already operating throughout the country. The other is a single research project to assess new technology requirements for a lower-heat-rate coal-fired plant design.

"Both are important," Yeager emphasizes, "because the issue for any utility in any year is to generate electricity at the lowest busbar cost. But there's a new envelope of physical conditions for power plants now, mostly in matters of coal quality and emission control requirements, and they've had a terrific influence on the plants.

"Our near-term R&D is a kind of troubleshooting, really, defining and doing incremental work with today's technology so that plants can come closer to what their basic designs were meant to provide. Actually, there are three envelopes; one is physical, and the others are regulatory and economic."

Taking the area of environmental controls, Yeager runs quickly through some EPRI data and projections. "Back in 1965 the beginning engineering cost of a coal-fired plant was about $425/kW—that's in 1978 dollars—and pollution controls were about 10% of it. By 1978 the total was typically $950/kW, and controls had become about 40%. For 1985, the way things are going—and still in 1978 dollars—controls could represent 66% of a total coal-fired plant cost of $1600/kW.

"That 66% is $1050, well above the whole plant cost in 1978," Yeager continues. "We think EPRI's research on baghouses, scrubbers, NO_x control, noise control, dry cooling, toxic waste handling, and so forth can clear the way for cutting that pollution control investment by 25 or 30%.

"Those are the savings from corrective surgery, so to speak," Yeager observes, "but savings may also result from preventive medicine, that is, from EPRI's work in examining the technical justification for environmental control requirements before they are imposed."

Troubleshooting today's designs

Performance and reliability of today's coal-fired plants are the responsibility of EPRI's David Poole, a former project engineer at The Detroit Edison Co.'s Monroe plant. Much of his R&D troubleshooting is influenced by fuels that worsen boiler fouling and slagging, gases that erode and corrode induced-draft fans, and today's necessarily varied operation, cycling, of plants that were designed to run under steady-state conditions. But Poole is quick to look at steam cycle equipment, too, at tube leaks, turbine blade erosion and corrosion, feedwater pumps and bearings, and water chemistry, for example, and to analyze root causes of failures.

"Among the most persistent generic problems with turbine blades are solid-particle erosion, water induction, and stress corrosion that leads to fatigue," says Poole. "Hard-particle erosion seems to stem from exfoliation in the steam superheaters and reheaters and maybe also in the steam piping to the turbines. The result is spalling, with particles blown into the turbine, mostly during the first few minutes of startup.

"One remedy," he goes on, "may be a chromate solution treatment that creates a hard oxide coating in the tubes. Foster Wheeler has done some R&D for us on this, and we think it has high potential for success. Now we're developing guidelines for chromate treatment as a retrofit step in boilers that have been acid-cleaned."

Work on just this one aspect of Poole's program should be done in 1981 and could produce an industry payback of as much as $10 million annually.

The problems of stress on turbine blades is getting help from the insights and projects of Robert Jaffee, manager of the Materials Support Program for EPRI's work with fossil fuel and advanced power plant systems. Blades in the last two rows of low-pressure turbines are the longest, most highly loaded, and most subject to corrosion, as well as to erosion, as impurities condense out of the low-pressure steam. Close monitoring of feedwater chemistry is one part of the remedy, in Jaffee's opinion, "but the realities of forced-outage experience create a role for titanium alloys in place of chromium steels. They resist corrosion better. Also, titanium blades of equivalent size are lighter and stronger, reducing their attachment stresses and resultant susceptibility to stress corrosion cracking.

"If the last stage was completely bladed with titanium," Jaffee says, "the cost of the whole turbine would go up only about 0.5%. For a 1000-MW or bigger machine, that's perhaps $400,000. Even so, it's no more than the typical cost of one day's forced outage."

Defining tomorrow's plant

Beyond the near-term need to do better with today's plants lies the advanced coal-fired plant specifically designed to work as an integrated system in Yeager's envelopes of physical, regulatory, and environmental constraints. This is the objective of a single EPRI project begun in 1979 that involves several research programs in Yeager's division.

Dan Giovanni and John Dimmer head the project, motivated by the utility needs and experience, historical perceptions, and ongoing R&D surveyed above. Their work is also guided by the improvements that have become available since the utility industry's early experience with the Philo-6 and Eddystone-1 plants, two projects of Ohio Power Co. and Philadelphia Electric Co., respectively, that 20 years ago took the first real step-function design leap into supercritical steam conditions above 3200 psi (22 MPa).

Lower heat rate is Giovanni and Dimmer's objective for their project, with the caveat that nothing of today's design criteria that influences availability can be overlooked. "Primarily, we're focusing on the boiler, the turbine, and the auxiliaries," says Giovanni, "and we've added important conditions. Even a plant planned for steady, baseload operation is likely to be cycled early in its life, certainly within five years, maybe even from startup. So operating flexibility is important to us.

"New heat rate economies won't be maximized individually," Giovanni continues, "and we won't justify the R&D to get them on that basis. They'll be optimized for the whole plant as a system under realistic duty conditions that will be developed as part of the project. Annual heat rate and life-cycle power costs are more important to us than an elegant design for theoretical efficiency or operating cost under baseload conditions."

Early project work is using cost and performance data for emission control systems that represent today's state of the art. "Meanwhile," Giovanni says, "several other EPRI projects are working toward optimized designs for scrubbers, baghouses, and precipitators—and also for water treatment and cooling systems—that will be worked into the integrated plant design."

Yeager sees an important collateral objective for this project: to develop a pulverized-coal plant concept and cost basis that is valid for the 1990s. Advanced power systems that use fluidized-bed coal combustion, coal liquids, and gasification-based combined cycles are necessarily being evaluated for that timeframe, and their assessment requires an authentic comparison with what we can then expect from direct-fired coal plants.

Bringing talent to bear

The organization of talent for the effort is as representative as it can be, and perhaps novel as a result. Two R&D teams are competing on the first, 18-month, $1.2 million phase to define areas of heat rate improvement and set the R&D required to attain them. General Electric Co. heads one team, aided by Babcock & Wilcox Co. (boiler manufacturer), Stone & Webster Engineering Corp. (architect-engineer), and four advisory utilities, Boston Edison Co., Jacksonville (Florida) Electric Authority, New England Electric System, and New England Gas and Electric Association. Westinghouse heads the second team, with Combustion Engineering, Inc.; Gilbert Associates, Inc.; Minnesota Power & Light Co.; Pennsylvania Power & Light Co.; Philadelphia Electric Co.; and Texas Utilities Co.

Eight project advisers from the utility industry have been drawn together as well: Joseph Davis of Duke Power Co.; Jack Fagar of Middle South Services, Inc.; John Holmes of TVA; Lee Hermansen of Commonwealth Edison Co.; Mansour Mansour of Southern California Edison Co.; John Rich of Arizona's Salt River Project; Walter Rogers of Florida Power & Light Co.; and Robert Stanley of The Detroit Edison Co.

What kinds of things interest these contributors? Flatly, the entire plant, from the number and capacity of coal pulverizers straight through to flue gas temperatures and low-pressure turbine annulus dimensions. All were discussed and questioned last August when the advisers first heard from the General Electric and Westinghouse teams. That occasion was built on what the contractors see as today's state of the art (and state of the market) for an optimized plant, that is, the departure point from which each improvement is being assessed for its effect on heat rate, availability, capital cost, O&M cost, and operability.

That detailed analytic assessment is now going on; and advances that call for new technology developments will be flagged with individual estimates of critical R&D cost, time, and probability of success. During the coming year the two competing teams will report their recommended new design steps and parameters, ranked (probably in groups) to yield a series of progressively more efficient overall plant designs. On the basis of their respective cost and availability estimates and of R&D needed, EPRI and its advisers will select the advances to be carried forward, both in a conceptual plant design (by one of the contractor teams) and in associated R&D.

Looking to a new goal

The earliest results will be guidelines (available in 1980) for utilities to use in assessing the design and operating criteria that govern their present coal-fired plants. Beyond this, methodical is the mode for the conduct of this new research project. Considering the cost and also the potential value of each R&D and design task likely to flow from it, it shouldn't be otherwise. It's good to think of the EPRI adviser for whom "a heat rate of 8000 and not running" is a legitimate concern. During his professional lifetime he may well find himself looking at "8000 and running at 90%." ■

Most Efficient Steam–Electric Generating Station in the United States

For nine straight years, from 1966 through 1974, Duke Power's coal-fired Marshall station led the company's and the Edison Electric Institute's statistics for annual heat rate. Harold Erskine, the station manager, had the plaque to prove it well displayed where his employees, not to mention passing visitors, could take it in.

But in 1975 Jim Leathers, the manager of Duke's new Belews Creek station, took dead aim on Erskine's record. Decals began to show up among Belews Creek employees: "We're gonna be Number One."

The coincidence, if that's any part of it, of how closely the Marshall and Belews Creek stations performed was too much to pass up. Others might scoff at their record keeping ("After all, the coal scales aren't any more accurate than a half-percent, so what's the point in tracking heat rate down to a tenth?") but Erskine and Leathers knew better.

Each of them good-naturedly claimed the underdog role, of course, and at the same time predicted victory for his own station. But how do you assign and weight advantages when one station dates from 1965, the other from 1974; when one station has two reheats, the other has one; when one has two 380-MW and two 630-MW units, the other has a pair of 1140-MW units? Erskine admits there couldn't be any handicapping.

"We just went after each other like Pittsburgh and Montreal did this year."

But when Leathers isn't listening, Erskine soberly insists that Marshall was at a disadvantage. "Belews Creek burned cheaper coal, so they got dispatched for more duty at their most efficient loading."

Leathers has sharp ears, and he retorts, "All that got wiped out when we had one generator outage at Belews Creek. Erskine picked up our load at Marshall and had the benefit of it all the time we were down!"

Not to be outdone, Erskine points out that Leathers has more pulverizer capacity and more consistent coal quality at Belews Creek, a nice plus for heat rate on the front end. Leathers counters that Erskine has lower-temperature cooling water at Marshall, a big bonus for heat rate on the back end.

But what happened? It was a close race, and EEI Prime Movers Committee data for that first year show TVA's Bull Run plant was the spoiler, posting a 1975 heat rate of 8850 Btu/kWh to beat out both Duke stations. Belews Creek did beat Marshall, 8941 to 8962, but this wasn't enough for Jim Leathers.

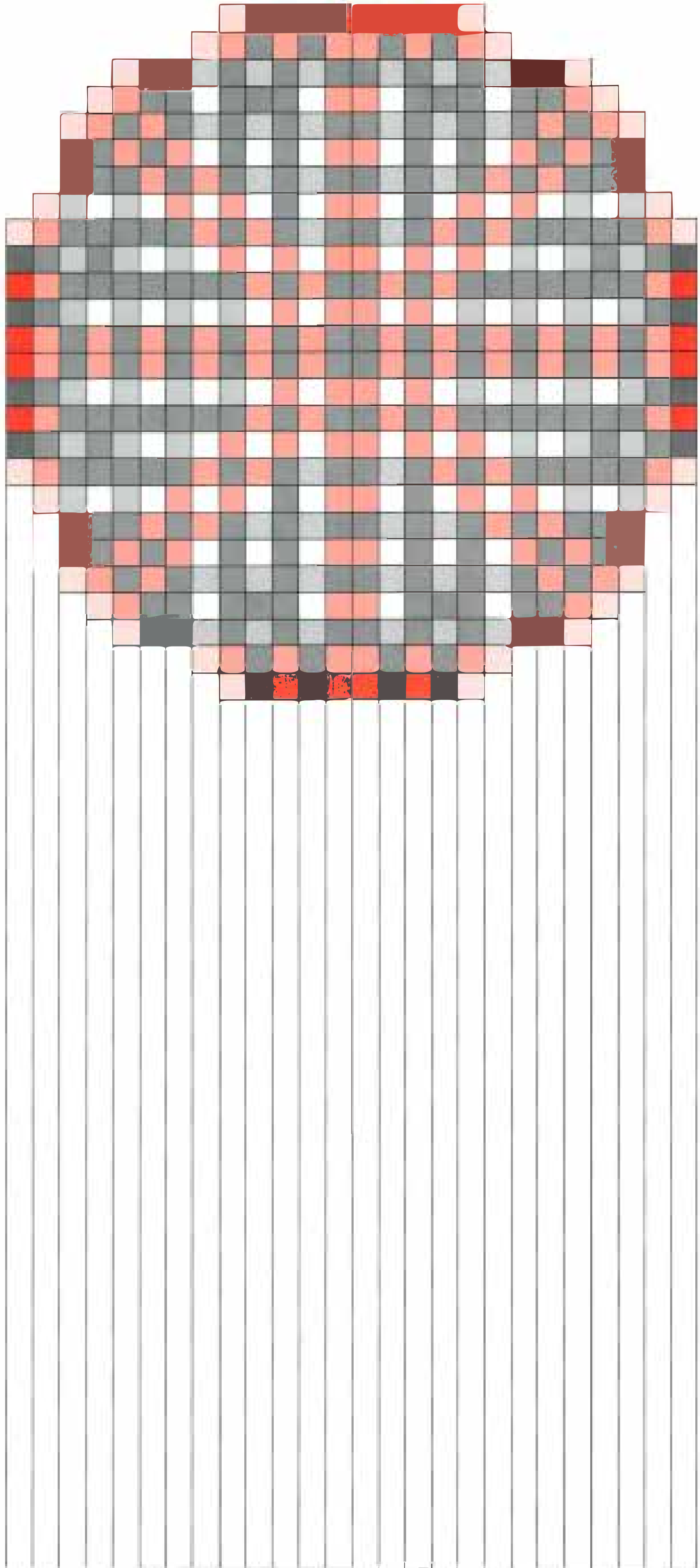
In 1976 he got his first gold medal at Belews Creek, recording an 8890 heat rate to better both Bull Run (a close second at only 8900) and Marshall (at 9024). Belews Creek repeated in 1977, achieving a still lower 8852 Btu/kWh against Marshall's 9074.

The tight competition has continued, the two Duke station managers keeping their cards against their vests right up to year-end. Last December Joe Davis, Duke's manager of system results, tried to pry loose the nearly complete data. His son, an engineering student, was working part-time at the Marshall station. Surely Davis could get figures from him, just as a matter of family loyalty. No way!

When 1978 was over, Bull Run had done it again, recording 8810 for the year. But Harold Erskine's Marshall station had regained its top spot in the Duke system with an even 9000, only 20 Btu/kWh ahead of Jim Leathers' 9020 at Belews Creek.

And how about 1979? We don't know. Nobody will tell us anything.

PSMS: Simulating the Core



When a BWR power plant is being brought up to operating power, an important choice must be made. If power is increased too quickly, some parts of the core will heat faster than desired, and the lifetime of some fuel elements will be shortened. If power is increased at a very low rate, the cost of power not generated is substantial.

This situation presents an economic trade-off in which the manufacturer of the fuel and the utility have different points of view and somewhat different objectives. The manufacturer desires his fuel to have maximum life and recommends a conservatively low rate of power increase. The utility is, of course, also interested in the economic benefits of protracting fuel element life but is keenly aware of the expense of unnecessary operational conservatism.

The problem of bringing a BWR to full power has further complications. In general, power is increased by the gradual withdrawal of control rods. But there are many control rods and a given withdrawal sequence does not necessarily lead to uniform heating. The conventional method for startup is to withdraw rods in a sequence and at rates that have been determined by experience to maintain temperature in all parts of the core adequately within bounds. This method

How will the core respond to a given rate and sequence of control rod withdrawal? Questions such as this are being posed to a prototype computer system with predictive capabilities.

is slow and expensive, and fuel elements can be damaged if hot spots develop during startup, even though the average rate of increase is entirely reasonable.

To assist in making a rational choice of the appropriate rate of power increase, a new computer tool has been developed—the power shape monitoring system (PSMS). In using the system, one asks the computer what the power profile within the reactor would become if the control rods are withdrawn in a specified manner. The computer makes the necessary computations and displays the predicted power profile on a color TV screen and as a curve on paper.

If the power profile indicates that hot spots are not expected, the control rods can be safely withdrawn in the manner specified. On the other hand, if the profile shows a hot spot, then the proposed schedule of control rod withdrawal is revised and the computer is asked for a new prediction. Or if more detail on any part of the profile is desired, the system will provide it on request. The computer requires about 5 minutes to understand a question, search its memory for relevant stored facts, perform thousands of calculations, and display its prediction. Even though multiple predictions may be required in the regime of coming up to full power safely, which may take 30 or 40 hours (and sometimes longer), this 5-minute turnaround per prediction is a satisfactorily short time.

Stored in the computer's memory are myriad details about the configuration of a particular core: where each bundle of fuel rods is placed, how it is cooled, where all the control rods are located, and so on. The computer's predictions are more precise if it has stored the duty-cycle history of every fuel element—for example, how much heat it has delivered over what time intervals and what its power history has been.

In addition to the primary function just described, the system can assist in the operation and management of a nuclear plant in other ways. If a postulated regime of future plant operation is proposed, for example, it will predict the burnup profile, the number of fuel elements that can be expected to fail, the locations of the elements in danger, and the time of expected failure. Thus the trade-off between load regime and the planned shutdown for refueling can be optimized.

In addition to its capability to predict future events, the system is able to display current and past performance of the reactor. The system receives information from the plant's process computer every 6 seconds. This information is not only permanently stored but is also analyzed and digested. Thus, on demand it can display parameters, such as core thermal power, feedwater flow, and reactor pressure. The capability to display this kind of information at 6-second intervals is invaluable in tracing the course of events after any malfunction of the plant.

The need for this kind of assistance in the technical management of nuclear power plants has become apparent, as have the economic benefits. The cost of replacement power for a shutdown reactor amounts to roughly $300,000 a day, which closely approximates the cost of an installed PSMS system.

The software of the system was jointly developed by Scandpower Inc., Nuclear Associates International, Inc., and Nuclear Services Corp. Important contributions in other areas were made by Exxon Nuclear Co., Inc., Babcock & Wilcox Co., and Prime Computers Inc. The first installation is now being tested at the Oyster Creek BWR near Toms River, New Jersey, with the cooperation of Jersey Central Power & Light Co. and General Public Utilities Corp. Presently, the system is available only as an aid to the plant engineering staff. It has not been reviewed by NRC and is therefore not qualified to be directly involved in day-to-day plant operation. ■

SOLAR SURVEY 1979

Arizona Public Service Co.

Solar Water Heating

Long Island Lighting Co.

Kansas Power and Light Co.

Rate Structure Study

Basin Electric Power Cooperative

Heat Pump Monitoring

Insolation Data Collection

Southern California Edison

Solar Space Heating

Commonwealth Edison Co.

Wind Resource Assessment

Otter Tail Power Co.

Solar Collector Comparison

El Paso Electric Co.

Portland General Electric Co.

Demonstration House

Load Management Demonstration

Materials and Component Testing

10-MW Solar-Thermal

Bonneville Power Administration

Platte River Power Authority

Residential Monitoring

Northeast Utilities Service Co.

Alabama Power Co.

Lincoln Electric System

Commercial Heat Pump

Nevada Power Co.

Site Feasibility Study

Hawaiian Electric Co., Inc.

PV Concentrator

Solar Hybrid Repowering

Methane Production

Pacific Gas and Electric Co.

Waste-Wood Generator

Utilities: A Growing Solar Program

Solar energy activities by America's electric utilities have expanded in the past year, according to EPRI's latest survey. More than 180 electric utilities are currently engaged in solar energy research, spending an estimated $19 million on solar projects. The 1979 data show a 25% increase over last year in the number of projects reported, from 600 to almost 750. The survey includes both independent utility projects and EPRI-sponsored projects.

Leading growth areas noted in the current report are solar-thermal electric power, wind energy conversion, and biomass conversion. In all three categories the number of utility-sponsored solar projects has more than doubled over a two-year period. The bulk of solar energy activity (68%) still remains in the area of solar heating and cooling (SHAC) of buildings.

The complete survey, containing summaries of industry trends and brief project descriptions, will be available from EPRI early in 1980.

Solar heating and cooling

Eighty-five percent of the utilities covered in this year's survey reported participation in one or more solar heating and cooling projects. Four-fifths of these involved demonstration or monitoring of SHAC systems, evaluating the feasibility of various solar systems, and assessing their potential impact on the utility industry. Strong interest in passive systems was the most dramatic trend among the SHAC projects; there was an increase from 15 projects in 1978 to 49 this year. Domestic hot water heating, active space heating or cooling, and swimming pool heating all registered moderate growth.

SHAC systems for buildings remain much closer to marketability than other applications of solar energy. About 10% of the 507 SHAC projects in the 1979 study had progressed to at least partial commercial integration, including special rate schedules, marketing of SHAC systems, and leasing arrangements. Of the non-SHAC projects, 58% were in the stages of initial assessment, design studies, or hardware development, with a smaller portion (42%) classified as project demonstration and monitoring.

Eight of the SHAC projects identified in the survey are being sponsored or cosponsored by EPRI. In one such project with Pacific Gas and Electric Co. (PG&E), researchers are monitoring the performance of a passive SHAC system in a Stockton, California, home. Some 76 sensors are being used to collect data that will be compared with a computer prediction of system performance.

Solar-thermal electric power

Continuing DOE interest in the area of solar-thermal electric power has helped spark utility interest. Among the best-known of these is the 10-MW (e) solar-thermal pilot plant to be located near Barstow, California. Utilities have also actively participated in a number of comprehensive studies of the integration of solar-electric generating equipment into utility power networks.

Results of DOE-, EPRI-, and SERI-funded studies have focused interest on the hybrid approach of partially repowering existing oil- and gas-fired plants. Originating in the 1974 initiative by the Public Service Co. of New Mexico, the hybrid repowering concept has drawn support from a large group of utilities located in the South and Southwest. Its goal is a flexible and reliable system in which variable use of fossil fuels can supplement solar output to help meet customers' demand for electricity.

Wind energy conversion

Like solar-thermal, wind energy has benefited from strong DOE interest. As newer DOE-funded wind turbine designs are developed and become available in the next two or three years, further expansion is likely. At present, many utilities are making preliminary studies of wind potential in their service areas, ranging from measurement of wind velocity and reliability to the monitoring of privately owned wind conversion systems. One utility, Southern California Edison Co. (SCE), has initiated a large turbine generator field test program. Construction is under way in the San Gorgonio Pass near Palm Springs, and by the end of 1980 the 40-mph winds that funnel through the pass will be harnessed by a 3-MW wind turbine generator. The $3 million project has experienced some delays, due, in part, to a takeover of the original wind turbine supplier by Bendix Corp. SCE expects the San Gorgonio wind turbine generator to demonstrate the technical and economic feasibility of wind energy conversion as a step toward more widespread use of similar installations within the SCE service area.

Photovoltaics, biomass, and other approaches

Much of the utility interest in photovoltaics arises from participation in DOE's 1977–78 photovoltaic field test design program, in which 15 of 29 design projects involved utilities. Utilities are substantially involved in several of the 9 projects recently selected for construction, generally in tandem with a major technology firm. At the Sky Harbor Airport in metropolitan Phoenix, Arizona Public Service Co. is collaborating with Motorola Corp. in a passively cooled solar concentration array that will develop 250 kW, linked directly with the APS power grid.

Biomass conversion projects more than doubled this year as a number of utilities undertook feasibility studies or launched demonstration projects. Most were individually tailored to fit the availability of waste biomass from lumber operations and farming. Solar radiation and weather data essential to other solar energy projects continued to be collected in utility-funded projects. Thirteen utilities

ELECTRIC UTILITY SOLAR ENERGY ACTIVITIES

Category	Number of Projects			Percent Increase	Percent of Total Projects			Utilities Participating*		
	1977	1978	1979	1978–1979	1977	1978	1979	1977	1978	1979
Solar heating and cooling	338	420	507	21	74	70	68	124	142	154
Solar-thermal electric power	28	42	60	42	6	7	8	18	26	33
Wind energy conversion	34	56	83	48	7	9	11	25	40	51
Solar data collection	22	21	22	5	5	4	3	22	21	22
Photovoltaics	12	30	33	10	3	5	4	10	23	26
Biomass conversion	3	10	21	110	—	1	3	2	7	19
Other†	21	21	23	10	5	4	3	16	15	20
Totals	458	600	749							

*Some utilities participated in more than one category.
†In 1979 other activities included 11 process heat projects, 5 ocean-thermal energy conversion projects, and 7 public information projects.

in the WEST Associates Solar Resource Evaluation Project have established a network of over 50 solar monitoring stations in the southwestern United States. Process heat for food and crop drying, public information projects, and several ocean-thermal energy conversion studies make up the balance (3%) of projects reported in the 1979 solar survey.

Utilities' role in solar R&D

The solar energy activities of electric utilities fill a crucial role in the overall pattern of solar R&D. Many levels of activity, including data collection, feasibility studies, design studies, hardware development, cost analysis, and prototype installation and monitoring, exist between a promising theoretical concept and successful commercial application. Many of these stages cannot be done entirely in centralized research facilities. They frequently must be done in the field, under conditions reasonably close to those that would be faced in larger-scale commercial applications.

"A major contribution of the utilities' approach," notes EPRI solar survey project manager Gary Purcell, "is to consider not only the displacement of energy [the DOE approach] but also the total cost of energy to consumers. That means including the cost of backup energy as well as the cost of solar equipment and installation." The utilities have to deal with the nuts-and-bolts problems, from multi-MW power generation to individual homeowners with private solar installations, and there are technical, economic, and institutional choices to be faced at every level. For many of these choices, utility solar hardware projects are the only source of data.

Benefits of the EPRI survey

"With their diversity of approaches, electric utilities can provide a different perspective on the solar energy field," notes Purcell, "and there is value in documenting this information in one volume. That's where our survey fits in." The solar survey is designed to facilitate the transfer of information in a variety of ways. For those working in the solar energy field, it is an up-to-date directory of what is happening, where it is being done, and how to locate key people or crucial data. For utilities initiating solar activities, it provides a public record and a vehicle for commercial and technical interchange with other interested parties.

The organization of the survey data into a convenient package has other benefits, including the cross-fertilization of ideas and the catalytic effects of seeing alternative approaches to old problems. Duplication of effort is also reduced; utilities can pool data from related but different solar projects.

At EPRI, the survey assists solar energy project managers in developing programs that are cost-effective and genuinely responsive to utility needs. It finds similar use at DOE and among other sponsors of solar research. In the larger area of public policy discussions, the survey provides authoritative information on the extent of electric utility participation and commitment in the solar field.

Because the electric utilities may be a significant market for solar systems (e.g., solar-thermal), the survey shows that they are interested in committing technical and financial resources to help in the development of various technologies. ■

CEQ: Environmental Adviser to the President

In its 10-year history, the Council on Environmental Quality has left its mark on environmental legislation and continues to identify and coordinate new policies for the president.

Council members and staff (from left): Paul Portney, James MacKenzie, Jane Yarn, Gus Speth, and Malcolm Baldwin.

The enactment of the National Environmental Policy Act (NEPA) 10 years ago next month ushered the United States into a decade of intense environmental activity on both legislative and administrative fronts. Following NEPA came the Clean Air Act Amendments, the Clean Water Act, the Toxic Substances Control Act, the Resource Conservation and Recovery Act, and a host of others. The Environmental Protection Agency (EPA) was formed, and strong environmental units grew up in other federal agencies.

In addition to establishing a national environmental policy and mandating environmental impact statements (EISs) from federal agencies, NEPA is responsible for creating a small advisory organization in the executive office of the president.

Like NEPA, the Council on Environmental Quality (CEQ) is 10 years old in January. It holds the distinction of being "the first organizational response to the political and environmental interest of the late 1960s and early 1970s and the first broad-based environmental agency in the federal government," comments Steven Jellinek, a past staff director for CEQ and now assistant administrator for toxic substances at EPA. CEQ predates EPA, which was formed by executive order in December 1970. Although such federal environmental organizations as the Fish & Wildlife Service and the Federal Water Pollution Control Administration existed before CEQ, they were focused on special problems, whereas CEQ was directed to survey the entire environmental field.

In its 10-year history the advisory body has taken a leading role in such issues as land use, toxic chemicals, water policy, solar energy, conservation, nuclear waste, and most recently, acid rain. The council is responsible for publishing an annual report for the president on the quality of the environment and for developing initiatives for the president's environmental programs. It conducts studies on environmental issues, and its members and staff sit on interagency committees and task forces that develop broad-ranging federal environmental policies.

Small but Influential

CEQ is by no means a large organization. There are three full-time members appointed by the president and confirmed by the Senate. The president decides who will serve as chairman. Current chairman is Gus Speth, a member of the council since 1977 and formerly a staff attorney with the Natural Resources Defense Council. Past chairmen have included such environmental giants as Russell Train, later EPA administrator and now president of the World Wildlife Fund; Russell Peterson, head of the National Audubon Society; and Charles Warren, former member of the California General Assembly who came to the council at the beginning of the Carter administration and resigned last summer.

The two other current council members are Jane Yarn, a farm owner and manager who has served on many national and state environmental advisory boards, and Robert H. Harris, a scientist formerly with the Environmental Defense Fund.

Backing up the council members is a permanent staff of about 32 environmental specialists, lawyers, economists, administrative personnel, and clerical workers. CEQ's budget has remained at about $3 million for several years, and its only regulatory authority is to oversee the NEPA process.

What CEQ lacks in staff size, budget strength, and regulatory authority, however, it makes up for in terms of its strategic location and role as adviser to the president, its ability to cut across agency lines and coordinate environmental activity in the executive branch, and its role as a pioneer in exploring uncharted environmental policy for the president and in focusing on new issues and problems. At various times throughout its 10-year history, one or another of these roles has been dominant in terms of CEQ's influence and mark on the federal environmental scene.

Evolving Role

In the federal lineup, CEQ is located within the executive office of the president, together with such other advisory bodies as the National Security Council, the Council of Economic Advisors, and the Office of Management and Budget. This location places CEQ in a strategic position for access to the president, although the reality of that situation depends on the president himself, his interest in environmental issues, and competition for White House attention.

In the early part of the Nixon administration, recalls Steven Jellinek, whose tenure with CEQ spanned the years from 1970 to 1977, the council functioned "truly as advisers to the president and as leaders in developing the president's environmental policy." Nixon issued four environmental messages (a tradition that was dropped after 1973 and not revived until the Carter administration), and CEQ had a major role in formulating the initiatives in the messages.

Jellinek says that in the early years it was the administration that really set the environmental agenda for the country. He recalls that President Nixon would send environmental proposals to Congress and key legislators would "take them a notch or two further toward environmental protection" by either "tightening the grip or adding teeth." The impetus came from the Nixon administration, however. Out of that era came the Toxic Substances Control Act, the Noise Control Act, the Coastal Zone Management Act, the Ocean Dumping Act, and a host of others.

"That was the springtime of the environmental movement in the country," said Speth in a recent interview, "and a lot of proposals that subsequently became law grew out of initiatives that started here at CEQ."

After about 1973, however, interest in environmental issues waned within the Nixon White House, Jellinek recalls. From then until the beginning of the Carter administration, CEQ shifted away from its role of advising the president and formulating policy internally and turned outward to activities involving the executive branch agencies, Congress, and the environmental public.

During that time the council concentrated on "solidifying the reach of NEPA within the executive branch," says Jellinek, and on strengthening its role of focusing federal attention on new environmental issues. Many of these activities continue today.

Malcolm Baldwin, CEQ's senior staffer for land use and wildlife, was involved with the council's early efforts to oversee NEPA and make sure that it "was taken seriously by the agencies." Although he admits that some of the agencies saw NEPA as an obstruction in the beginning, he believes that NEPA has now proved its worth and the agencies have come "a considerable distance in accepting it, working with it, and using it to their own advantage."

In recent years, one of CEQ's major efforts—and one pointed to with pride by council staff and members—has been the formulation and issuance of regulations to streamline the NEPA process, reduce red tape, limit the size of the EISs, and generally to expedite the process. "I like to think of [NEPA] as a ship that had picked up some barnacles, and we tried to take those barnacles off," commented Speth. He is joined by current and past

CEQ staff members in pointing to the regulations as one of the major accomplishments of the council during the past 10 years.

"They have been applauded by both industry and citizen groups," says Douglas Buffington, senior staff member for environmental data and monitoring, "and have been declared models of what good government regulations should look like."

The other role adopted by the council during the interim years is what Speth characterizes a pioneering function, exploring new environmental territory, focusing on new issues, and getting things started. "It is in this area where environmental problems were spotted, identified, sized up, and appropriate legislative and administrative actions were formulated that I believe the council has had its biggest effect," he says.

Take, for example, the problem of toxic substances. "That's an area where there was not much going on in the government a few years ago and the real focal point was here at CEQ," says Speth. The council helped to get various interagency groups to examine the issue and aided in formulating the proposal that later became the Toxic Substances Control Act. Although CEQ remains involved in the toxic chemicals issue today (Speth chairs the president's Toxic Substances Strategy Committee), the major responsibilities for the issue were spun off to other agencies.

Similarly, CEQ identified the problem of off-road vehicles on public lands, and it was cited in the president's environmental message in 1977. The result was an executive order directing the Bureau of Land Management to take steps to control the problem.

CEQ staff members, past and present, list a number of other issues for which CEQ has served a pioneering or a focusing role—energy conservation and solar, the environmental effects of energy development, and land use. "Clearly, in terms of the executive branch focus, the council was first on many of these issues," remarks Jellinek.

Coordinator and Intermediary

Concurrent with its pioneering role is a coordinating function on many environmental issues. Paul Portney, CEQ's senior staffer for economics and pollution control, describes this as "the advantage of being able to reach out to each of the agencies and coordinate their positions on issues that go across agency lines." He believes it is helpful to have some arm in the executive office of the president to keep tabs and, where possible, to get agencies to act in a coordinated fashion. Malcolm Baldwin, too, believes that this is an important function, although he says that it is "thankless, invisible, and difficult."

An example of CEQ's coordinating role is found in the new 10-year acid rain assessment program announced by President Carter in his August 2 environmental message. To begin with, CEQ developed the message and the acid rain initiative. Although the interagency committee that will direct the study will be cochaired by EPA and the Department of Agriculture, CEQ will serve as executive secretary, putting together the research plan due January 1, 1980, preparing documents, calling meetings, making sure that agencies reprogram the $10 million in funds for the first year of the effort, and, basically, coordinating the effort. That work falls in Portney's economics and pollution control unit. He believes the January 1 deadline can be met, although "it will be tight ball," and he expects the first year of the program will be devoted to cataloging existing research in the government, private, and nonprofit sectors, as well as initiating and coordinating new research. Both Portney and Speth also expect that CEQ will interact closely with EPRI on this program.

Another role that CEQ plays is that of an intermediary between the White House and the environmentally concerned public.

"We are a major pipeline between the environmental community and the White House," says James MacKenzie, senior staffer for energy and resource recovery. "We assist in arranging meetings at the White House and inform the president about environmentalists' concerns and views."

Speth admits that a certain tension exists between this advocacy role and the broker or arbiter role that CEQ serves in coordinating environmental policy and studies within the executive branch. He adds that the council plays different roles with different issues and this confuses people sometimes.

The various roles that CEQ played during the time it focused outward—pioneer, coordinator, advocate—continue in an even stronger form today. Moreover, with the advent of the Carter administration, the council again turned inward to the White House, and it revived and expanded its function as adviser to the president.

"Here was a president who honestly and sincerely wanted environmental advice from the council," says Jellinek, "and for the first time, included the council in the formal White House decision-making process." The council chairman started attending cabinet meetings, and Jellinek comments, "What was even more important, the council was included on the sign-off list for major policy issues in the presidential decision process."

Speth refers to a continuing dialogue these days between the White House and the council. "We're constantly in touch with the president and his senior White House staff members." Speth himself meets regularly with the president and attends weekly White House staff meetings. CEQ also sends weekly memos to the president on a variety of environmental issues, and the staff knows he reads them because they are often returned with comments written in the margins.

"We certainly let the president know what we think," says MacKenzie. "We don't always prevail, but we're there and he hears."

Future Priorities

What are the issues that CEQ hopes to focus on in the future? Speth outlined a number of priorities: preserving agricultural land; better management of coastal zones; working toward a sustainable energy future based on the president's goal of 20% solar by the year 2000; addressing global environmental impacts that include the loss of tropical forests, the depletion of biological resources, and the CO_2 and acid rain issues; and making sure that the environmental concerns regarding nuclear power get a full airing inside the administration.

On the nuclear issue, CEQ played a major role in the Interagency Review Group (IRG) on nuclear waste management, and Speth hopes that a presidential message based on the IRG report will be forthcoming shortly. He feels that the future of nuclear energy in this country is "bounded on both the low and the high side." By that he means that the country won't need any more nuclear plants in this century other than those that are already on-line or under construction. But the country will need all these plants, he comments, "because it would be very hard to replace that amount of nuclear, even if we achieve our goals for renewable energy resources and conservation."

Speth and his staff members see a bright future for both renewables and conservation, however. Through MacKenzie's energy unit, CEQ published the 1978 report issued before Sun Day that said renewable resources could provide some 25% of energy demand by the year 2000. Subsequently, the council became heavily involved in the domestic policy review of solar energy. Earlier this year the council published a report called "The Good News About Energy." That report concluded that the United States can maintain a healthy economy without massive increases in energy. With a moderate effort to increase energy productivity (getting more with the energy we use), the report said that energy consumption in the year 2000 need not exceed current use by more than 25%, and possibly 10–15%.

Both Speth and MacKenzie see utilities closely involved with a renewable energy future. "We're not going to get the kind of progress we want in renewable energy and conservation if utilities are shut off," Speth says. MacKenzie sees "utilities generalizing the concept of what they're about, from the delivery of electricity to the delivery of services." He feels that utilities may become involved in installing and leasing solar equipment, for example, as the telephone company installs and leases telephones. And he believes that utilities should make a profit on this and develop creative approaches that would aid in utility load management. For example, utilities could install solar hot water heaters that would not go on at peak times. MacKenzie's unit has sponsored a number of conservation studies conducted by outside concerns.

Speth and his staff are also interested in the economic aspects of environmental policy and continually stress the theme that "good environmental policy makes good economic sense."

Economist Portney says he has been concerned about what he sees as "people's perception of economics as being inherently inimical to environmental interests." He wants to use economics to further environmental protection as opposed to environmental protection inhibiting the economic strength of the country. He is interested in studying how economic incentives might be used to further environmental policy. "I believe that while we've set out high but generally defensible goals for ourselves in this country, sometimes we've chosen to attain these goals through a regulatory process that may sometimes make it more expensive than if we were to use economic incentives." Both on the council and with interagency groups, Portney tries to make the point that while the goals should be maintained, "we should try to find less expensive ways of meeting them."

Upcoming Reports

In the near future CEQ expects to issue "Global 2000," an attempt to look comprehensively at the question of global environmental impacts, including discussion of GNP, population, fisheries, forest resources, energy, and other elements. The work has involved many other agencies in government, Speth commented, and will produce many interesting findings.

A report may also be expected in the near future on the work of an interagency task force to examine environmental data and monitoring efforts of the government and recommend ways to improve them. Sometime in 1981 the results of the major agricultural land use study that CEQ is conducting with the Department of Agriculture should be released.

As an early actor on the federal environmental scene and one that continues to play a pioneering, coordinating, and advisory role today, CEQ can be expected to continue leaving its mark on environmental policy in the United States. ■

INPO Board Selected

William Lee elected as chairman of 11-member board.
Briefings around the country on TMI response.
Film reveals TMI exposure.

Eleven utility executives representing all sectors of the industry were named to the first Board of Directors of the Institute for Nuclear Power Operations (INPO), and an executive committee was chosen. Articles of incorporation and bylaws were approved in principle, and machinery was set in motion to incorporate the new institute. A committee was assigned to search for a president who will be INPO's chief executive officer. And the search for a site for the new institute continues.

These were among the actions taken at a joint meeting on October 4 in Washington, D.C., of the newly selected directors and of the INPO Steering Committee, the latter group serving in effect as the predecessor of the board. The participants at the October 4 meeting expressed their indebtedness to Chauncey Starr, vice chairman of EPRI, who carried out the studies on the prospective form, structure, and scope of the new organization.

William Lee, president of Duke Power Co., was elected first chairman of the board. Other members of INPO's board, who formally become directors on completion of the incorporation process, are Carl Andognini, Boston Edison Co.; William Gould, Southern California Edison Co.; Don Jordan, Houston Lighting and Power Co.; Frank Linder, Dairyland Power Cooperative; James O'Connor, Commonwealth Edison Co.; Jack Pfister, Salt River Project; Glenn Reed, Wisconsin Electric Co.; John Selby, Consumers Power Co.; Lelan Sillin, Northeast Utilities; and William Walbridge, Sacramento Municipal Utility District.

Lee, Pfister, and Selby were elected to the Executive Committee, and the search for INPO's president was assigned to this committee.

Funding for 1979 stands at $200,000, plus $40,000 for contingencies, and machinery has been set in motion to obtain access to additional industry funds. A budget for 1980 is being drafted.

The planned organization of INPO provides for an industry advisory structure similar to EPRI's Research Advisory Committee, division committees, and task forces to give technical guidance. An interim advisory structure for INPO will consist of the INPO Steering Committee and the Atomic Industrial Forum's Ad Hoc Policy Committee on TMI, with its subcommittees. ■

TMI Briefings

Utility leaders in 13 cities throughout the nation, together with leaders of EPRI and NSAC, gave one-day briefings in October to government, community, and business leaders and the media on the industry's response to the Three Mile Island accident. They described progress in setting up a mutual insurance program by nuclear utilities, the Institute for Nuclear Power Operations (INPO), and the current activities of the Nuclear Safety Analysis Center (NSAC).

Briefings were held in New Orleans, Phoenix, Boston, Seattle, Dallas, Kansas City, Richmond, Norfolk, Cleveland, Hartford, and in Costa Mesa, San Bernardino, and Los Angeles, California.

EPRI staff members involved in the briefings included Robert Breen, deputy director, NSAC; William Layman, associate director, NSAC; Miles Leverett, consultant, NSAC; Michael Kolar, technical specialist, Nuclear Power Division; Joseph Prestele, executive assistant to the vice president for power supply, Consolidated Edison Co. of New York. ■

TMI Population Exposure

As part of its surveillance of the radiation exposures experienced by the populations around the Three Mile Island plant, EPRI's Environmental Assessment Department has collected the various estimates made by different investigators. A new source of impartial data to help determine the actual exposure has been developed.

The new data come from an unlikely source—photographic film. The Bureau of Radiological Health, U.S. Public Health Service, has collected six rolls of unexposed photographic film from five pharmacies or camera shops within 5 miles of the TMI plant. The film had been stocked on shelves at the time of the release and was of a type that is sufficiently sensitive to ionizing radiation to detect exposure (by fogging) from as little as 5 mrem.

The results of the bureau's study of the film confirmed the low dose estimates made earlier by the federal Ad Hoc Population Dose Assessment Group. That group, which included officials from EPA, HEW, and NRC, concluded that the average dose to a typical person living within 10 miles of the plant was 8 mrem, and the average dose for persons within 50 miles, 1.5 mrem.

Further, the group estimated that a hypothetical person who stood outdoors continuously from March 28 to April 7 at the location of highest off-site dose would have received a total cumulative body dose of less than 100 mrem.

In its study of the photographic film, the bureau compared control films from Rockville and Frederick, Maryland, with those obtained in the vicinity of Three Mile Island.

The results of these comparisons showed the average level of fogging of the Pennsylvania film to be slightly lower than that of the film from Maryland. Thus it would appear that if any radiation released during the TMI accident reached the location of the film stored near TMI, it was too little to be measured as there was no measurable fogging. Consequently—because the sensitivity threshold of the film is known—exposure was less than 5 mrem at those locations.

Furthermore, the exposure of the Pennsylvania film was sufficiently low as to exclude the possibility of personal exposures greater than 10 mrem at or near the sites where the film rolls were stored. A detailed report on these studies will appear in the *Health Physics Journal*. ■

First NDE Research Center

Plans for a new nondestructive evaluation (NDE) research facility, the first of its kind in the United States, were recently approved by the EPRI Board of Directors. To be located in University Research Park, Charlotte, North Carolina, the center will allow the electric utility industry to evaluate various NDE methods now being used to verify the structural integrity of power plant equipment and components.

The center will be operated by J. A. Jones Applied Research Co., a subsidiary of J. A. Jones Construction Co., under an EPRI contract. Initial startup costs are estimated at $1.7 million, and EPRI has budgeted $13 million for the center's operations over the next five years.

J. A. Jones Construction Co., headquartered in Charlotte, is one of the nation's largest construction firms. Jones's participation in major construction projects includes many years of experience in construction of hydroelectric, nuclear, and fossil-fueled power plants, as well as other large industrial, process, and commercial facilities.

Thomas A. Nemzek, a vice president and senior energy adviser with Jones, will manage the new facility for EPRI. Nemzek previously served as director of ERDA's Division of Reactor Research and Development. He said the center will have a staff of about 30 engineers, as well as "an equal number of [electric] utility employees-in-training and several experts-in-residence on loan from educational institutions, laboratories, and industry." He added that the work will be coordinated with the region's universities and schools to encourage interest "in this important and complex engineering field."

Gary Dau, manager of EPRI's Nondestructive Evaluation Program, said operation of the center will have "a direct bearing on improved safety in the industry. This project reflects the fact that the U.S. electric utilities have decided to take matters into their own hands when it comes to ensuring that adequate and qualified inspection technology is available."

Dau added that three distinct functions have been outlined for the new center. The first function, technology transfer, will concentrate on converting the results of research into equipment and procedures for field use in the shortest time possible.

The second function and an offshoot of the first, training, will concentrate on providing training courses for utility and commercial service company personnel to ensure that qualified people perform all required inspections. (All U.S. nuclear plants are required by federal law to undergo periodic inspection to assure complete structural integrity.)

The third function is to work with universities to promote their involvement in the technology to ensure a future supply of trained people.

Nemzek said the goal of the center will be to provide electric utilities a means of verifying the physical condition of power plants without damaging the materials being tested. To do this, various techniques, including radiography, ultrasonics, acoustic emissions, and optics, will be employed. ■

CALENDAR

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

JANUARY 1980

9–10
Municipal Solid Waste as a Utility Fuel
Ft. Lauderdale, Florida
Contact: Charles McGowin (415) 855-2445

15
Regional Review: Fossil Fuel Power Plants Department
Jacksonville, Florida
Contact: B. G. McKinney (615) 899-0072

16
Regional Review: Fossil Fuel Power Plants Department
New Orleans, Louisiana
Contact: B. G. McKinney (615) 899-0072

MARCH

9–13
Second International Symposium on Gaseous Dielectrics
Knoxville, Tennessee
Contact: Don Bouldin (615) 574-6200

OCTOBER

6–7
Third NO_x Control Technology Seminar
Denver, Colorado
Contact: Edward Cichanowicz
(415) 855-2374

Focusing on Particulates

Industry efforts to understand the health and environmental effects of airborne particulates and the implications for control technology and waste disposal/recycle were the central issues of a recent EPRI conference, "Focus on Particulates." Held in St. Louis in late October, the conference drew over 120 management personnel in utility engineering, operations, environment, and research.

It was the consensus that industry efforts to control total suspended particulates are well in hand. The issue is now focused on the fine-particulate fraction —submicrometer particles that are not captured as efficiently by electrostatic precipitators (ESPs) and those formed in the atmosphere from gaseous precursors. Concerns stem from possible effects on health, effects on visibility, and rainfall acidity.

Technologies on the horizon for enhancing the control of fine particles include the baghouse and several emerging concepts to improve the ESP. Baghouses are still an immature technology, and much remains to be learned about their design and operation. ESP advances under development, including the high-intensity ionizer, pulsing high-voltage power supplies, and wide electrode spacing, are proving to be effective in improving the collection efficiency of ESPs in the submicrometer range. Significantly, these developments will also lend themselves to retrofit applications.

On the first conference day, speakers dealt with puzzling chemistry, composition, and human health effects from fine particulates and then explored the technologies now being developed to collect them. The second day was geared to discussions on disposal of the enormous amounts of waste produced from coal-fired power plants. These wastes, some of which are potentially toxic if leached into groundwater or if mixed with surface water during floods or spills, are being closely regulated by the Resource Conservation and Recovery Act of 1978.

For conference proceedings, call David Ulrich, (415) 855-2418. ■

Successful Scrubber Tests

Successful tests of a new, more reliable and economical system for removing sulfur dioxide (SO_2) pollutants from the stack gases of coal-fired power plants were announced in late October by EPRI. The system was developed in Japan by Chiyoda Chemical Engineering & Construction, Ltd., and tested under EPRI sponsorship by Chiyoda and Radian Corp. at the coal-fired Scholz power station of Gulf Power Co.

Chiyoda's flue gas desulfurization (FGD) system is designed to overcome several problems that have long been apparent in conventional scrubbers and threaten to make them uneconomical in some locations when the requirements of the Resource Conservation and Recovery Act of 1978 are implemented.

In conventional scrubbers, water containing dissolved calcium from lime or limestone is sprayed through the smoke and gases coming from a power plant furnace. SO_2 is removed from the flue gas when it combines chemically with the calcium to form particles of calcium sulfite. A new problem then occurs, however, because the particles of calcium sulfite suspended in water form a particularly unmanageable sludge. The particles do not settle out, and when placed in a pond, contaminants may leach into the soil.

In addition, present scrubbers waste as much as 30% of the limestone they use, and they require a great deal of maintenance because a calcium scale encrusts the interior of pipes and nozzles in the system. This scale can cause scrubber shutdown, resulting in higher emissions of SO_2 or reduced power plant output.

In the Chiyoda FGD system, stack gases and air are bubbled through a vessel containing a slurry of water and limestone. Because of longer exposure to the dissolved calcium and the presence of oxygen from the introduced air, the final product is calcium sulfate, which is more easily managed than calcium sulfite. This product is not a sludge but a familiar and useful solid—gypsum. Calcium sulfate in the form of gypsum can be stacked, used for landfill, or pressed into wallboard.

During the eight-month test, the prototype system also proved more reliable and more economical than conventional methods. Over 98% of the limestone was utilized, only minimal scaling occurred, and the system operated more than 97% of the total time without shutdown for maintenance.

The tests showed that the new system is now ready for commercial demonstration, according to George Preston, EPRI program manager. He says that the new system for scrubbing stack gases could substantially help utilities meet the more stringent pollution abatement regulations now coming into effect.

Preston says that EPRI is now seeking a utility willing to share the costs of installing a full-scale commercial version of the Chiyoda FGD system. In addition to improving scrubber reliability, such an installation could save a utility more than 10% of the operating costs of conventional desulfurization methods. For a typical 50-MW electric power generation plant, the new process may save at least $3 million in operating costs. ■

French Visitors at EPRI

Visitors from France recently met with René Malès, director of Energy Analysis and Environment Division, to discuss the energy outlook in the United States. Of major interest were the questions on how new energy sources are perceived in the United States, what fuels will be most important in the next few decades, and the prospects for nuclear energy. For the French, the difference between their breeder policy and that of the United States is of particular interest. From left: Albert Costa de Beauregard, chief engineer in the Department of Mines; Georges Puravet, the Attaché Industriel from the Consulat Général in San Francisco; Malès; Jacqueline Beytout, an editor with *Journal les Eclos* (the equivalent of our *Wall Street Journal*); Jean Paul Pigasse, an adviser to the journal; and Isabelle Sala, interpreter.

Energy Specialists to Gather at ET7

More than 6000 people are expected to convene in Washington, D.C., March 24–26, 1980, for the 7th Annual Energy Technology Conference and Exposition (ET7). EPRI will again cosponsor the event with the American Gas Association, the Gas Research Institute, and the National Coal Association.

The forum, which will include 59 technical sessions and workshops, will open with a state-of-energy message by David Morrison, director of IIT Research Institute. The sessions will close with a series of speakers on world energy matters, including Abdelaziz Alwattari, assistant secretary general of the Organization of Arab Petroleum Exporting Countries and former minister of oil for Iraq.

Technical sessions will include industrial energy supply planning, energy storage, coal supply and demand, health and environment, public communication of technical information, central solar power, solar heating and cooling, nuclear safety, synfuels commercialization, flue gas cleanup, energy facility siting, energy systems planning, cogeneration, wind energy systems, electric/hybrid vehicles, conversion of oil burners to coal.

The concurrent ET7 Exposition will display energy hardware, services, and research (including state-of-the-art technical advances in power generation, power transmission, industrial energy management, and energy conservation in buildings).

ET7 is managed by Government Institutes, a private educational and publishing organization. The ET7 advance program, registration materials, and exhibitor information are available from Martin Heavner, Government Institutes, 4733 Bethesda Avenue, N.W., Washington, D.C. 20014, (301) 656-1090. ■

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS

Dwain Spencer, Director, Advanced Power Systems Division

Kurt Yeager, Director, Coal Combustion Systems Division

Fritz Kalhammer, Director, Energy Management and Utilization Division

CHEMICAL ENERGY CONVERSION

Chemical energy conversion (CEC) concepts are of interest because they might improve the efficiency, economics, or flexibility of future energy systems. The primary thrust of CEC research is to evaluate and explore the technoeconomic feasibility of chemical reaction systems (CRSs) as energy carriers.

CRSs use an energy source—heat, electricity, or perhaps solar energy—in an energy-charging (endothermic) step to convert a chemical system to a metastable, higher-energy state; the chemical can then be transported or stored (possibly for long distances or periods) without energy loss. At the desired location and time, the chemical energy is released in an energy-yielding (exothermic) step. The most familiar CRS is the production of hydrogen by the decomposition of water. This hydrogen is stored and/or transported and subsequently reconverted to water, releasing thermal energy (by combustion) and/or electric energy in a fuel cell. Other CRSs that have been proposed and studied are benzenecyclohexane, methane–carbon monoxide–hydrogen, sulfur trioxide–sulfur dioxide, and so on.

Technoeconomic studies completed during the past years suggest that hydrogen production by water electrolysis may have beneficial applications within the utility industry in the near term; thermochemical dissociation of water is less attractive because of the higher capital costs of equipment needed to handle the extremely corrosive chemicals and the lack of the required high-temperature heat source. The studies also imply that other known CRSs would not be attractive for utility application in the near-to-intermediate timeframe because for the known systems the basic advantages of ready energy storage and transport are offset by low efficiency and high cost. Consequently, the near-term focus of the CEC projects is to develop advanced water electrolysis technology for such utility applications as generator cooling and to expand the role and technology base of hydrogen through other small-scale but cost-effective uses.

The role of hydrogen

The emergence of hydrogen as a nonpolluting, storable, easily transportable fuel or chemical will hinge largely on the availability and cost of dwindling fossil fuels. Since the future cost of hydrogen is a critical factor, the quest for nonfossil hydrogen production processes has focused on advanced processes that promise higher efficiency and lower cost. A major emphasis of research in the United States and Europe has been on developing advanced thermochemical concepts for dissociating water into hydrogen through a series of chemical steps that permit use of thermal energy at temperatures well below those required for direct thermal decomposition of water. More recently, hybrid processes that use a combination of thermal and electric energy inputs have been identified as possibly more efficient than pure thermochemical processes. Specifically, the hybrid sulfur-cycle–water decomposition system being developed by Westinghouse Electric Corp. is currently a preferred concept. Under RP1086-2, Westinghouse compared this hybrid process with a conventional water electrolysis system. In both cases similar sulfuric acid electrolyzers were employed for the hydrogen production steps. The results (Table 1) indicated that the hybrid process had little cost advantage over water electrolysis despite its better (47% versus 41%) efficiency. Considering the very esoteric nature of the hybrid process and the optimistic assumptions made for the sulfur-cycle electrolyzer performance, this efficiency difference is not thought to be significant.

Table 1
EFFICIENCY AND COST COMPARISONS OF HYDROGEN PRODUCTION PROCESSES

Process	Overall Plant Efficiency* (%)	Production Costs** ($\$/10^6$ Btu H_2)
Westinghouse Electric Corp. Sulfuric Acid Electrolysis	41	7.80
Westinghouse Electric Corp. Hybrid Sulfur Cycle	47	7.30
General Electric Co. SPE Water Electrolysis	40	6.90
General Electric Co. SPE Hybrid Sulfur Cycle	42.5	7.60

*Plant efficiency is defined as the ratio of higher heating value of 380×10^6 standard ft^3/d hydrogen product to the thermal rating of the very-high-temperature nuclear reactor (1850°F; 1010°C), configured for a self-sufficient grass-roots production unit.

**Costs are based on $\$0.50/10^6$ Btu nuclear fuel cost (1976 dollars). Westinghouse data are from RP1086-2, and General Electric data are from RP1086-3.

It was suggested the hybrid cycle cost and efficiency might be further improved by using an advanced electrolyzer, such as the solid-polymer-electrolyte (SPE) water electrolyzer being developed by General Electric Co. Under RP1086-3, General Electric evaluated the cost and efficiency for producing hydrogen if conventional sulfuric acid electrolyzers were replaced by advanced SPE electrolyzers in both the hybrid and conventional systems. The only variations in the two designs related to the choice of materials of construction, which differed because of the use of sulfur dioxide to depolarize the anode in the hybrid cycle. Table 1 shows that even with the advanced electrolyzer as a component, the hybrid cycle does not offer significant advantages over conventional water electrolysis (within the accuracy of the cost estimates and performance assumptions). Even the most favorable hybrid process was only marginally more efficient and not necessarily less costly than a conventional electrochemical process. Coupled with the unavailability of the required high-temperature (nuclear reactor) heat source, the use of exotic materials, and the long-range speculative nature of the thermochemical reactions, these results suggest that the development of the advanced electrochemical process would offer the most feasible route to lower-cost hydrogen production and beneficial utility applications of hydrogen in the near-to-intermediate timeframe.

Strategy for hydrogen generation

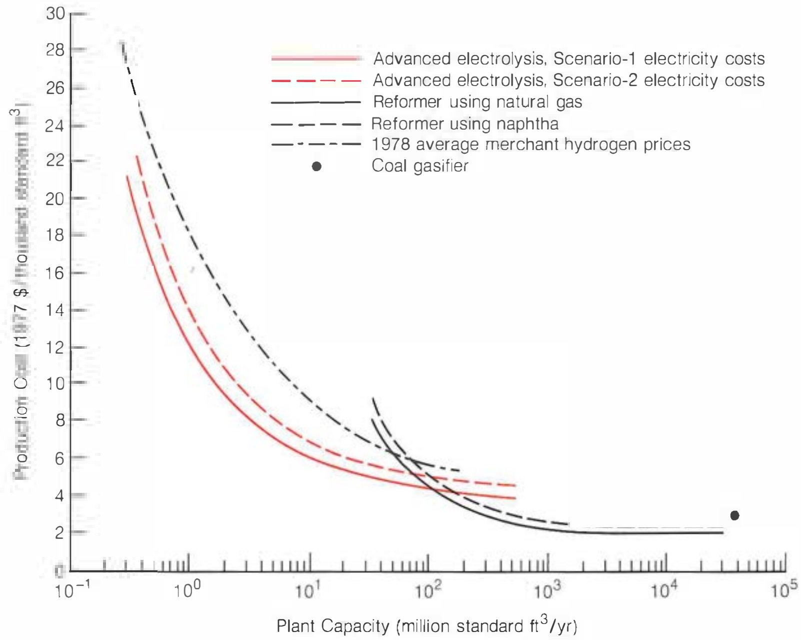
A project was initiated to determine the market potential for electrolytic hydrogen through the year 2000 and to identify near-term applications that could have operating and economic benefits for electric utilities (RP1086-4). Markets that currently use merchant hydrogen were analyzed to determine their potential for using electrolytic hydrogen. The cost of electrolytic hydrogen, compared in Figure 1 with costs of alternative sources of hydrogen, were projected for a more favorable Scenario 1 and a less favorable Scenario 2, as follows.

- Scenario 1: Electricity costs escalate less rapidly (by 0.8% per year in real terms) than fossil fuel costs.
- Scenario 2: Electricity costs escalate more rapidly (by 2.9% per year in real terms) than the cost of fossil fuels.

This market analysis concluded that for either scenario, electrolytic hydrogen could be economically attractive, in the 1980–2000 period, for small specialty users with demands of less than 100×10^6 standard ft^3 per year hydrogen. For large-volume users, such as the ammonia, petroleum refining, and petrochemical industries, the hydrogen produced by reforming fossil fuels (naphtha, natural gas, and coal) will likely remain more economic. The potential markets for electrolytic hydrogen were particularly attractive for those small uses (100×10^6 standard ft^3/yr hydrogen) now serviced through the industrial gas (merchant hydrogen) supply network by gas cylinders, tube trailers, or liquid tankers. For example, in a recent survey it was found that it may be attractive for utilities to produce electrolytic hydrogen on-site for electric generator cooling application. The one requirement for the commercial implementation of this application is the timely development of advanced electrolyzer technology in reliable, cost-effective packaged units that have capacities up to 100×10^6 standard ft^3/yr hydrogen.

The current CEC research strategy is to develop and demonstrate SPE and alkaline water electrolysis units for generator cooling applications. Other specialty uses of hydrogen, within power plants and for outside specialty applications, could serve as an evolutionary step toward the production and more general use of hydrogen as an energy carrier, closely linked to and complementing electric power and its role in our industrial society.

Figure 1 Comparison of different methods of making hydrogen shows that electrolytic hydrogen production is competitive for hydrogen consumption of less than 100 million standard ft^3/yr. At such low capacity levels, the conventional steam reforming plants that use fossil fuels are not cost-effective. The average merchant hydrogen prices, based on marginal price schedules quoted in the user survey, are higher than alternative methods of making hydrogen in quantities up to 100 million standard ft^3/yr.



Other CRS concepts

The concept of transporting and/or storing primary energy (from coal or nuclear sources) via reversible chemical reactions originated a decade ago in Germany; it is now being developed in a major program at the Kernforschungsanlage Jülich. The specific application will be to transport heat from a high-temperature, gas-cooled pebble bed reactor to a district heating network by means of a CRS system. The proposed chemical scheme (known as EVA–ADAM) is based on the high-temperature (1300°F; 704°C) steam reforming of methane to form hydrogen and carbon monoxide and the reverse reaction that takes place around 400°F (204°C). This original district heating concept has been adopted and extended by investigators in the United States to higher-temperature industrial uses (e.g., the dispersed generation of process steam and electricity) by recovering reject heat by such reversible chemical reactions as the hydrogenation of benzene to cyclohexane, transporting the cyclohexane by pipeline, and then recovering the thermal-electric energy on site by the reverse reaction.

RP1086-1 was established to assess the potential benefits of these and other CRSs to electric utilities. Under this joint DOE–EPRI study, potential sources of reject heat in power plants and industrial processes were matched to selected CRSs, which in turn were conceptually coupled to on-site or remote use in power generation and energy supply for the industrial, residential, and commercial sectors. Analysis of conceptual design and life-cycle costs for four such systems concluded that such CRSs are technically feasible but less efficient and more expensive than conventional sensible heat transport and storage concepts. For example, the benzene-cyclohexane system, which transports thermal energy from a cement kiln exhaust at 1300°F (704°C) through a 25-mile pipeline to generate 400-psia (2.76-MPa) process steam, recovered 47% of the reject heat at a life cycle cost of $8.40/10^6 Btu (1979 dollars), while a hot-oil energy transport concept for the same application was estimated to be 55% efficient and delivered thermal energy at $7.60/10^6 Btu. Evaluation of three other CRSs (sulfur trioxide–sulfur dioxide, methane–carbon monoxide–hydrogen, and sulfuric acid systems) concluded in every case that the conventional systems were more attractive than the CRS. Thus, although these preliminary studies indicate that CRS concepts are technically feasible, the ones identified to date are not attractive compared with alternative means of storing or transporting energy. CEC research will continue to survey promising new CRS concepts by performing assessments, using the methodology developed, and by continuing involvement in the DOE program. *Program Manager: B. R. Mehta*

HEAT REJECTION

EPRI heat rejection research focuses on four primary objectives: demonstration of water-conserving cooling systems, development and validation of predictive models of atmospheric and hydraulic discharge plumes, development of performance models and test procedures for cooling towers and ponds, and development of design guidelines for intake structures of once-through cooling systems.

Water-conserving cooling systems

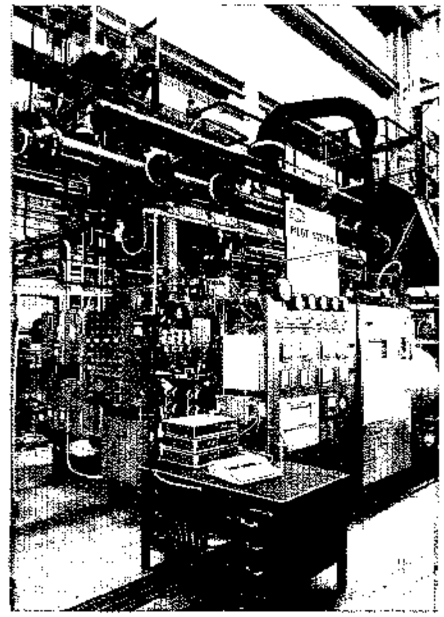
As discussed in a recent *EPRI Journal* (October 1979, p. 6), EPRI's primary thrust in water conservation is development of a demonstration heat-rejection system to be constructed at Pacific Gas and Electric Co.'s Kern power plant in 1980 and tested through 1984. The system rejects heat directly to the atmosphere through air-cooled heat exchangers (dry cooling) and uses water cooling for augmentation on hot days. Heat is transferred to the cooling tower in a circulating ammonia loop. A pilot-scale facility (Figure 2) is currently in operation. Cost savings of up to 50%, compared with the corresponding commercially available technology, are projected. This translates to a projected industry savings of $10 billion by the year 2000 (RP422).

A closely related project has concentrated on the performance testing of a commercial wet-dry cooling tower at the San Bernardino plant of Southern California Edison Co., the contractor and principal sponsor. The testing program, recently completed, has shown savings in water consumption of 20–30%, compared with a conventional evaporative tower. As part of this effort, a predictive model of wet-dry cooling-tower performance was successfully validated. The model was developed by PFR Engineering Systems, Inc., under EPRI sponsorship. An EPRI report summarizing test results will be published early in 1980 (RP738).

In an associated analytic study, Dynatech R&D Co. developed and demonstrated a method of including electrical supply and production economics in both design procedures and operating strategies for wet-dry cooling systems. The model of the wet-dry systems was applied in a case study of the design and operation of a 1000-MW (e) fossil-fired baseload plant. Consumption of the available cooling water in an economically optimal manner resulted in an annual savings of $650,000 over the cost of using the conventional method of water deployment, which is based on ambient temperature (FP-1096). Analysis is continuing for the case of cycling plants, which now represent about 35% of plants currently in design (RP1182).

Related project development is in process to study in greater detail the power system economics of plants cooled with wet-dry systems. This planned study is a direct outgrowth of the EPRI–DOE workshop on power system economics held in November 1978. Existing economic models cannot adequately deal with the large capacity and energy replacement penalties associated with water-conserving cooling systems. Because the replacement penalties dominate the design calculations, this leads to a considerable uncertainty about what the optimal cooling system should be. A project planned to start in 1980 will be aimed at establishing appropriate criteria for using these existing models to produce optimal designs with little uncertainty. The effort will attempt to provide insight into the long-term impacts that the use of alternative cooling systems will have on overall power system economics and water conservation.

Figure 2 Pilot-scale dry-cooling system.



Models for predicting plume behavior

In an ongoing effort at Argonne National Laboratory, computer models of the exhaust plumes from natural-draft and mechanical-draft cooling towers are being analyzed, improved, calibrated by using experimental data, and validated by comparison with full-scale test results. This effort, which concentrates on visible plume trajectories and saline drift deposition, includes both single towers and clusters of towers. Pertinent results include an extensive review of European field data and development of a single-tower, natural-draft model with a predictive capability of plume trajectory that is superior to that of other published models. (An EPRI report summarizing work to date will be published shortly.) In the proposed continuation of this work, efforts will be focused on developing a user-oriented computer code for siting studies and licensing. A workshop to acquaint potential users with the code is also planned (RP906).

In EPRI seminars held in Washington, D.C., and Salt Lake City in the spring of 1979, results of the Chalk Point cooling tower project were disseminated to the utility industry. This project, the most comprehensive of its kind yet undertaken, was established by the State of Maryland in 1972 to evaluate the environmental impact of effluent emissions from a large natural-draft cooling tower using brackish water as coolant (Figure 3). Results of this project were found useful in the plume model validation efforts previously discussed (RP906). Primary results of this project conclude that although prediction of saline drift deposition from such a tower is difficult, the effect of salt deposition on natural vegetation and cultivated crops is negligible except in the immediate vicinity of the tower (RP256). An EPRI report summarizing project results will be available in 1980.

Several closely related efforts are in progress. At the University of Iowa Institute of Hydraulic Research, laboratory tests are being performed on hydraulic models of mechanical-draft cooling towers (RP732). These tests, which measure the plume recirculation of a tower and interference effects between adjacent towers, will provide tower siting guidelines to utilities. An EPRI report on results of this work will be published in early 1980. In an associated ongoing study at the University of Waterloo, a computer code is being developed to predict effluent recirculation in cooling towers (RP901). In research recently begun at the Massachusetts Institute of Technology (MIT), competitive methods of plume droplet drift measurement will be evaluated in a laboratory study (RP1260-11).

Performance models and test procedures

Research is currently under way to develop validated performance models and accurate, unambiguous test procedures as a means to design cooling systems more precisely and thus avoid costly overdesign.

Environmental Systems Corp. (ESC) has recently completed an effort aimed at developing improved test methods for cooling-tower performance evaluation during acceptance of the tower by the utility from the vendor. Results of this work (reported in FP-953) show that significant plume recirculation can occur under wind conditions that fall within allowable limits of the current test codes. The effect of recirculation (a decrease in tower heat duty on the order of 10%) translates to a utility cost in decreased plant performance of about $100,000 annually, depending on plant size and economic factors (RP905).

In related research on testing methodology, ESC is seeking improvements in methods of measuring water flow rates in cooling systems (RP1260-15). It has been shown in work to date that there are substantial limitations on the accuracy of many presently available water flow measurement devices. An EPRI final report will be published in 1980.

A model development and validation effort by Cham of North America, Inc., has resulted in two-dimensional models of both cross-flow and counter-flow natural-draft cooling towers (RP1262). The validation was performed by comparing model predictions with performance data (collected as part of the project) from both U.S. and European towers. Results are documented in an EPRI project report that will be available shortly. Plans call for extension of the code and a validation study for the case of mechanical-draft towers.

At MIT's Ralph Parsons Laboratory, a project has been started to improve the capability for predicting performance and evaporative losses from cooling ponds (RP1260-17). The initial effort will include review of available field test data and formulations, plus a scoping study for a field test program and a workshop to review progress and identify measurement techniques.

Figure 3 Chalk Point cooling tower project.

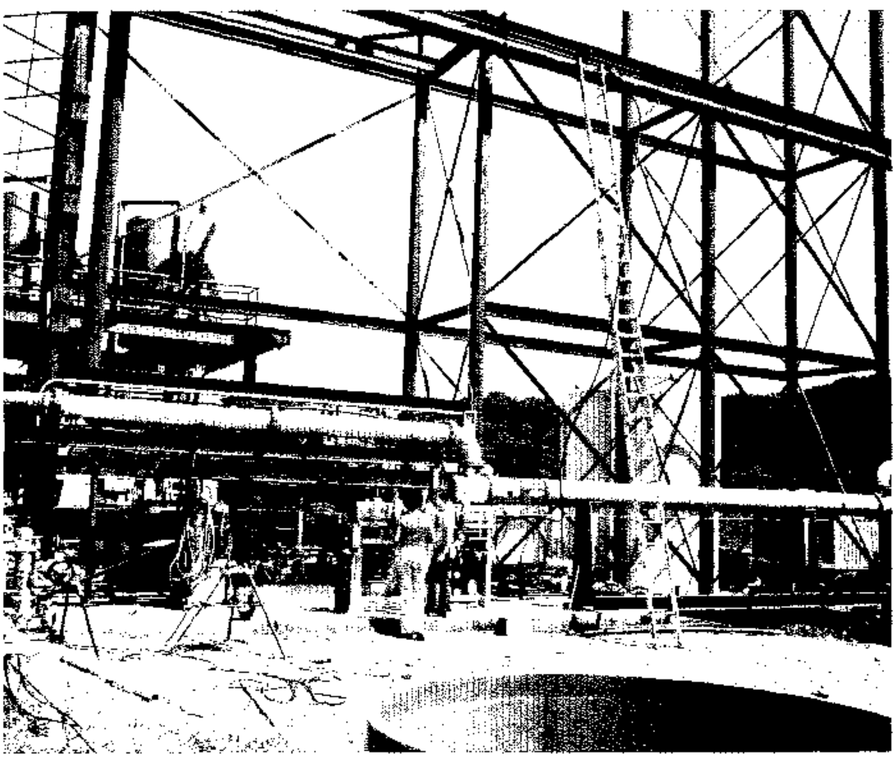


Figure 4 Condenser simulator for entrainment mortality studies.

Once-through cooling

Several projects in progress are investigating once-through cooling systems, with emphasis on entrapment and entrainment mortality and required modifications in intake structure design.

Construction of a porous dike intake structure is in progress, with New England Power Service and Marine Research, Inc. as contractors (RP1181). The objective of the project is to develop, construct, and demonstrate a porous dike that eliminates the entrapment of certain aquatic species and reduces their entrainment. The 45,000-gal/min (2.8-m^3/s) test facility was completed in May, and tests are in progress. Project completion is scheduled for late 1981.

In a related effort, Oak Ridge National Laboratory is performing tests on a 200-gal/min (45.4-m^3/h) simulated circulating water loop in an effort to provide designers with a basis for selecting design parameters that minimize entrainment mortality (Figure 4). Under experiments currently in progress, several aquatic species are being subjected to passage through the loop under a matrix of test conditions. Work is expected to be completed in early 1981 (RP1183).

At Georgia Institute of Technology, a project is under way to develop field-validated models for use in transient design calculations of circulating cooling water systems (RP1342). Field measurements of flow transients on the circulating water plant at Shoreham Nuclear Plant have been initiated by Long Island Lighting Co. and Stone & Webster Engineering Corp. Experimental results will be used to test the model and upgrade it, if necessary. An EPRI final report is scheduled early in 1980.

In a project development effort on power plant intake screening, an information clearinghouse is being planned for collection, interpretation, synthesis, and publication of existing biological performance data, engineering and cost studies, and operating problems. It is hoped this effort will assist in defining limits of applicability of specific screening systems and in making site-specific comparisons. *Subprogram Manager: John A. Bartz*

MATERIALS SUPPORT

*The materials support group provides advice and guidance on materials and manages materials projects for EPRI's technical divisions. In a previous status report (*EPRI Journal, *April 1978, p. 42), materials for FBC boiler tubes, improved large rotor forgings, and titanium low-pressure turbine blades were described. In this report, several other materials developments are described.*

Refractories for coal gasifiers

Refractories are used to line gasifier pressure vessels and associated piping. They provide the insulation needed to maintain the thermal efficiency of the gasifier. Thus the temperature of the pressure vessel shell is lowered to less than 600°F (316°C). At this temperature, carbon steel or low-alloy steel can be used for the construction of the pressure vessel shells and piping.

To perform reliably for several years, the refractory lining must resist the corrosive and erosive action of slags, particulates, and gases present in the gasifier. It must also resist cracking caused by thermal and mechanical shocks that occur during operation of the gasifier. Refractory linings are generally fairly thick, 9–18 in (23–46 cm). Large materials losses of up to several inches can therefore be tolerated before replacement is needed. To prevent thermal shock damage, refractories are usually porous. Thus corrosion is not always limited to the surface of the refractory liner.

Selection of refractories for specific applications is to a large extent empirical, although it is partially based on expected chemical reactions between the refractory and the gasifier atmosphere, as predicted by phase diagrams. For dry ash gasifiers and cool areas in slagging gasifiers (<2000°F; <1093°C), refractory experience in the petrochemical industry generally serves as a guide, while experience with blast furnaces and slagging boilers may serve as an initial guide for refractory selection in slagging gasifiers. However, in both cases, there are significant differences that require modified refractory use. For this reason, the refractory performance in various pilot plants is closely watched, and laboratory studies were initiated by both EPRI (RP625) and DOE to select the most cost-effective refractories. EPRI is supporting slagging gasifier development at Texaco's Montebello site, British Gas Corp.'s Westfield site, and Combustion Engineering, Inc.'s Windsor site.

Pilot-plant experience and laboratory studies to date indicate strongly that existing low-cost refractory concretes containing 45–60% Al_2O_3 are the prime candidates for lining dry ash gasifiers that operate at temperatures below 2000°F (1093°C). A typical lining for such an application will consist of 3–4 in (7.6–10.2 cm) of dense concrete at the hot face. This concrete may be reinforced with stainless steel fibers to minimize spalling during thermal cycling. The dense erosion-resistant layer is backed up by 6–8 in (15.2–20.3 cm) of insulating concrete that has about half the density of the dense concrete. The refractory liner is generally attached to the pressure vessel shell by stainless steel anchors. The strength of the dense component of such a lining actually increases during service in high-pressure gasifiers. The strength increase depends on the partial pressure of steam in the gasifier atmosphere and is believed to be caused by the hydrothermal precipitation of calcium aluminum silicate at about 600°F (316°C).

The insulating concrete generally shows only a marginal increase in strength under the same conditions because of its higher porosity. Further laboratory testing has shown that silica loss does not occur at temperatures up to 1850°F (1010°C) and steam partial pressures up to 600 psi (4.14 MPa). However, at 2000°F (1093°C) and 1000 psi (6.89 MPa) steam pressure, silica loss is evident in laboratory tests. After service, the erosion resistance of the alumina silica concrete is generally higher than that of the 96% Al_2O_3 concretes widely used for erosion-resistant applications in the petrochemical industry. Actually, 96% Al_2O_3 concretes tend to show a reduction in strength in gasifiers and therefore are not recommended.

Refractory service in slagging gasifiers is much more demanding than in dry ash gasifiers because of the higher temperatures and the presence of corrosive slag. Thermodynamically, none of the presently available refractories is stable in the presence of a typical molten coal slag, especially one with a high fusion temperature. The trick, therefore, is to reduce the reaction rate to obtain an acceptable service life. This probably can be achieved best by optimizing the refractory composition and through the judicious use of cooling. Laboratory tests at Argonne National Laboratory demonstrate the superiority of Al_2O_3–Cr_2O_3–MgO spinel refractories and the beneficial effect of cooling on wear rates. Laboratory data generally can not be used to predict actual wear rates in slagging gasifiers but are a useful guide for selecting refractories for test panels in pilot plants and more elaborate test rigs designed to closely simulate actual gasifier wear conditions. Such a test rig is presently being built at IIT Research Institute for DOE.

Embrittlement of steel

One of the major factors affecting the reliability of low-alloy steel components exposed in the 600–1100°F (316–593°C) range is the embrittlement of the steel caused by segregation of impurity elements, such as phosphorus, tin, and antimony, to the grain boundaries. The segregation leads to weakening of the grain boundary interfaces and premature low-ductility failures. Among the components where the problem has been of special significance are high-pressure and low-pressure rotors and chemical and nuclear pressure vessels. A number of failures of some of these components in the past have been related to the impurity segregation problem. Consequently, severe limitations are imposed on the manufacture as well as on the operation of the steel components. During manufacture, the components must be heat-treated above the critical temperature range of embrittlement and cooled rapidly if embrittlement is to be avoided. Neither of these conditions can be satisfied in the case of high-strength, heavy-section components because the tempering temperatures required to achieve high strength overlap the range of embrittlement temperatures, and the cooling rates are dictated to a large extent by the size of the component. Some residual embrittlement is therefore inevitable in the as-received condition, and allowances must be made for this in the design. The embrittlement problem also imposes a ceiling on allowable operating temperatures of highly susceptible steels, such as those used in Ni-Cr-Mo-V low-pressure rotors. The yield strength level at which the steel is put into service is again limited by the embrittlement problem because higher-strength steels are more susceptible to grain boundary embrittlement.

The embrittlement problem that results from impurities has several aspects. The segregation and concentration of impurities at grain boundaries can result in appreciable increases in the ductile-to-brittle transition temperature, sometimes to values as high as 400°F (204°C). Correspondingly, the fracture toughness values are lowered, with a concomitant lowering of the critical stress needed to cause fracture. Premature brittle fractures can thus result at low temperatures, warranting stringent controls on the startup-shutdown cycles. Then too, the impurity segregation can exacerbate environmental effects, such as stress corrosion cracking and hydrogen-assisted cracking. The widely publicized Hinkley Point disc failure in England is an example where the synergistic interaction between impurity-induced embrittlement and stress corrosion cracking was found to be a major cause of the failure. In the case of the more recent Gallatin rotor failure in the United States, the involvement of impurity-induced embrittlement, with or without the compounding effect of residual hydrogen, was again considered to have contributed to the failure. Examination of several retired rotors also has revealed large concentrations of segregated impurities at the grain boundaries (RP502).

Some evidence indicates that the creep ductility and susceptibility to stress relief cracking of steels may also be related to segregation of impurity elements. The impurities may influence both the nucleation and growth of creep cavities at grain boundaries.

The materials support group has been working with EPRI's Coal Combustion Systems Division and Nuclear Division on a comprehensive study at the University of Pennsylvania to address the problem of brittle fracture caused by concentration of impurity elements at grain boundaries (RP559). A number of useful results have been generated. The role of alloying elements such as Mn, Cr, and Si in promoting embrittlement has been clarified, and the specific impurity elements responsible for embrittlement of specific steels have been identified. For instance, it is now believed that phosphorus is the major culprit in temper embrittlement of 2¼ Cr–1 Mo-type steels. Guidelines have been evolved for optimizing the composition of steels to minimize embrittlement. For instance, SA508 class-2 grade steel has been identified as a desirable substitute for SA533-B grade steel in reactor pressure vessels because of its lower susceptibility to stress relief cracking.

Equations have been developed that correlate the embrittlement susceptibility to the grain size, hardness, and composition of the grain boundaries in Ni-Cr steels. If such equations can be applied to rotor and pressure vessel steels, the utilities will have a rapid, nondestructive method of estimating the damage to the component caused by embrittlement mechanisms at any desired location. The future direction of this research involves extending the results of the laboratory studies to commercial rotor steels of the Cr-Mo-V and Ni-Cr-Mo-V types. Theoretical predictions will be verified by examination of field rotors retired from service.

In a related project EPRI is also evaluating the effects of impurity embrittlement on susceptibility of 2¼ Cr–1 Mo pressure vessel steels to cracking in high-pressure, high-temperature hydrogenous environments typical of those encountered in coal liquefaction vessels (RP627). Preliminary results have shown that prior embrittlement of the steels could lead to increased subcritical crack growth in hydrogen at room temperature but not at elevated temperatures. However, a different source of concern has been uncovered at the elevated temperatures. In rising-load-type tests with precracked specimens, plastic deformation appears to set in at much lower loads in the presence of hydrogen-containing environments than in tests in air, indicating a reduction in the apparent yield strength of the material. Further work is in progress at Westinghouse to verify the reproducibility of this damage mechanism and to characterize it in detail.

Erosion

Erosion is the mechanical removal of material as a result of the impact of a particle on the material's surface. The particle may be liquid—the last stages in steam turbines suffer from water droplet erosion, while fan blades on aircraft gas turbines suffer from raindrop erosion. At the moment, however, problems associated with solid-particle erosion are of more interest to EPRI. For ductile materials, an impacting particle displaces material by plastic deformation processes. If the displaced material forms a lip around the groove as a result of the impact, the process is called plowing. If the displaced material is detached as a chip, the process is called machining. Material plowed by one particle may be removed by a later impact.

It is clear that only limited material removal by these processes will occur with normal impact and very little with impacts at very shallow angles. Detailed analysis shows that the maximum removal can be expected at angles in the range of about 20–30°, and experimental results are consistent with this.

For a given particle size, the damage increases markedly with velocity, typically varying as $v^{2.3}$. It is possible that there is a threshold velocity below which there is no damage, but this has not yet been established with any certainty. Very small particles probably do not cause damage. For gas turbine conditions, with relative velocities on the order of 300 m/s, particles smaller than 2 μm do not seem to erode, and it is possible that particles as large as 5 μm do not cause serious damage. Hard particles result in more erosion than soft ones, but it is not yet clear that hardness, however defined, is the parameter of significance. It is not known whether loose agglomerates of particles will result in more or less damage than a solid particle of the same mass. On the basis of experiments with relatively large particles, it is believed that sharp, angular particles are more erosive than round particles of the same material. The properties of the eroding material are clearly also of importance, but it appears that hardness in itself does not define erosion resistance. The temperature dependence of erosion appears to vary from system to system, but in the majority of cases, the erosion rate seems to remain fairly constant as the temperature is raised to a certain level, and then diminishes with further increases in temperature. This may be associated with the growth of a thick oxide layer on the surface.

Erosion is encountered in a number of energy systems. In a pulverized-coal boiler, the combustion gases entrain ash particles, which then pass over the heat exchanger tube surfaces in the gas passes. Erosion is of most significance in the economizer section, and various palliatives are used. In particular, furnaces are designed to have a maximum free-area gas flow velocity that depends to some extent on the coal, but this velocity is typically 20–25 m/s. After passing through the electrostatic precipitator, the gas is accelerated through the induced-draft fan. Local velocities may be on the order of 100–200 m/s, and erosion losses from the blades in the fan can be serious. This is countered by using replaceable armored sections in areas that are particularly susceptible to erosion, such as the leading edges of blades. Recently, systems involving the combustion of coal in pressurized fluidized beds have been considered. In some of these, the hot combustion gases, after various cleanup systems, are expanded through a gas turbine. The local gas velocities are about 300 m/s, and the particle loading is determined by the efficiency of the hot gas cleanup system. There are economic penalties associated with the cleanup system, and relaxing the conditions by increasing the ability of the turbine to accept particulates or by better defining the turbine's resistance has clear advantages.

A number of materials projects (RP979-4, RP978-8, RP1337-1, and RP1649-4) are addressing various aspects, both fundamental and applied, of these problems.

Aqueous corrosion

Many of the power outages in fossil power plants are caused directly or indirectly by corrosion in aqueous environments at relatively low temperatures. For instance, various forms of localized corrosion, such as corrosion fatigue, have been observed to occur on low-pressure steam turbine blades and discs in the zone where the steam first starts to condense. The condensate, which can be a fairly concentrated solution of chlorides, sulfates, and other contaminants, contacts the metallic components of the turbine and may induce localized corrosion and premature failure. Several EPRI research projects address this problem. For instance, in RP912 the corrosion fatigue susceptibilities of several turbine blade materials are being determined in various turbine environments in an attempt to more fully understand the cracking mechanism and thus determine how turbine reliability can best be improved. One approach to the problem is to replace the commonly used blade material (12% Cr stainless steel) with a more corrosion-resistant alloy. This approach is being evaluated at Commonwealth Edison Co.'s Kincaid station where the stainless steel blades in the L – 1 row are being replaced by titanium blades (RP1264). Another potential method for reducing corrosion and extending the lifetime of the turbine is to apply corrosion-resistant coatings to the conventional blade and disc materials, an approach being evaluated in RP1408.

It has already been established that turbine reliability would be greatly improved if some of the more aggressive contaminants (such as chlorides) could be eliminated from the steam. The source of most of these aggressive species can be traced to leaks in the condensers. Condenser tubes are susceptible to pitting, erosion-corrosion, fretting corrosion, and other forms of localized corrosion. If one of these corrosion processes occurs rapidly enough, the tube wall can be broached prematurely and the cooling water (typically river, sea, or lake water) can leak through the opening and contaminate the primary water. Thus, corrosion-induced leaks in a condenser are important, not only because the structural integrity of the condenser is compromised but also because the cooling water contaminates the primary water and results in corrosion in the steam turbines and elsewhere in the primary system. The problem of aqueous corrosion in condensers has been identified as one of the more important areas for future research.

Another group of aqueous corrosion problems that will require increased attention over the next few years is associated with gas scrubbers, also called flue gas desulfurization (FGD) systems. Because of the revised Environmental Protection Agency regulations, all new coal-burning power plants must install scrubbers to remove sulfur dioxide (SO_2) from the stack gases. A lime or limestone slurry is used in most FGD systems to absorb the SO_2. After absorption, the slurry is acid, and chlorides originating from the coal or scrubber water may also be present in significant quantities. These acid chloride conditions, coupled with the erosive effects of the lime or limestone, create many varied corrosion problems in the scrubber and in the downstream ducting and gas reheaters.

For instance, erosion-corrosion can be a problem in the slurry recirculation pump and in the water-spray nozzles; pitting and crevice corrosion are possibilities in the absorber trays; dew point corrosion is a potential problem downstream of the demister; and corrosion fatigue has been reported in the induced-draft fans. These and other problems are currently under review (RP982-14). It seems likely that some of the more critical problem areas will require further study so that corrosion can be controlled either by selection of proper materials or by suitable modification of the environment.

The supply of fossil fuels is not expected to meet demand within a few decades, so alternative forms of energy have been sought. Geothermal fluids are a source of energy that is currently of great interest to the energy industry. Hot geothermal steam is being exploited to produce electricity at The Geysers in Sonoma County, California; the geothermal brines found in the Imperial Valley, California, and at several other locations throughout the United States are also being carefully evaluated for similar use.

The geothermal fluids vary considerably in their composition and, therefore, in their corrosivity. Critical components, such as heat exchangers, valve seats, and pumps, must be fabricated from materials that have adequate corrosion resistance but a minimum cost. A recent EPRI project indicated that inexpensive low-carbon steel corroded sufficiently slowly in one low-salinity brine found at Heber in the Imperial Valley that it could be recommended for use as a heat exchanger tubing material (RP846-1). On the other hand, it was recognized that pitting of the steel would be a problem if air was ever allowed to leak into the system. This slight risk of pitting in carbon steel must be weighed against the cost advantage over more expensive corrosion-resistant materials like titanium. A more detailed evaluation of a carbon steel heat exchanger module is now under way at East Mesa, the site of another low-salinity geothermal well in the Imperial Valley (RP1094). In this and other geothermal systems, it will be necessary to ensure that the materials of construction are selected with due consideration to both cost and corrosion resistance.
Technical Manager: Robert Jaffee

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

NUCLEAR DATA DEVELOPMENT AND UTILIZATION

During the past five years EPRI has participated in the development of a national reference nuclear data library. A new version of this library, ENDF/B-V, has recently been released for distribution by the National Nuclear Data Center (NNDC). The library contains many features developed under EPRI support. EPRI's present emphasis is on evaluating the validity of this library and its adequacy for use as an industry standard data source for LWR design and safety analysis.

Nuclear data libraries used for reactor core design or fuel cycle optimization calculations generally contain various adjustments introduced to ensure agreement between calculations and measurements, referred to as benchmarks. Such data adjustments improve the predictive capability of calculations for systems similar to the ones used for benchmarking. However, the accuracy of calculations involving different systems or nonbenchmarked parameters may not be adequate. Thus, for example, a multigroup cross-section library adjusted to correctly predict criticality and isotopics may produce large uncertainties or biases in calculations of the temperature coefficients of reactivity.

To reduce the need for such data adjustments and to provide a standard source from which various application-specific libraries can be derived in a straightforward manner, EPRI has participated with DOE in the development of the national evaluated nuclear data library, ENDF/B. A new version of this library (ENDF/B-V) has recently been released by NNDC at Brookhaven National Laboratory (BNL). Although EPRI will continue to support basic data development projects that may result in future improvements to ENDF/B-V, at present the main emphasis is being directed toward the processing of the library and the evaluation of its adequacy for use in thermal reactor applications.

The ENDF/B-V library contains a number of improvements over ENDF/B-IV, many of which were developed completely or in part under EPRI support. The library features expected to have the greatest impact on thermal reactor applications include the following.

- Reduced capture widths for the low-energy resonances of ^{238}U (RP220, RP511, and RP620)
- Revised thermal-energy-range cross sections for ^{235}U (RP512) and ^{232}Th (RP353 and RP511), and increased capture and neutron widths for ^{240}Pu
- Higher estimates for the number of neutrons produced in a fission event for all fissile nuclei (DOE evaluations are being continued under RP707-3 and RP707-4)
- New evaluations of the amounts of energy released in a fission event for 16 fissionable nuclei (RP1074)
- New data files for structural or control materials, such as zirconium, hafnium, and gadolinium (RP343 and RP975-1)
- Considerably expanded data files for the heavy actinide nuclides of interest to studies of burnup, alternate cycles, and waste management (RP707-2 and RP975-1)

In addition, for the first time the new library will include gas production and activation files as well as considerably expanded information on data uncertainties and covariances. Covariance information can be used not only to determine the amount of adjustment that is reasonable for a particular data item but also to indicate what other data items must be adjusted simultaneously in order to retain consistency with experimental evidence.

EPRI's validation program has two objectives. One is to determine the accuracy of the ENDF/B-V library when used with the most rigorous methods of analysis (such as Monte Carlo methods or transport theory) for the calculation of thermal reactor benchmarks. The other is to determine whether reactor design codes, such as EPRI-CELL and EPRI-CPM, are in adequate agreement with the more rigorous Monte Carlo calculations when the same data base is used.

The primary Monte Carlo program to be used for this purpose is the SAM-CE program developed by Mathematical Applications Group, Inc., under RP972. Very detailed data libraries based on ENDF/B-V are being produced for this code at BNL under RP975-1. Because of the expense of running large numbers of Monte Carlo calculations, the transport theory code HAMMER, revised by Technion-Israel Institute of Technology under RP709-1, will be used as an auxiliary validation tool for calculations involving clean critical lattice experiments. During the development of ENDF/B-V, this code has been used extensively at EPRI to test the effects of various proposed data modifications.

Libraries for the ARMP lattice physics codes EPRI-CELL and EPRI-CPM are being generated by Los Alamos Scientific Laboratory (LASL) under RP452-1. The program NJOY (used to prepare the above libraries) has been verified by using the earlier version of ENDF/B. The present ENDF/B-V validation effort is being carried out primarily at LASL, Oak Ridge National Laboratory, and in-house at EPRI. This effort consists of detailed comparisons of few-group parameters and reaction ratios obtained during the analysis of UO_2-fueled critical lattice experiments, using ENDF/B-V data in various calculation procedures, including EPRI-CELL and EPRI-CPM, Monte Carlo, and transport theory. These comparisons will be extended to calculations of isotopic variations in fuel assemblies as a function of burnup.

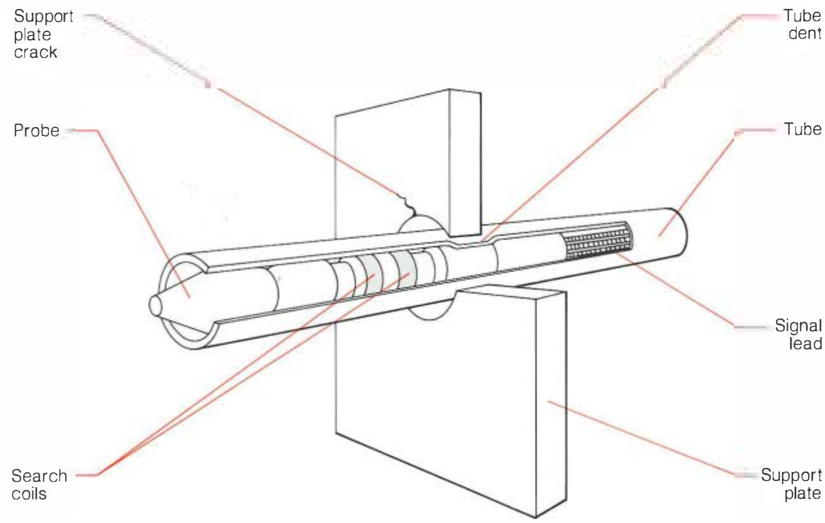
At the conclusion of this initial stage of the validation program, it is expected that it will be possible to determine whether the new ENDF/B-V EPRI-CELL and EPRI-CPM libraries constitute a significant improvement over the existing libraries. If this is found to be the case, an extensive benchmarking effort will be undertaken, including comparisons with a comprehensive set of clean criticals, reactor isotopics, heterogeneous critical configurations, and operating reactor data.

If successful this effort will result in a thermal reactor nuclear data base that can be used by the industry with confidence for a wide range of economic and safety-related analyses. *Project Manager: Odelli Ozer*

MULTIFREQUENCY EDDY-CURRENT INSPECTION OF STEAM GENERATORS

Steam generators in operating nuclear plants are inspected periodically to determine if flaws have developed in their tubes and supports or if previously detected flaws have increased in size. The inspection technique presently in use, the single-frequency eddy-current test, works well for detecting and sizing some types of flaws. However, many types, including those that have become more widespread over the past few years (most notably denting and degradation near tube supports), are more difficult to detect and interpret. To compensate for this difficulty, utilities may either repeat portions of the inspection or make tube-plugging decisions that are more conservative than necessary.

Figure 1 Eddy-current probe used in the inspection of steam generators. Tube denting and cracking of the support plates affect the eddy currents detected by the probe.



Eddy currents are induced in steam generator tubes by the alternating current that flows through the inspection probe's search coils. The magnitude and depth of penetration of the eddy currents depend on several factors, including the frequency of the excitation current, the electric and magnetic properties of the tube, the spacing between the probe and the tube, and the presence of a flaw or a support plate. The eddy currents in turn induce a voltage across the search coils. Any change in the eddy currents from the above factors will also change the induced voltage. Skilled interpreters look for changes in the relationship between the current in the coil and the induced voltage to identify and size flaws.

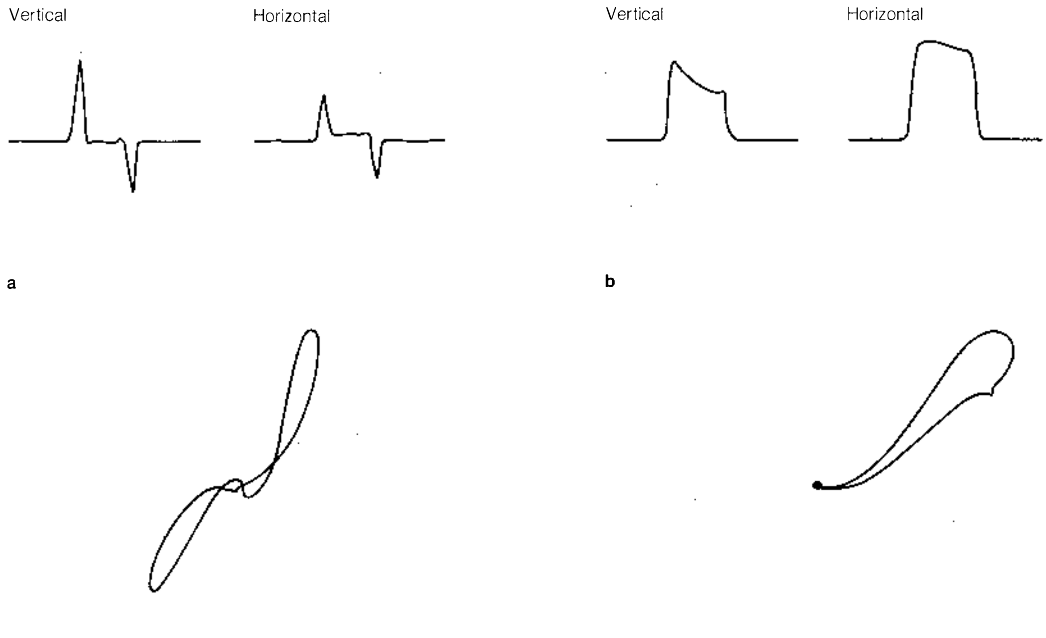
Not all these changes are indications of flaws, however. In fact, variations in the spacing between the probe and the tube, caused either by probe wobble or by inside diameter variations, can make it difficult for interpreters to determine the depth of the flaws. Furthermore, signal changes caused by support plates or dents can also hinder the assessment of flaw depth.

Unwanted indications can be eliminated by linearly combining the indications from independent eddy-current sources. These sources can be currents at the same frequency flowing through separate coils, currents at different frequencies flowing through the same coil, or currents at different frequencies flowing through separate coils.

Single- and multifrequency systems presently in use weed out some of the unwanted factors by using a differential test in which there are two coils on the probe (Figure 1). These types of systems measure the difference in the voltages induced in the coils, so changes common to both windings are not detected. In this manner the system ignores gradual changes in electric and magnetic properties of the tube and, to some extent, probe wobble. Flaws are still detected because one coil is always closer to the flaw except at the instant when the flaw is centered between the two coils. Unfortunately, the differential test also disregards some very useful information, such as gradual changes in the profile of a flaw. In addition, the existing single-frequency test is inherently unable to eliminate signals produced by support plates and, when used in conjunction with conventional differential probes, signals produced by dents.

Many of the shortcomings of the differential test are overcome by using an absolute test, in which only one coil on the probe is used. As the probe is pulled through the tube, the absolute test measures the continuous profile of a flaw, whereas the differential test is sensitive primarily to the edges of the flawed regions. Figure 2 compares the signals from the two tests. In laboratory tests of a system under development, Battelle, Pacific Northwest Laboratories has shown that the ability of the absolute test to measure a continuous profile both reduces sizing errors and facilitates identification of the type of flaw present (RP403). In addition, the absolute test has been used in the laboratory to identify support plate cracking and support hole corrosion and to assess flaw depth in regions of small and medium dents. Although the absolute test has many advantages, it cannot eliminate unwanted signals that make assessing flaws difficult. To overcome this problem, the inspection system being developed performs eddy-current tests at several frequencies simultaneously. Signals produced at each frequency by flaws, support plates, and probe wobble are combined in a way that eliminates unwanted signals, while retaining those that are of interest.

Figure 2 Comparison of signals from a multifrequency differential test **(a)** and an absolute test **(b)**. The vertical and horizontal components recorded on the strip charts (top) combine to form the oscilloscope patterns (bottom) used to interpret the flaw data. Approximately 50% of the tube thickness was machined away to manufacture this flaw. Note that the differential test is sensitive primarily to the edges of the flaw, whereas the absolute test profiles the flaw, showing that the flaw is slightly deeper at the left edge than at the right.



Signals from three frequencies (200 kHz, 400 kHz, and 1.6 MHz) are combined, using vector addition to detect flaws while excluding the unwanted signals. Both differential and absolute multifrequency testing are employed simultaneously (using the same conventional probe), with the former used to size small flaws and the latter used to size larger flaws. Accuracy in laboratory tests exceeds that of the conventional single-frequency test. In addition, signals produced by the 1.6-MHz current can be used to size dents, and signals from a fourth frequency, 25 kHz, can be combined with those from 1.6 MHz to monitor support plate corrosion and cracking.

The system was recently evaluated on a mock-up of a steam generator at Battelle, Columbus Laboratories. Inspection data are being analyzed to determine the system's accuracy under simulated field conditions. *Project Manager: Gordon Shugars*

AUTOMATIC INSPECTION OF EDDY–CURRENT SIGNALS

Interpretation of data from the eddy-current inspection of steam generator tubing is presently performed manually. This interpretation is carried out by individuals highly trained to discriminate between actual flaws and other conditions (such as changes in tube geometries or the presence of corrosion products) that generate signals very similar to those from flaws but that do not significantly affect tube integrity. To increase accuracy and eliminate the extensive training required for manual data interpretation, EPRI has launched a major research effort to develop methods of automatically interpreting eddy-current inspection data.

Automatic signal analysis

Steam generator tubing inspections are performed by passing an eddy-current probe through each tube for distances up to 60 ft; the resultant signals are recorded for analysis at a later time by a person highly skilled in the art of eddy-current interpretation. For simple defect conditions (e.g., axial flaws not in the vicinity of geometric factors such as tube support plates) this manual interpretation of data has been sufficiently accurate. The recent onset of the denting phenomenon, however, has made it important to gather more information than can reliably be acquired with a conventional eddy-current test (*EPRI Journal*, June 1979, pp. 33–34). In an earlier study the feasibility of automatically interpreting eddy-current signals was demonstrated (TPS78-723). Based on these encouraging results (*EPRI Journal*, June 1978, pp. 42–45), a follow-on project was initiated to develop the hardware and signal-processing routines necessary to automatically acquire and analyze eddy-current signals from steam generator tubing.

The method being used to develop the signal-processing routines is a statistical pattern recognition technique called the adaptive learning network (ALN). In this approach, signals from flaws of known dimensions are recorded and then analyzed with already developed pattern recognition techniques in order to establish parameters for identifying each signal. Once these distinguishing parameters are established, the relative importance of each is determined by testing against known flaw data. The result of this effort is an analysis routine that contains the necessary discriminating parameters and the relative importance of each in a computer program that can be used to automatically identify and size specific flaws as data are generated in the field.

Equipment

To use this powerful signal-processing technique effectively, hardware appropriate for field use must be available. Thus an effort was undertaken to develop the necessary hardware for real-time field analysis. The hardware consists of a specially designed microprocessor-based portable computation system that uses high-speed arithmetic logic functions to perform real-time signal analysis. The equipment is generic in nature and can be used in many different applications with different preprogrammed instruction cassettes.

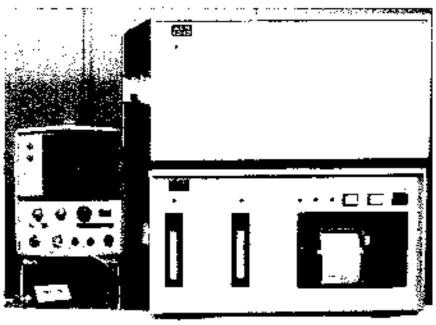
For the convenience of the field operator, abbreviated results of the analysis are printed out on a paper tape. Later, the complete results can be printed out by using auxiliary equipment, such as a teletypewriter or appropriate display screens. In addition, the equipment maintains a complete record of all the raw data obtained, providing a convenient and efficient means of storage in case the data are needed for later comparisons. Figure 3 shows the hardware in operation alongside a commercial eddy-current inspection instrument (RP1125-1).

Analytic effort

Often a complete theoretical prediction of a probe response to a given flaw is not possible because either the necessary physics is not completely understood or the mathematical description that results is so complex that a complete closed-form solution is not possible. Since ALN is statistical in nature, it will arrive at a solution to these problems in a totally empirical manner. However, it requires a significant flawed-specimen data set in order to obtain typical flaw response signals.

A theoretical study paralleling ALN work could produce analytic functions that would update present theoretical understanding and lead to an eventual capability to describe an eddy-current test completely in analytic terms, thereby avoiding the costly sample program. With this goal in mind, two analytic projects were designed. The first uses well-known physical relationships in electromagnetic theory to study the interaction of eddy currents with different flaw conditions as a function of the predicted response. Numerical evaluations of some of the recent mathematical formulas have shown considerable promise and have indicated at least one new direction to take in probe design (RP1395-3). The second effort involves applying the finite element analysis method, well known in structural mechanics and electric machine design work, to describe the eddy-current flow about different flaw conditions in a steam generator tube. Results achieved so far indicate considerable promise in this approach.

Figure 3 A portable signal-processing unit (right) automatically analyzes and interprets signals generated by a conventional eddy-current instrument (left).



The finite element description of the eddy-current flow for simple flaw conditions corresponds very closely to that predicted by the mathematical descriptions developed in other programs. The confidence generated by this agreement has now led to application of the techniques to more realistic flaw conditions. The specific conditions of interest are flaws in the presence of magnetite or dented tube geometries. Analysis of this condition is now under way (RP1395-2).

Evaluation

All the development efforts described above will need to be evaluated before a commitment can be made to full-scale field qualification. To do this effectively, mock-ups that simulate steam generator conditions have been developed through funding by both the Steam Generator Owners Group and EPRI (RP1172-1). The mock-ups consist of a series of tubes arranged with spacing and support plates that duplicate steam generator designs now in use (*EPRI Journal*, July/August 1979, p. 42). Many of the tubes that are used contain known defect conditions. One system consists of quarter-section full-scale mock-ups of the three steam generator designs now in commercial use. The second test bed consists of a portable module that duplicates the tube spacing and grid patterns found in steam generators and that can be easily transported to different locations for specific limited evaluations. The tubes contain flaws that simulate as closely as possible service failure conditions found in the field.

Present status

EPRI has a well-formulated research program in eddy-current inspection technology, with the objective of providing capability for real-time analysis and interpretation of eddy-current inspection results. Achievement of this objective requires the development of field-qualified hardware and the necessary analysis routines. These two goals are being achieved. Development of the hardware and analysis routines should be completed by the end of 1979, and evaluation of these products will begin in 1980. In addition, there is good evidence that the theoretical and analytic work, proceeding in parallel, will successfully develop techniques for analytically developing the characteristic flaw signatures for future defect conditions of interest, thereby avoiding the costly sample program now needed to develop the analysis routine. Finally, mock-ups have been built and are now in use for the evaluation of specific hardware concepts. In the future, these same mock-ups will also be used for training people to use the new hardware in field applications. *Program Manager: Gary J. Dau*

RESIDUAL STRESS MEASUREMENTS IN THICK METAL SECTIONS

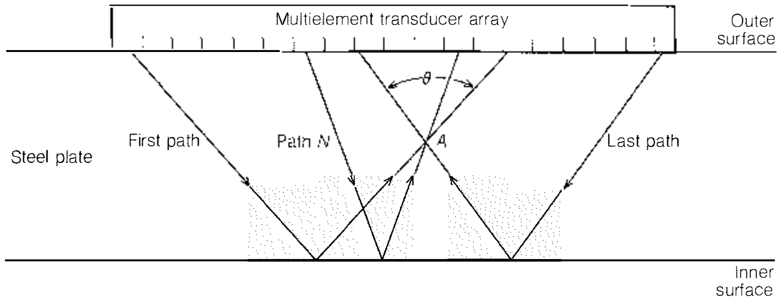
In the past it has not been possible to nondestructively measure or accurately calculate residual stresses in thick metal sections. As a result, designers, structural analysts, and regulators have had to make very conservative assumptions concerning residual stresses in welded structures. These conservative assumptions can lead to extended outages for repair of flaws, whereas actual residual stresses, if known, would show many of these flaws to be safe. Additionally, the ability to verify optimal residual stress profiles will provide added confidence that appropriate action has been taken to mitigate intergranular stress corrosion cracking (IGSCC) in austenitic pipe welds. The objective of this project is to determine the engineering feasibility of measuring residual stress distributions in thick steel sections by using ultrasonic tomographic techniques.

Recently developed tomographic techniques allow the generation of a two-dimensional map of material properties, using a computer reconstruction based on a series of one-dimensional projection measurements. The properties that may be mapped include X-ray attenuation, acoustic attenuation, and acoustic time of flight. Acquisition of the projection data usually requires coplanar views of the object over at least 180° included angle. Variations in acoustic time of flight are related by acoustoelastic theory to residual stress in the material.

The initial phase of this project was successful in establishing the feasibility of mapping (in the laboratory) acoustic velocity in thick metal plate (RP504-1). The technique developed used recent advances in medical imaging and was based on a phase-steered array, time-of-flight measurements, a limited-angle data base, back-surface reflection, and an algebraic reconstruction technique (ART) algorithm. The success of these early tests led to an expanded program to develop a field-usable prototype system.

The system concept developed was based on practical assessibility requirements. In most inspection situations only one surface of the vessel or pipe wall will be available; thus, limited-angle tomographic data collection is required. Additionally, acoustic indexes of refraction and geometry restrict the data collection to a maximum included angle of approximately 120°. As shown in Figure 4, a series of acoustic time-of-flight measurements are made from first to last path over the included angle θ. For practical cases, θ is approximately 90–120°; for infinitely long arrays, θ approaches 180°. Having less than 180° of data forces the use of a limited-angle reconstruction algorithm (developed for medical imaging), using an ART method. Reflection of acoustic energy from the far surface of the plate is necessitated by the one-surface accessibility.

Figure 4 Data collection about point *A* over angular range $\theta \leq 120°$. The range is defined by plate thickness, length of array, and refractive properties of the metal. Three paths are shown, including the intermediate path ***N***.



The components have recently been integrated into a complete system (Figure 5). These components consist of a 240-element, phase-steered transducer array for rapid data collection, a microprocessor-controlled remote analog electronics package for time-of-flight measurements, a main console with microprocessor for digital reconstruction, a display and data hardcopy unit, and a larger display-only unit. The analog and digital units may be remotely located and are connected by a high-speed digital serial link.

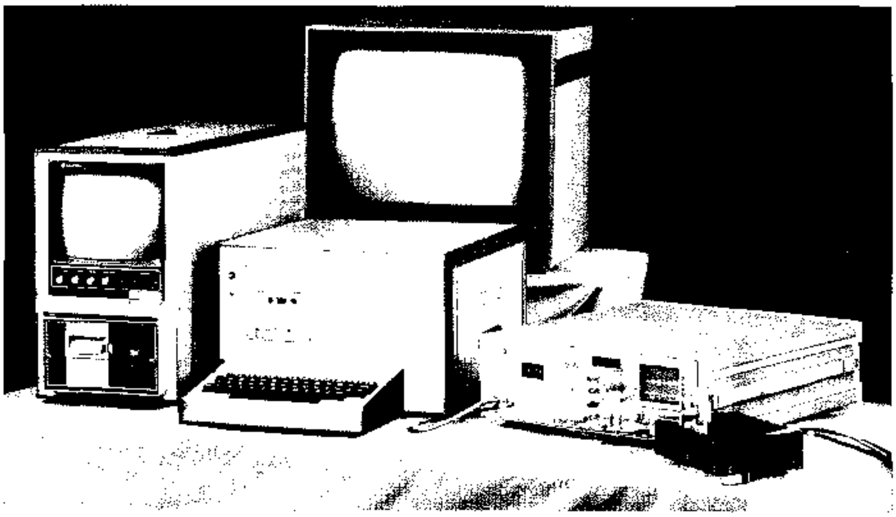


Figure 5 Ultrasonic tomography unit, showing the microprocessor for reconstruction and display (left), main console (center), transducer array and remote analog processor (right), and large display unit (background).

The complete system is currently undergoing initial laboratory testing to establish fundamental performance parameters. Tests for reproducibility (system stability) and for uniformity (degree of transducer array channel-to-channel mismatch) of the time-of-flight measurements are now nearing completion. Reproducibility of ±0.85 ns was demonstrated on a 7075 aluminum alloy plate, corresponding to ±1700 lb/in^2 (±11.7 MPa) stress variation in steel. Uniformity has been demonstrated to be dominated by dimensional differences in the transducer array–metal surface coupling. The array face is now being flattened to eliminate this problem, and uniformity will be ensured by a computer-stored calibration data set and correction routine.

Further testing under the present contract is planned to verify instrument accuracy and precision, detect the presence of a crack in a steel plate, and map the stress field on an aluminum bar under a 4-point load.

The development of this acoustic tomographic technique for residual stress measurement is being coordinated with the engineering of an X-ray stress analyzer (RP823-1). These two nondestructive approaches to residual stress measurement will yield valuable data on plate, pressure vessel, and pipe (both inside- and outside-diameter) conditions. Acquisition of such data is expected to lead to more cost-effective inspections, reduction in plant capital expense, and reduction in repair frequency through mitigation of the IGSCC problem in austenitic welds. *Project Manager: J. R. Quinn*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

POWER SYSTEM PLANNING AND OPERATIONS

Transient and midterm stability

Large-scale power system disturbances have become of greater concern to both the industry and the public during the last decade. One way to minimize the effects of such disturbances is to analyze their causes. Unfortunately, because today's system analysis tools are inadequate to do this effectively, new and better tools are needed.

The goal of a five-part research project is to develop new analytic tools to facilitate studies of large-scale disturbances (RP1208). New concepts in computation structure, network simplification, and numerical analysis will be incorporated in any new operating computer program that may result. The contractors involved will draw on the results of RP670, RP745, and RP763 for improved techniques involving transient stability and midterm stability computations, dynamic equivalents, and numerical methods.

Arizona Public Service Co. (APS), the lead contractor on RP1208, is responsible for coordinating the efforts of the other four contractors. In addition, APS is in charge of computer program coordination, evaluation, and documentation. APS will also be incorporating an improved, two-terminal dc transmission line model, as well as improved machine models and auxiliaries. Arizona State University (ASU) is conducting the research efforts involving network reduction and output analysis. Boeing Computer Services, Inc. (BCS) is providing the numerical integration algorithms, step-size control, machine model modularization, and system relative-angle computations. Systems Control, Inc. (SCI), in conjunction with Energy Systems Computer Applications, Inc. (ESCA), has been developing algorithms for midterm generator aggregation and generator bus reduction. ESCA is extending the aggregation-reduction process to include the external system on a prefault basis.

This project was started during the first quarter of 1978 and is scheduled to continue through October 1980. As the work progresses, ASU, BCS, SCI, and ESCA will provide APS with new or revised computer subprograms for implementation and evaluation.

Transient and midterm stability computations use large amounts of computer storage and time, so parallel processing is also being investigated as an alternative that will provide results with shorter run times and reduced costs. Both BCS and SCI are working on algorithms involving array processors. *Project Manager: John Lamont*

Human factors affecting dispatch operators

Dispatch centers are staffed around the clock with teams of skilled, experienced operators who make the necessary decisions to maintain power continuity or quickly restore power following a storm or other emergency. Unfortunately, the number of power interruptions reported to the Federal Power Commission each year has been growing. Part of the reason is that communications capabilities adequate for normal operations often tend to become overloaded or ineffective during emergencies.

Humans are normally extremely adaptable and can put up with inconsistent or unfamiliar environments and procedures. However, inconsistent or unfamiliar data formats in operating procedures often cause stress when individuals are confronted with emergency situations.

The industry is gradually changing from substations that are manned to substations that are remotely controlled via supervisory control and data acquisition (SCADA) systems. These systems require the SCADA operator to perform restoration procedures that earlier were shared by several substation operators. Such a potential bottleneck may extend the period of interruption rather than shorten it.

Dispatchers who are accustomed to functioning with strip chart recorders, a power system wall diagram, and voice communications may not be as confident when using cathode-ray tubes (CRTs) and keyboards. In fact, some dispatchers cannot distinguish between the colors used on CRTs as well as others can.

A new EPRI research project has been initiated to study the environment in which the power system dispatching team is now expected to make its decisions (RP1354). The purpose of the study is to investigate dispatcher environments and to identify human-engineering deficiencies common to the majority of sites surveyed. The deficiencies will then be analyzed to determine how better information processing and/or presentation techniques can improve the dispatchers' environment.

A number of utilities, representing a cross section of the industry, have agreed to cooperate in the survey. The contractor, Stagg Systems, Inc., has developed several information-gathering techniques for use during the site survey. The information will be gathered from structured interviews with operating and support personnel, photodocumentation, light- and audio-level recordings, copies of guidelines and operating procedures, and various other sources. *Project Manager: Donald Koenig*

DISTRIBUTION

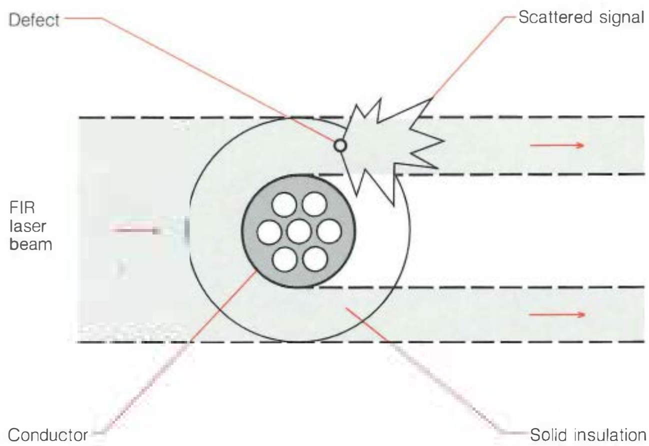
Laser inspection of polyethylene-insulated distribution cable

Over a billion feet (300 million meters) of high-voltage distribution cable insulated with polyethylene and cross-linked polyethylene are presently installed in the United States. Approximately 100 million additional feet (30 million meters) are being installed each year. There is growing evidence that the anticipated 30–40-year life expectancy of these cables may not be attained. Several utilities have reported they are experiencing more frequent failure than expected on cables in service less than 15 years. It is possible that other utilities with cables operating at other electrical stress, energized for fewer years, or subject to less lightning incidence will, in time, also experience premature failure. Since a large portion of the installed cables are direct-buried, with replacement costs of $5–$15/ft ($15–$46/m), the utility industry is confronted with a large potential expenditure to replace failed cable much earlier than originally anticipated. An additional concern is that replacement cable and new installations may also experience premature failure, resulting in a continuing problem of early cable failure and attendant replacement costs.

Reliable field service of extruded-polyethylene-insulated cables depends on the purity of the dielectric material and the processing techniques associated with cable manufacture. The manufacturers of electric power cables have directed their efforts toward eliminating microporosity, voids, and contaminants during the manufacturing process. However, an instrument to continuously monitor the quality of the cable during extrusion is not available. An instrument that can provide a continuous inspection and characterization of cables during extrusion and identify the presence of microporosity, voids, and contaminants during the manufacturing process is an essential tool for a meaningful quality control program.

A project with United Technologies Research Center (RP794) is aimed at the development of an instrument that can inspect cable insulation in real time during cable manufacture. The system uses a far-infrared (FIR) laser beam (wavelength 119 μm) to penetrate the cable insulation. If the insulation material is homogeneous, the laser beam passes through the insulation unimpeded (but not through the conductor itself). If the laser beam encounters a void or contaminant in the insulation, it is scattered (Figure 1). Sensors are arranged to detect the scattered signal, and a trace of the scan is recorded for analysis (Figure 2).

Figure 1 A far-infrared (FIR) laser beam passes unimpeded through homogeneous solid insulation (except for that portion blocked by the conductor) but is scattered by defects.



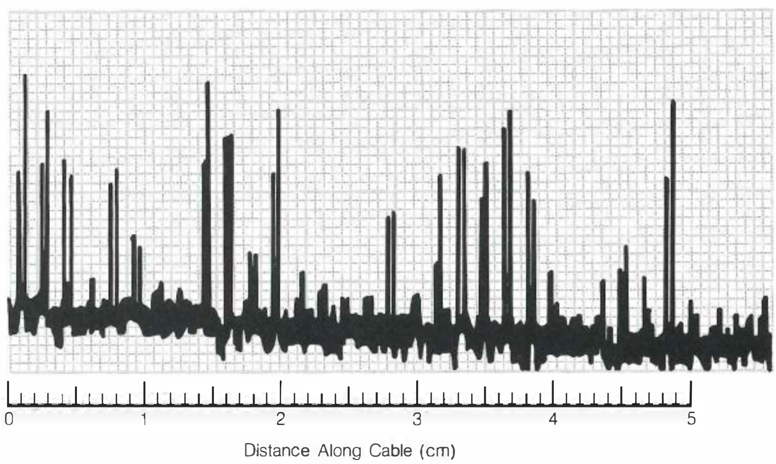


Figure 2 Scattered FIR laser signals, detected by sensors, are recorded and studied to characterize cable insulation flaws. Spikes indicate the positions of voids and contaminants along the length of the cable.

The Phase 1 feasibility study was started in May 1976 and concluded in December 1977. An EPRI report has been published that details this work (EL-738). In this phase, a single, fixed laser beam, used to demonstrate the feasibility of the concept, showed that defects as small as 63 μm (2.5 mils) can be detected in a 25-kV cable.

After the concept's feasibility was demonstrated in Phase 1, a Phase 2 development was conducted from January 1978 through June 1979. In this phase it was demonstrated that the laser beam could be swept rapidly through the insulation of a moving cable so as to penetrate all the insulation volume except the area blocked by the conductor. In addition, techniques were developed for identification and characterization of the defects by studying the scattered signal. This phase culminated in demonstration of real-time inspection of defects in power cable insulation. It also demonstrated that aberrations of the conductor shield could be detected in addition to voids and contaminants in the insulation material. An EPRI report will be available early in 1980 that details this phase of the project.

The development of this cable inspection instrument is continuing in Phase 3, which began in July 1979 and is expected to be completed in June 1981. The two major goals for this phase are to establish the practicality of a cable inspection system that is compatible with and applicable to cable manufacturing and to establish the nominal system specifications and the design criteria for a prototype cable inspection instrument suitable for use in a factory environment.

This system will use an array of laser beams and detectors to minimize the area shadowed by the conductor. The design objective is to inspect at least 95% of the insulation volume of a 5-cm^2 (1000 kcmil) cable with 0.445-cm (0.175-in) insulation thickness. It is expected to culminate in the laboratory demonstration of an instrument that will inspect long cable lengths moving at typical factory extrusion speeds. *Project Manager: Joseph Porter*

Integrated control and protection of distribution substations and systems

Automatic control and protection of distribution substations has steadily advanced to its present high level of efficiency and reliability. In fact, conventional control systems have exploited what appear to be the maximum practical and economic capabilities of electromechanical and analog devices.

The continued growth of power demand, the customers' expectation of service quality and reliability, and the increased cost of energy have prompted utilities to explore and implement system automation with computer-based technology. Automating distribution substation control and protection through digital techniques and integrating them with distribution system controls allow utilities to:

- Improve the economics of distribution plant operation
- Conserve energy through implementation of load management by system monitoring and control
- Improve service continuity by faster and automatic response to system outages, overload conditions, and various other troublesome distribution problems
- Relieve system operators of repetitive functions that can be performed more efficiently by computers

The advantages of digital techniques have already been proved in some power system applications, but the use of digital techniques for the protection and control of distribution substations and systems is still in its infancy. Nevertheless, recent decreases in digital hardware costs and rapid increases in utilities' costs of operation, construction, and maintenance have paved the way toward application of faster and more responsive techniques in the protection and control of distribution systems.

General Electric Co., under the sponsorship of EPRI, has been selected to develop and demonstrate a digital-based protection and control system. The system will be installed on the Texas Electric Service Co. system in Fort Worth (RP1472). This project has as its overall objective the development and demonstration of an engineering prototype of a computer-based system for automating distribution substation protection and control. To integrate this system with complementary transmission protection devices and controls, remote dispatch controls, and remote distribution feeder control devices will be employed via a bidirectional communication system. *Project Manager: T. J. Kendrew*

Distribution system simulator

A power distribution system is the network of primary-voltage lines (usually 4–35 kV) that supplies residential and commercial customers. Until recent years the principal distribution concerns were related to frequencies of 60 Hz—such variables as current, voltage drop, and power factor. Except for lightning surges, non-power-frequency phenomena were of minor importance and only occasionally warranted detailed study.

The prominence of non-power-frequency voltages and currents on distribution systems has increased considerably in recent years. In both the transient and steady-state timeframes, these voltages and currents are being generated in increasing variety and frequency. The new generators combine with the traditional sources to make a long list of non-power-frequency voltages and currents that propagate on the modern distribution system. The more important sources include the following:

- Fault clearing by current-limiting devices
- Capacitor switching
- Transformer magnetization
- Ferroresonance
- Lightning
- In-rush current and switching surges
- Power line carrier
- Load components, such as rectifiers, fluorescent lights, and motor speed controllers
- Arcing faults

Some of these sources have always existed but now must be considered in detail either because of their adverse effect on sensitive loads and system operation or because of their potential utility use. For instance there is renewed interest in power line carrier in connection with communication systems for distribution automation (RP850).

The analysis of the 60-Hz behavior of a distribution circuit is relatively easy compared with the analysis of higher-frequency components. As the frequency increases above the low-order harmonics, a distribution circuit can no longer be represented simply by lumped inductances and resistances. Additional characteristics of the circuit must be considered—for example, capacitance and the signal-modifying effect of line junctions. As a result, the behavior of the higher frequencies is extremely difficult, if not impossible, to analyze by manual computation.

Existing digital computer codes and analog analyzers are useful primarily for transmission systems, which tend to employ fewer kinds of equipment and simpler circuit configurations than distribution systems. Similar analytic aids are needed to give a distribution engineer the opportunity to study the non-power-frequency components on the system. A 16-month project was undertaken to prepare for the design and construction of such an aid—a distribution system simulator (RP1526).

The objectives of the project are to identify the various non-power-frequency voltages and currents that appear on a distribution system and the uses to which a simulator may be put, to define the requirements for the design of a simulator, and to plan how one could be developed and built.

In carrying out this project, McGraw-Edison Co., Power Systems Division, has surveyed the literature for data applicable to the simulation of distribution systems and equipment. It has also held several one-day seminars for small groups of utility engineers, who contributed the utility viewpoint of potential simulator uses and functional requirements.

Presently, the non-power-frequency components are being categorized and their relationship to the system and equipment is being defined. This investigation will lead to the outlining of simulator requirements—a process that will describe the simulator in broad terms.

The simulator is envisioned as a digital computer code containing the mathematical models and algorithms necessary to solve problems in all frequency and time domains.

A modular construction is anticipated, which, along with interactive access, is expected to offer maximum flexibility in construction, maintenance, and use.

With the functional requirements and the general design of the simulator thus established, McGraw-Edison will prepare a plan that includes recommendations for the following.

- Simulator architecture
- Computer methods and hardware, taking into account expected improvements in the state of the art
- Software development and language
- Compilation of the model library
- Verification tests and methods

McGraw-Edison will also estimate the level of effort needed to build the simulator. Thus the utility industry will have all the information necessary to assess the benefits of the simulator in relation to the cost and to decide whether to proceed with design and construction. *Project Manager: Richard Lambeth*

Broadcast radio system for distribution communications

One of the requirements for the future success of distribution automation and load management is the development of communication and control systems that are reliable and cost-effective. Without such systems, it is impossible to provide distribution automation functions, such as sectionalizing of feeders, switching of capacitor banks, and load management functions (e.g., load control and remote meter reading). EPRI and DOE are jointly sponsoring research to determine the capabilities and limitations of three technologies: power line carrier, radio carrier, and telephone carrier.

Radio communications have unique advantages in that they connect point-to-point, provide long-range service, and are independent of the power distribution system (i.e., they do not use utility poles or substation equipment). For some utility purposes, radio communication can be less expensive and provide capabilities unattainable with telephone and power line carrier communications. Present one-way and two-way radio communication systems are too expensive for systemwide utility load management applications for residential customers. To improve the performance and reduce costs for utility applications, EPRI is sponsoring research in UHF radio (940–952 MHz), VHF radio (154 MHz), and medium-frequency (broadcast) radio (550–1600 kHz).

EPRI has contracted with Altran Electronics, Inc., to develop and evaluate a bidirectional radio communication system (RP1535). The system will involve two parts: a forward link that uses a standard broadcast channel and a return link that uses a VHF channel assigned for utility communications. This project will test the unusual concept of using the broadcast station to provide inexpensive and reliable communications to utility customers without interfering with the standard broadcast service.

The forward link will use phase modulation for digital data communication, and this modulation must not interfere with the standard amplitude modulation used for analog voice communications in the broadcast radio band. The FCC has authorized EPRI to use the CBS clear-channel station KNX in Los Angeles for the tests; station KNX operates at 1070 kHz with 50 kW effective radiated power. It is expected that KNX will provide reliable forward (control) communications covering an area exceeding 40,000 km² (14,400 mi²).

A second concept uses a VHF link to provide narrow-band communication. Using the broadcast carrier signal as a reference, the VHF link can be synchronized so that a conventional VHF channel can be divided into several subchannels, allowing several remote transmitters to be polled simultaneously for remote meter reading and status reading.

If the prototype tests are successful, 50 units will be fabricated and tested in the field for six months. EPRI has selected Southern California Edison Co. to be the host utility to test and evaluate the performance of the system. The system tests are scheduled for 1980, and results should be available in December 1980. *Project Manager: William E. Blair*

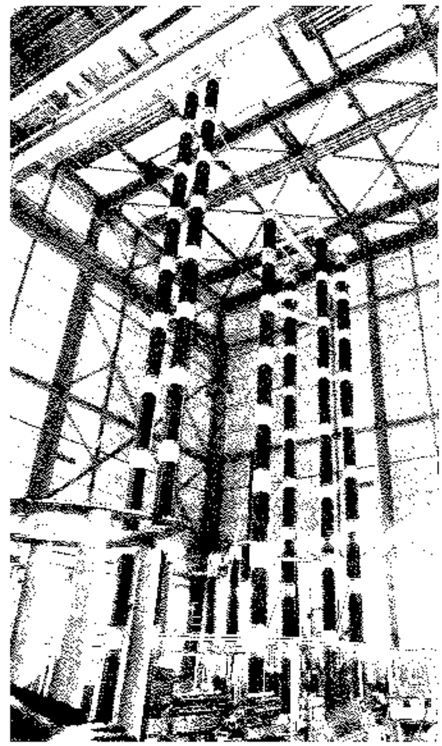
OVERHEAD TRANSMISSION

HVDC transmission line research

In the fall of 1978 new facilities for HVDC transmission line research were dedicated at Project UHV in Lenox, Massachusetts. These facilities provided bipolar voltages up to ±750 kV and were initially used for the study of fields and ions. New equipment has been added to make it possible for EPRI and DOE to conduct research into bipolar HVDC transmission lines with voltages above ±600 kV (RP1282). The power supply dedicated in 1978 was furnished by DOE. The complementary EPRI power supply is now operational.

Under this contract, General Electric Co.

Figure 3 EPRI HVDC power supply to be installed at the Lenox test site, showing the 1500-kV dc, 120-mA Haefely test set supplied by American HV Test Systems, Inc. Under construction at this point, the test set will be 16.1 m (53 ft) tall when complete. It is mounted on rails to facilitate relocation for different test configurations. This set will energize one-half of the bipolar test line, and another power supply will energize the other half for long-term tests.



will provide utilities with the design information (conductor sizes, insulators, and air distances) needed for future HVDC transmission systems operating between ±600 kV and ±1500 kV. The 48-month project will include full-scale tests of HVDC line configurations and will use existing test lines, equipment, and staff at the Project UHV facility. A parallel 40-month project supported by DOE will include the study of the electric fields and ions produced by bipolar HVDC lines above ±600 kV.

UHV ac testing, which has been going on at the Lenox facility for the past 12 years, was completed October 1, and the facility is being reconfigured for the dc testing now scheduled to begin January 1, 1980. The total cost of the HVDC line research, including reconfiguration of the facility, is $5.5 million.

Line configurations at the highest voltages (between ±1000 kV and ±1500 kV) will be tested from January through September 1980. For the remainder of the project, efforts will concentrate on the study of lines with voltages in the ±600- to ±1000-kV range, where the most immediate need is for design data. A design reference book for HVDC lines will be prepared during the project.

At the conclusion of this research project, an ac-dc research facility will be made available for testing new conductors and insulation systems, testing concepts for specific system applications, and obtaining data for advanced applications. *Project Manager: Richard Kennon*

UNDERGROUND TRANSMISSION

High-temperature, gas-insulated cable systems

The basic aim of RP7850, recently completed by Gould–Brown Boveri Inc., was to design, engineer, and test a gas-insulated cable system that would offer a significant cost reduction over systems presently in use. This improvement in performance was to be achieved by using lower-cost components, by operating closer to the intrinsic thermal limit of the insulation system, and by possible introduction of forced cooling.

Although there are obvious advantages to the increased temperature limits associated with gas-insulated systems, a realistic upper limit had to be established so that an optimal balance between hardware cost, installation cost, and cost of losses could be established. Because this upper limit is a sensitive function of the three basic cost components and relative costs may vary significantly in future years, the feasibility of operating at a conductor hotspot temperature of 150°C was examined so maximum design freedom could be retained. The 150°C upper limit was chosen because of general agreement that SF_6 can be operated at least up to this level.

Tentative conclusions or results were reached in six major research areas: general design, insulation, enclosures, conductor joints, heat transfer, and prototype development.

For general design, increased temperature limits lead to reduced present-worth cost for underground self-cooled systems above a certain power level, but the optimized conductor temperatures still remain substantially below 150°C. It appears economically desirable to operate continuously with conductor temperatures in the 100–110°C range. For short-term overload capability, however, systems should be built with a hot spot capability of 150°C, even if that temperature is rarely attained. In general, forced cooling does not provide improved economics as a steady-state option, but it may be attractive for short-term overload capability.

The insulation researched consisted of 63 insulator base materials and 26 coatings; all were tested to find the optimal material for operation at 150°C and 5.905 kV/mm (150 kV/in). Two materials were identified as the best, based on a combination of such properties as resistance to arc tracking, glass transition temperature, dielectric constant, dissipation factor, and dielectric strength. Samples of both these insulating materials were exposed to a hot-dielectric life test at 150°C and 7.874 kV/mm (200 kV/in) for more than 15,000 hours without failure.

A star-shaped insulator that used considerably less material than the equivalent disc insulator has been designed and perfected through repeated mechanical and electrical testing for a 242-kV rating at 0.27 MPa (26 psig) and for 362-kV at 0.37 MPa (40 psig). However, manufacturing problems still exist with one of the two materials.

Various alternatives were investigated to obtain an aluminum-to-copper transition at the conductor joints. Friction and inertia welding and commercially available Al-Cu laminates were considered. None proved to be practical for a diameter corresponding to the conductor. Friction-welded joints of 2-cm (0.79-in) diameter are available as needed for a flexible cable joint, but long-term stability of aluminum-to-copper joints is questionable because of the formation of intermetallics at elevated temperatures.

A wear-test fixture was built and operated to test sliding contacts under realistic conditions in an SF_6 atmosphere at 150°C; the tests covered sliding motion, continuous current loading, and contact pressure. Reliable operation for 50,000 wear cycles with 200 A/finger at 150°C was demonstrated with suitable materials.

The heat transferred by thermal radiation represents 15–20% of the total when a system is operated at 0.3 MPa (30 psig). The emissivity of internal surfaces can be raised by a factor of 6 by coating with a flat black paint; painting only the conductor raises the radiative heat transfer by a factor of 2.3.

Components developed in this project were incorporated into a 9-m-long, 362-kV prototype. The ampacity corresponding to a 150°C hot spot temperature was determined for three modes of installation: open air, covered trench, and direct burial. To conclude the project, the entire system (including the developed components) was successfully tested under steady-state and transient conditions, including the use of forced cooling. *Project Manager: John Shimshock*

ROTATING ELECTRICAL MACHINERY

Torsional fatigue life of large shafts

Damage to turbine-generators caused by transmission line transients, out-of-phase synchronizing, fast reclosing of breakers, and other switching is a problem of increasing importance to the utility industry. Although any one of these occurrences may not cause failure, damage is cumulative over the life of the turbine-generator because each transient produces torques that can reduce the fatigue life of the turbine-generator shaft. Damage resulting from excessive fatigue can then cause long, time-consuming, and extremely costly outages.

A method of predicting shaft damage at the planning stage is needed for new systems and for additions to existing systems. A prerequisite for such work is a method of predicting the fatigue life of a turbine-generator shaft. A project to provide this method has been placed with General Electric Co. (RP1531). After an analytic method of predicting the torsional fatigue life of turbine-generator shafts has been established, the method will be validated by tests on large specimens. This four-year project is expected to be completed in 1982.

In a related project, EPRI has funded research to determine the electromagnetic response of turbine-generators to subsynchronous resonance conditions (RP1513). These conditions result from application of series compensation on long transmission lines, which introduces currents in the system that can cause mechanical resonance of the turbine-generator shaft. This resonance can cause severe damage to the shaft.

The largest unknown factor in solving this problem is the prediction of the generator's characteristics under subsynchronous resonant conditions. To design a system that uses series compensation, the effect on the turbine-generator must be predicted in advance. A development project has therefore been initiated by General Electric to provide an accurate model of a generator. This model will then be used to predict the generator characteristics under subsynchronous conditions. Equipped with the capability to predict the turbine-generator's reaction to these conditions, system designers can then apply series compensation with confidence, which in turn should defer or eliminate additional parallel transmission lines in many instances.

In the first phase of this project, the torsional mechanical stability and transient mechanical response of the turbine-generator will be determined in terms of its terminal impedance, and torque-producing characteristics will be determined as a function of the shaft's resonant frequency. Validation tests will then be performed on a suitable generator to verify the calculations. *Project Manager: James Edmonds*

High-voltage stator winding development

Superconducting generator conceptual design studies completed in 1977 indicate that a generator constructed with an air-gap winding offers the opportunity to design this type of generator with a high-voltage winding suitable for direct connection to a transmission line. Such a generator would eliminate the need for (and cost of) a step-up transformer and improve present efficiency by about 1%. Total efficiency savings from use of a superconducting generator at a rated transmission network voltage without a step-up transformer would be about 2%.

Conventional generator armatures manufactured according to present design practices limit the terminal voltages to a maximum of about 30 kV. No existing design methods (using conventional armature winding configurations) will allow operation at 235–500 kV. To accomplish this requires the development of a new insulation system, probably using concepts similar to those of high-voltage transformer technology. Such a design must provide for adequate cooling of the armature and must electrically isolate it from the rest of the generator.

EPRI is funding a three-year project to produce a primary conceptual design, with at least one alternative design for a high-voltage stator winding for large cylindrical-rotor synchronous generators (RP1716). *Project Manager: James Edmonds*

Fiber-composite retaining rings for turbine-generators

Most of the generating capacity installed between 1980 and 2000 will be served by large turbine-generators running at 3600 or 1800 rpm. Each of these generators requires two extremely high-stressed retaining rings to support the end windings of the rotating field. These rings must support the entire weight of the copper end windings when rotated at rated speed and must also endure stress caused by supporting their own weight. The utility industry and the manufacturers need a ring material that is lighter, has a higher strength-to-weight ratio, and is capable of being manufactured by presently available facilities in the United States. At present, these rings can be obtained only from overseas vendors.

A material such as carbon-fiber composite could possibly offer a solution to this problem. This material is readily available in this country and the rings would be produced at a price that should be significantly lower than rings manufactured overseas. Using this material should also bring a significant improvement in the quality of generator rotors. To pursue these goals, EPRI has funded a project with Westinghouse Electric Corp. to develop a carbon-fiber material suitable for the manufacture of retaining rings and to manufacture and test a completed, full-size ring progressively to destruction after many nondestructive tests have been made (RP1474). The resultant information and proof tests should provide an improved, lower-cost method for manufacturing retaining rings from this new material. *Project Manager: J C White*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

HIGH-VOLTAGE HEALTH EFFECTS STUDIES

*Overhead high-voltage transmission is the most effective way to move large amounts of electric energy over long distances. Higher line voltages improve transmission efficiency and cut costs (*EPRI Journal, *June/July 1977, p. 7). However, accompanying the higher voltages and currents applied to the lines are higher electric and magnetic fields that reach the ground beneath the lines. Public concern about whether these fields affect health has grown rapidly in this decade, and EPRI is sponsoring a number of projects to resolve this question.*

Before new high-voltage lines can be sited and rights-of-way granted, utility representatives must appear at public hearings to convince local authorities that no evidence exists linking the electromagnetic environment to serious health or safety risks. One of the key triggers of this concern was a Soviet report to the 1972 CIGRE Conference in which a variety of maladies suffered by switchyard workers were attributed to electric fields. Since then, several articles in the popular literature have quoted the assertions of the Soviets and other researchers that 60-Hz electromagnetic fields pose a serious health risk. Much of the research cited in these articles was not carried out in well-engineered exposure systems, nor were the studies validated by replication. As a result, the scientific community and the electric utility industry have felt the need for research programs that would methodically address the issue of how 60-Hz electromagnetic fields interact with biological matter.

In 1974 EPRI initiated its high-voltage health effects subprogram, an extension of activities begun earlier by the Edison Electric Institute. At that time the IIT Research Institute (IITRI) in Chicago undertook a state-of-the-art literature review to help provide direction for the program (RP381). This review, originally published in 1975, has been updated in a recent EPRI report (EA-1123), which outlines areas that warrant immediate research.

Effects on cardiac pacemakers

One such area concerns the question of whether electromagnetic fields from overhead transmission lines can interfere with the operation of implanted cardiac pacemakers. Almost all pacemakers in use today are R-wave inhibited; that is, they are quiescent until the heart misses a beat, at which point they pulse the heart once and then await the next missed beat. If interference is picked up, the pacemaker will revert to a mode in which it pulses the heart independently of any other stimuli. Cardiologists agree that reversion is not in itself hazardous.

To investigate the pacemaker question, IITRI undertook a project to mathematically model the interaction between electromagnetic fields and pacemakers and to test pacemakers implanted in baboons (RP679-1, RP679-2, and RP679-3). The IITRI research showed that reversion is the worst-case consequence of 60-Hz irradiation and that under most conditions, reversion is not probable. Similar findings were obtained when the interaction between pacemakers and the electromagnetic environment of a high-voltage dc converter station was studied. Although there was a high probability that reversion would be initiated at certain locations in the converter facility, it was determined that a patient would not be endangered. These studies are soon to be published by EPRI. The final phase of the pacemaker research is under way at the University of Rochester, where human pacemaker patients are being exposed to transmission line environments under constant medical supervision (RP679-6).

Other major research projects are examining the effects of electric fields on a variety of living systems: honeybees, crops and other plants, birds, and large and small mammals.

Effects on honeybees

Honeybees are being studied for three basic reasons. First (and central to research needs), the beehive contains a highly organized and integrated caste society in which each individual is programmed from conception to death (roughly two months) to perform specific functions. If power line environments produce biological alterations, such changes could stand out clearly in the complex but highly formal chain of beehive events. Second, each beehive contains upward of 50,000 bees, an enormous sample size. Third, a number of commercial apiaries, for convenience of space, are located beneath transmission lines, and beekeepers are concerned about whether this environment will affect honey production.

Bioconcern (RP934-1) and an IITRI engineering team (RP934-2) have developed an approach to studying beehives under the 765-kV Commonwealth Edison Co. line near Joliet, Illinois. Preliminary results indicate that hives situated in the field gain less weight, have lower brood production, and may fail to survive the winter. As a defensive mechanism, the exposed bees tend to deposit a resinous substance called propolis around the hive entrance. Before concluding that electric fields per se are responsible for these effects, researchers must exclude the possibility that the bees are receiving unavoidable minishocks (a sensation similar to that which one receives after walking across a carpet on a dry day and touching a doorknob). These minishocks would arise from field-induced voltages on the hive parts and, if present in sufficient magnitude, would likely be stress-provoking. Whether fields alone or minishocks are responsible for the observed effects awaits resolution.

Effects on plants

Since 1974, engineers at Westinghouse Electric Corp., in collaboration with biologists at Pennsylvania State University, have sought to determine what effects electric fields have on seedling plants (RP129 and RP1064). The issue of risk to plants is important because transmission lines are often sited over valuable farmland. Researchers at PSU have studied 85 species of seedling plants, including crops of economic importance, such as corn, wheat, and alfalfa. They observed that other than limited damage to the tips of pointed leaves, the seedlings were not affected by fields up to 50 kV/m, roughly five times the maximum field strength found beneath the largest lines. Only pointed leaves are susceptible to damage because the electric field is enhanced at the leaf tip. If enhancement exceeds a threshold, the air around the tip ionizes, a condition known as corona. With the onset of corona, the tip of the leaf is singed but there is no further damage.

It is still unknown whether maturing and fully grown plants are affected. A greenhouse containing overhead electrodes (9 ft high) is now under construction at EPRI's Waltz Mill facility. Species such as corn, wheat, oats, alfalfa, and soybeans will be allowed to germinate and grow in the electric field. Scheduled for completion in 1981, this research should provide important information to utilities and farmers.

Effects on birds and small animals

The PSU small-animal studies, under the same project, analyzed the electroencephalograms (EEGs), electrocardiograms (ECGs), body weights, and gross motor activities of domestic chicks that had been exposed to 40- and 80-kV/m fields for three weeks. No adverse effects were observed in the EEGs, ECGs, or body weights, but gross motor activities were reduced by 28% in the fourth week of life, that is, after exposure had terminated. There is as yet no explanation for this result, although it may be related to an ability to perceive the field through feather stimulation. PSU researchers have demonstrated that pigeons can perceive fields as low as 10–20 kV/m. This area of investigation will continue.

Another experiment at PSU examined how corticosteroid levels in mouse blood were affected by 25–50-kV/m fields. (Corticosterone is secreted by the adrenal cortex into the blood when an animal or human is under stress.) After a brief (45-min) increase in steroid secretion when the mice were introduced to the field, the levels dropped to normal for the remaining six weeks of the experiment. The researchers feel that the brief increase in steroid does not represent true stress as much as it reflects a short period of adaptation to a newly perceived stimulus.

Interpretation of animal studies and extrapolation to humans must be tempered by the realization of an important fact: to simulate human exposures in small laboratory animals, larger fields must be generated. This is because the field is distorted when biological matter is introduced into it, and the extent of the distortion is dictated by the size and shape of the subject. Thus, an 80-kV/m exposure to a chick (or a mouse) is roughly equivalent to human exposures of 5 kV/m under actual conditions.

The animal work at PSU is now turning to the investigation of field effects on developing chick embryos. An exposure facility with a capacity for 1600 eggs is in place, and experiments are under way. Chick eggs are considered excellent for studying electric field effects because the dose to each egg is relatively easy to calculate (field enhancement is very predictable on the egg's rounded surface) and because the embryo is a system undergoing rapid cell division, thus allowing investigation of whether fields interfere with the cell cycle.

At Battelle, Pacific Northwest Laboratories an interdisciplinary team has constructed and implemented exposure systems for small (mice, rats) and large (Hanford miniature swine) animals. The small-animal research is being supported by DOE and the large-animal research by EPRI (RP799-1). This joint study represents the largest effort of its type ever undertaken.

To summarize briefly the small-animal results to date, no effects have been observed in growth, development, metabolic status, fertility, or cardiovascular function after 120-day exposures to 100 kV/m. Subtle effects have been observed in the areas of immunology, behavior, and neurophysiology. The immunological studies showed that although the humoral immune responses (those related to antibody production) were unaffected, exposure to the field decreased the skin response to a foreign protein. The skin response, similar to that seen in a positive tuberculin test, is linked to the cell-mediated immune response. Humoral and cell-mediated immune responses together make up the major components of the immune system. These results may reflect perception of the field at the animals' skin rather than a true effect on the immune response.

Behavioral tests measured the rats' preference to remain in the field or seek a shielded area. The rats avoided 90 kV/m but surprisingly showed a preference for 50 kV/m. These results have not been interpreted. In the neurophysiology studies, ganglia (the major junction points in nerve pathways) from exposed rats displayed a slightly higher excitability than those from controls. Again, the results are open to interpretation.

Effects on large animals

The large-animal studies have only recently begun, and there are no data to report at this time. The major accomplishment has been construction of a facility to house 40 miniature swine (60 kg when fully grown) in a 30-kV/m field and an accompanying control facility to house 20 swine in conditions that are identical except for the electric field. At the completion of the project, researchers hope to have a complete survey of the biological status of the animals originally placed in the field, plus two generations of offspring conceived, born, and raised in the exposure facility.

The research to date has suggested that if ac electric fields induce biological effects, the nervous system and possibly the endocrine system are the likely sites. To explore these possibilities further, EPRI has recently funded work at Tulane University (RP1641) that will involve both live animal exposure and evaluation (in vivo) and exposure of adrenal cortical tissue isolated and placed in a culture medium (in vitro). The adrenal cortex secretes corticosterone; the stimulus for secretion is adrenocorticotropic hormone (ACTH), a circulatory mediator secreted by the central nervous system into the circulation system. The in vitro experiments will show whether the electric field stimulus modulates ACTH-induced corticosteroid secretion. A major objective of the in vivo experiments will be to determine whether electric fields disrupt information transfer on selected nerve tracts. It is still too early to report results.

As part of its expanded field of research, EPRI's Biomedical Studies Program is beginning to tackle important problems in the occupational health area (*EPRI Journal,* May 1979, p. 59). In the high-voltage area, Tabershaw Occupational Medicine Associates, P.A., will begin an epidemiological study of linemen and switchyard workers in January 1980 (RP1644). The aims of the study are to provide information on individuals regularly or frequently exposed to high-level electric fields and to use an electric field dosimeter to provide estimates of exposures from various utility tasks and procedures. In preparation for the full-scale epidemiological study, Equitable Environmental Health, Inc., prepared a feasibility study (EA-1020) that delineated the various approaches available and pointed out their potential pitfalls.

Evaluating the results

Through its high-voltage health studies subprogram, EPRI is gathering the information necessary to evaluate the risks associated with exposures to ac electric fields. Given the variety of life-forms being researched and the broad range of biological parameters being measured, there is small doubt that some field-induced effects will be uncovered. The question about how serious these risks are will continue to be debated in the regulatory and political arenas, and decision makers will have to grapple with the issue of how one discriminates between a biological effect and a biological hazard. EPRI's objective is to collect the most reliable scientific information available.

A future report will discuss planned studies related to the health effects of dc transmission, about which many questions remain unresolved. EPRI hopes to help the industry anticipate the environmental and health impacts of this developing technology. *Project Manager: Robert Kavet*

ANALYZING ATMOSPHERIC PARTICLES

In recent years the utility industry has been paying increasing attention to the particulate matter in the atmosphere. Results of recent research indicate that particles may play a role in human health effects, the formation of acid rain, and visibility degradation. This is of importance to utilities because the burning of coal is one significant source of particles in the atmosphere. Unfortunately, the actual chemical composition of individual particles emitted from stacks is largely unknown. This makes assessment of the environmental effects difficult. However, new techniques for examining particle surfaces by means of energy beams are being applied for detailed characterization of particulate matter.

Typically, atmospheric particles are collected in mass (i.e., thousands of particles are collected on a filter), and chemical analyses are run on this mass. Although it is possible to learn which elements are present in the mass, there is no information on how these elements are combined within individual particles. Knowledge of precise composition (and form) is important for designing meaningful toxicology experiments and for assessing the role of utility activity in creating such phenomena as acid deposition and visibility reduction. This information is also needed for understanding the many complex chemical reactions that take place in the atmosphere.

EPRI's Physical Factors Program carried out a feasibility study at the University of Wisconsin–Milwaukee to evaluate the use of new and sophisticated instrumental techniques for characterizing the shape and chemical composition of individual particles (RP1310).

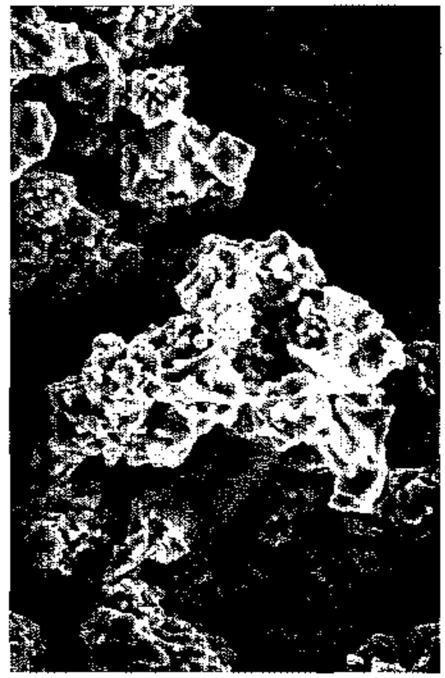
Atomic absorption, infrared spectrometry, spark-arc emission, gas chromatography, X-ray diffraction, and other standard analytic techniques have serious drawbacks for the analysis of microspecies and, in some cases, even for large samples. Generally, these methods examine millions of atoms at a time; consequently, only a bulk analysis is obtained. Certain elements, such as hydrogen, boron, carbon, oxygen, fluorine, nitrogen, phosphorus, and sulfur, are very difficult to detect (especially those in combination with metallic elements) and even harder to quantify.

Irradiating a sample with an electron or ion beam allows investigation of microareas as small as 0.2-μm diameter with depth resolution as small as 0.1 nm (1 angstrom). This means that a region perhaps 2000 atoms wide and only 1 or 2 atoms thick can be chemically identified. Similarly, morphology may be determined for species as small as 50 nm (perhaps a group of only 500 atoms). Thus, energy beam irradiation is ideal for characterization of small (0.1–20 μm) particles and represents the state of the art of microsystem investigation. The analytic equipment capable of this sophistication is referred to by the general term *surface analysis system*. The most useful commercially available technologies are the following.

- Scanning electron microscopy (SEM)
- Transmission electron microscopy (TEM)
- Energy-dispersive X-ray spectrometry (EDX)
- Scanning Auger microscopy (SAM)
- X-ray photoelectron spectroscopy (XPS)
- Secondary ion mass spectrometry (SIMS)
- Ion-scattering spectrometry (ISS)

The appropriate choice or combination of techniques can detect all elements (in many cases, to better than 100 parts per million), reveal information about how these elements are combined (i.e., compound information), and define their location in three dimensions. The analysis is performed on individual small particles, typically of 1–10-μm diameter. Surface area information is initially obtained by irradiation of the particle with an appropriate beam (X-ray, ion, or electron). Depth information is obtained by removal of the surface atoms with an ion beam. Particle size, shape, and topography are obtained by actually forming an electron image, or micrograph, by using the scanning electron microscope. The resultant electron micrograph provides three-dimensional information by detecting electrons emitted from nearly all positions of the particle's surface. Figure 1 is an example of such a micrograph.

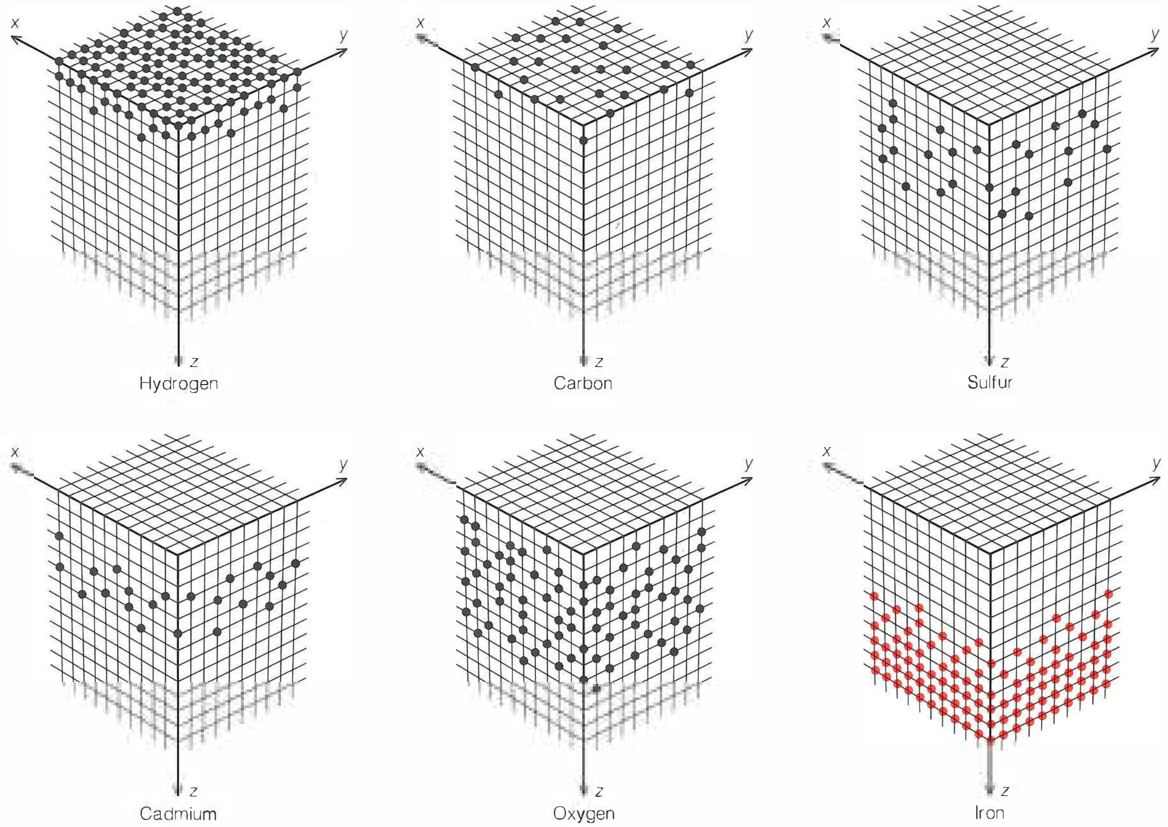
Figure 1 Micrograph produced by a scanning electron microscope provides topographic information on particulate matter.



The TEM system is rather ineffective for imaging the topography of unmodified environmental particles. However, this tool is excellent for very thin samples and can provide crystallographic data. Figure 2 illustrates the types of chemical information that can be obtained with the remaining tools (EDX, SAM, XPS, SIMS, and ISS). The figure demonstrates that the surface of the particle is typically quite different from the bulk.

It is not yet clear which chemical or morphological variables govern the environmental effects of particulate matter. For example, it may be only the top layer of pollutant particles that are a health hazard; or it may be the particle size, shape, or topography that is harmful. Thorough character-

Figure 2 Elemental structure of an iron particle, based on a hypothetical surface analysis measurement. The particle, idealized as having originally been a cube, has been sliced on the *x-z* and *y-z* planes in order to expose the true internal composition. Note that the top surface (*x-y* plane) only shows hydrogen and a little carbon (typically a thin organic coating) and that iron is not present at all in the first six atomic layers. Thus it is evident that this iron particle is coated with a thin layer of a cadmium-sulfur-oxygen compound, perhaps in the form of a sulfate.



ization of particles should aid in providing answers to questions about environmental impact. RP1310 indicated that the use of sophisticated surface analysis systems could indeed provide badly needed information on pollutant particles produced by utilities. Therefore, a follow-on project is planned to continue this characterization on particles actually emitted from power plants. *Project Manager: Jacques Guertin*

ACID RAIN INVENTORY

As part of a state-of-the-art study on ecological effects of acid rain (SOA77-403), the U.K. Central Electricity Research Laboratories (CERL) has compiled for EPRI an international inventory of current and planned research projects on acid precipitation. The inventory attests to the international character of acid deposition research by identifying projects in eight countries: Canada, Federal Republic of Germany, France, Norway, Poland, Sweden, United Kingdom, and United States of America. Researchers responsible for individual projects, as well as researchers and administrators responsible for integrated programs, are listed. Copies of the inventory are available from Robert Goldstein, manager of EPRI's project on acid rain, (415) 855-2593.

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Electrical Systems Division				
RP1142-2	Application Development and Field Trials of 15-kV Current-Limiting Circuit Protectors	2 years	400.9	Phoenix Electric Corp. *J. Porter*
RP1277-4	Transmission Line Wind-Loading Research: Field Measuring Program	17 months	508.0	Synergistic Technology, Inc. *P. Landers*
RP1359-5	Transmission Line Control and Protection System	33 months	707.0	General Electric Co. *S. Nilsson*
RP1422-2	Analyses of Ultrahigh-Speed Relays and Fault Limiter Control Devices	22 months	82.3	Rensselaer Polytechnic Institute *S. Nilsson*
RP1469-2	Calibration of Dynamic Simulation Programs Using Real Time Data Acquisition Systems	7 months	49.8	ESCA Corp. *J. Lamont*
RP1470-1	Development of a Fail-Safe Distribution Surge Arrester	29 months	525.0	General Electric Co. *R. Stanger*
RP1510-1	Revenue Metering Device for High-Voltage DC Transmission Systems	30 months	99.6	Washington State University *S. Nilsson*
RP1511-1	Phototransistor Switch for Breaker Application	2 years	376.0	General Electric Co. *G. Addis*
RP1511-2	Light-Triggered Surge Thyristor for Breaker Application	2 years	364.9	General Electric Co. *G. Addis*
RP1737-1	Power Plant Instrumentation Scoping Study	9 months	80.0	FPA Corp. *J. Lamont*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP983-4	System Optimization Support for CONAC	9 months	233.3	Science Applications, Inc. *O. Tassicker*
RP992-3	Ceramic Materials Applications to Low-Activity Fusion Power Plants	1 year	150.7	Rensselaer Polytechnic Institute *D. Paul*
RP1191-6	Performance Monitoring of Ground/Solar-Assisted Heat Pump Systems	3 months	57.6	Oklahoma Gas and Electric Co. *G. Purcell*
RP1200-7	Factors Controlling O_2 Reduction on Platinum Catalysts in Acid Electrolytes	7 months	60.8	Case Western Reserve University *J. Appleby*
RP1265-7	Failure Cause Analysis—Feedwater Heaters	1 year	80.0	International Energy Associates Ltd. *I. Diaz-Tous*
RP1463-2	Feasibility Assessment of Fusion-Fission Hybrids, Phase 1	18 months	84.2	Lawrence Livermore Laboratory *N. Amherd*
RP1651-3	Air-Gas System Dynamics of Fossil Fuel Power Plants	4 months	41.8	NUS Corp. *I. Diaz-Tous*
RP1658-1	Process Engineering Evaluation of Major Coal Liquefaction Processes	2 years	561.1	Stone & Webster Engineering Corp. *W. Reveal*
Nuclear Power Division				
RP701-2	Stress Corrosion Cracking Investigation of BWR Pipe Remedies	7 months	9.5	Aptech Engineering Services *J. Danko*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP701-5	The Effects of BWR Deaeration on the General and Localized Corrosion of Plain Carbon and Low-Alloy Steel	2 years	186.9	Ohio State University *J. Danko*
RP1116-1	Dynamics of BWR Pressure Suppression Systems	11 months	23.5	University of California *C. Sull*
RP1449-2	On-Line Monitoring and Diagnostics for Reactor Coolant and Charging Pumps	6 months	115.4	Westinghouse Electric Corp. *G. Shugars*
RP1450-1	Evaluation of Alternative Alloys for PWR Steam Generator Tubing	3 years	261.8	Inco Research and Development Center *M. Povich*
RP1554-5	BWR Recirculation Piping Instrumentation, Phase 1	8 months	50.5	Aptech Engineering Services *R. Jones*
RP1557-1	Advanced Low-Level Radwaste Treatment Systems	44 months	208.7	Sargent & Lundy Engineers *R. Shaw and M. Naughton*
RP1579-3	Integrated Design and R&D Assessment of Nuclear Waste Disposal	5 months	42.4	Science Applications, Inc. *R. Williams*
RP1722-1	Feedwater Heater Tube Erosion and Flow Effects	22 months	267.5	Joseph Oat Corp. *T. Libs*
RP1730-1	Evaluation of Reflective Plate and Multifoil Insulation	18 months	118.3	Dynatech R&D Co. *T. Law*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Energy Analysis and Environment Division				
RP679-6	Evaluation of Electrical Fields on Implanted Cardiac Pacemakers in Humans	2 years	55.7	University of Rochester *L. Sagan*
RP1009-4	Coal Supply Analysis System Implementation Project Management, Coal Supply Functions, and Computer System Integration	26 months	200.6	Charles River Associates Inc. *T. Browne*
RP1367-1	Estimation of Uncertainty in Coal Resources and Coal Assessment	2 years	248.9	Texas Energy & Natural Resources Advisory Council *J. Platt*
RP1432-1	R&D Options for an Uncertain Future	2 years	420.5	Applied Decision Analysis, Inc. *S. Sussman*
RP1484-1	Energy Model Assessment Program	42 months	800.0	Massachusetts Institute of Technology *R. Richels*
RP1588-1	Load Data Management and Analysis System	9 months	121.2	Datrix Corp. *E. Beardsworth*
RP1615-1	A Study of Water Resource Constraints on Energy-Related Activities	1 year	98.0	Stanford University *D. Geraghty*
RP1744-1	Atmosphere Emissions From Cooling Systems	18 months	260.0	SRI International *P. Jones*

New Technical Reports

Each issue of the *Journal* includes summaries of EPRI's recently published reports.

Inquiries on technical content may be directed to the EPRI project manager named at the end of each summary: P.O. Box 10412, Palo Alto, California 94303; (415) 855-2000.

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ELECTRICAL SYSTEMS

Bipolar HVDC Transmission System Study Between ±600 kV and ±1200 kV: Corona Studies

EL-1170 Interim Report (RP430-1)

This reports the results of a comprehensive study of the corona aspects of bipolar HVDC transmission at voltages between ±600 and ±1200 kV. The study included long-term bipolar line studies, special bipolar line studies, bipolar cage studies, and bipolar bus studies. Basic technical information for the corona performance aspect of design for HVDC transmission systems in the above voltage range is given. The scope of future work is briefly reviewed. The contractor is Institut de Recherche de l'Hydro-Québec. *EPRI Project Manager: Richard Kennon*

ENERGY ANALYSIS AND ENVIRONMENT

Evaluation of a Cooling-Lake Fishery: Fish Food Resources Studies

EA-1148 Final Report, Vol. 4 (RP573)

This volume documents the assessment of benthic communities, zooplankton, and algae in Lake Sangchris (a cooling lake) and in Lake Shelbyville (a nearby ambient flood control reservoir). Samples of each group of organisms were collected in each lake to obtain information on changes in species composition, relative abundance, density, biomass, and species diversity. Data were compiled and analyzed statistically. The contractor is the Illinois Natural History Survey. *EPRI Project Manager: John Reynolds*

Effects of 60-Hz Electric and Magnetic Fields on Implanted Cardiac Pacemakers

EA-1174 Final Report (RP679-1)

The effects on implanted cardiac pacemakers of 60-Hz electric and magnetic fields produced by EHV transmission lines were studied by in vitro bench tests of 13 cardiac pacemakers, in vivo tests of 6 cardiac pacemakers implanted in baboons, and nonhazardous skin measurement tests. Analytic methods were developed to predict the thresholds of body current and electric fields capable of affecting normal pacemaker operations in humans. Results indicate that alterations in normal operations are highly dependent on the type of pacemaker and location of the implanted electrodes. The contractor is ITT Research Institute. *EPRI Project Manager: Leonard Sagan*

FOSSIL FUEL AND ADVANCED SYSTEMS

Evaluation of the George Neal No. 3 Electrostatic Precipitator

FP-1145 Final Report (RP780-1)

The electrostatic precipitator at the George Neal Station Unit 3, Iowa Public Service Co., was evaluated from a total-system aspect that included emission performance testing and thorough engineering and economic analyses. The overall collection efficiency, determined with impactors, was 99.7% at 520 MW with outlet mass concentrations of 0.025 lb/10^6 Btu. The stack opacity was measured at 4.6%. The unit capital cost was $52/gross kW. The operating costs are 1.6 mills/kWh for 1979, based on a 70% capacity factor. The contractors are Meteorology Research, Inc., and Stearns-Roger, Inc. *EPRI Project Manager: R. C. Carr*

Design and Fabrication of a 1-MW (th) Bench-Model Solar Receiver

ER-1149-SY Interim Summary Report (RP377-2)

The design and fabrication of a 1-MW (th) bench-model solar receiver (BMSR) following guidelines developed in Phase 1 are highlighted in this Phase 2 report. Documentation is provided for test configuration, design parameters, thermal scale modeling, materials, fabrication, hot-flow testing, instrumentation and functional testing, transportation, and an experimental plant study. The BMSR was configured for testing at the DOE Central Receiver Test Facility in Albuquerque; Phase 2 concluded in August 1978 with the arrival of the BMSR at the facility. Phase 3 (solar testing) is in progress. The contractor is Boeing Engineering & Construction. *EPRI Project Manager: John Bigger*

Design of Refractories for Coal Gasification and Combustion Systems

AF-1151 Final Report (RP625-1)

A study was conducted to design refractories for use under the high-temperature erosion-corrosion and slagging conditions found in coal gasification and combustion systems. The report documents the state of the art; construction and use of large-scale, gas-fired test facilities (both fluidized bed and pneumatic impingement tube); drip and gradient slag tests; wear-resistance ranking of 15 refractories; identification of failure mechanisms; and establishment of design criteria for refractories. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: John Stringer*

Solvent-Refined Coal Process: Data Correlation and Analysis

AF-1157 Final Report (RP915)

SRC process data, obtained at three plants and from a literature review, were compiled and correlated. Data relating to liquefaction reactors and to vapor-liquid separation were analyzed, and data on filtration of SRC were reviewed. Procedures for the design of an SRC plant were developed, and recommendations for future work were made. The contractor is The Lummus Co. *EPRI Project Manager: H. E. Lebowitz*

Process Development for Improved SRC Options: Interim Short-Residence-Time Studies

AF-1158 Interim Report (RP1134-1)

The short-residence-time liquefaction of bituminous Indiana V coal was investigated in a continuous bench-scale unit. In the second phase of the work, gaseous hydrogen was added. In a parallel study, a batch microautoclave reactor examined the effect on coal liquefaction performance of variations in solvent boiling range and the addition of selected residual product fractions to a distillate recycle solvent. "Light SRC" was found to increase conversion when used as a solvent component in the presence of molecular hydrogen. The contractor is Conoco Coal Development Co. *EPRI Project Managers: H. E. Lebowitz and C. J. Kulik*

Production of Methanol From Lignite

AF-1161 Final Report (RP832-1; TPS77-729)

This report contains the summary volume of the Wentworth Brothers, Inc., North Dakota methyl fuel study, C F Braun's review of the study, and Wentworth's comments on Braun's review. The study was limited to a conceptual design and economic evaluation of a project to convert North Dakota lignite into 25,000 t/d of methyl fuel and to develop distribution and marketing of the product. Braun's review discusses the appropriateness of the slurry concentration selected and the selection of the Wentworth methanol synthesis reactor system. The contractors are Wentworth Brothers, Inc., and C F Braun & Co. *EPRI Project Managers: N. F. Herskovits and H. E. Lebowitz*

Exploratory Studies in Catalytic Coal Liquefaction

AF-1184 Final Report (RP779-18)

A scoping study relating to the direct catalytic liquefaction of coal was conducted. Liquid products, coal residues, and spent catalysts from several bench-scale test runs were characterized. Materials were obtained from tests in which both commercial and developmental catalysts were evaluated. The same fresh and aged catalysts were contacted with mixtures of model compounds in the presence of molecular hydrogen, which provided information on activity, selectivity, and deactivation for the various catalyst functions related to liquefaction and heteroatom removal.

The contractor is Mobil Research and Development Corp. *EPRI Project Manager: William Rovesti*

NUCLEAR POWER

Special TIP and Gamma Scan Comparisons From Hatch-1

NP-561 Final Report (RP130)

Experimental measurements by gamma-scanning techniques were performed at the Hatch Nuclear Plant, Unit 1, at the end of cycle 1. The data are indicative of the power distribution in the reactor prior to shutdown. This report compares axial, radial, and nodal Ba-140 fission-product distributions, traversing in-core probe (TIP) asymmetries, and control blade effects between the thermal neutron TIP, gamma-sensitive TIP, and gamma scan measurements. The contractor is General Electric Co. *EPRI Project Manager: R. N. Whitesel*

On-line Monitoring and Diagnostic Systems for Generators

NP-902 Final Report (RP970-1)

This report includes a survey of recent generator outages and an assessment of how effective new monitoring techniques would have been in reducing the durations of the outages. Two of the most promising monitoring techniques were developed further: radio frequency monitoring, which detects generator arcing, and temperature monitoring, which uses optical fibers to detect localized overheating. A monitoring system capable of detecting incipient failures while discriminating against false alarms was conceptually designed. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: H. G. Shugars*

Measurements of ^{239}Pu and ^{235}U Fission-Product Decay Power From 1 to 10^5 s

NP-998 Final Report (RP766-1)

The absorbable components of the fission-product decay power from thermal neutron fission of ^{239}Pu and ^{235}U were measured in the 1–10^5-s cooling-time interval. The measurements were made by a nuclear calorimeter, which is based on a large liquid scintillation detector capable of detecting a large fraction of the fission-product decay energy. Separate beta- and gamma-ray contributions to the total decay power were determined. The contractor is IRT Corp. *EPRI Project Managers: F. J. Rahn and Walter Eich*

Limiting-Factor Analysis of High-Availability Nuclear Plants (BWRs)

NP-1136 Final Report, Vols. 1 and 2 (RP894-1)

The first volume of this report summarizes a plant availability limiting-factor analysis, which focuses on the Peach Bottom-2 Atomic Power Station but includes a limited study of operations at 20 other operating BWRs. The key limiting factors identified were refueling activities; reactor fuel problems; reactor scrams; systems or major component failures; and delays due to radiation, water turbidity during refueling, and repair of valves and piping. Recommendations for improvements are included. Volume 2 contains project data, presented on activity sheets compiled during the study. The contractor is General Electric Co. *EPRI Project Manager: Thomas Libs*

Characterization of Irradiated Zircaloys: Susceptibility to Stress Corrosion Cracking

NP-1155 Interim Report (RP1027)

Irradiated Zircaloy cladding specimens were gas-pressure-tested in an iodine environment to investigate their stress corrosion cracking (SCC) susceptibility. Several cladding sources were used, and both PWR and BWR claddings were tested. Scanning electron microscopy and optical metallography were used to characterize SCC failures. An analytic model for iodine SCC was developed. The contractor is Argonne National Laboratory. *EPRI Project Manager: Howard Ocken*

Evaluation of Spectral-Shift-Controlled Reactors Operating on the Uranium Fuel Cycle

NP-1156 Final Report (RP978-1)

The performance of the spectral-shift-controlled reactor (SSCR) operating on uranium fuel cycles is evaluated and compared with that of the conventional PWR. Analytic methods are developed and validated for typical LWR lattices moderated with both light and heavy water. The resource requirements and economics of the uranium-fueled SSCR are evaluated. The potential of lattice optimization to enhance resource savings and improve the economics of power generation is determined. The contractor is Combustion Engineering, Inc. *EPRI Project Managers: C. L. Lin and B. R. Sehgal*

Analysis of Single- and Two-Phase Flow Fields Around PWR Steam Generator Tube Support Plates

NP-1162 Final Report (RP1121-1)

A thermal-hydraulic analysis of the Westinghouse Series 51 U-tube PWR steam generator was conducted, using a new two-fluid, two-phase-flow model. The analysis concentrated on the local flow field a few inches above and below the tube support plates at various levels. A full-scale simulation was also performed. Predicted vapor friction and velocity fields are plotted for both simulations. The development of the model used and the current state of its constitutive modeling are described, and initial data comparisons are presented. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: Henry Till*

Influence of Crack Growth Kinetics and Inspection on the Integrity of Sensitized BWR Piping Welds

NP-1163 Final Report (RP1325-2)

A fracture mechanics analysis of stress corrosion crack extension in sensitized weldments in BWR recirculation piping was performed. The results were combined with estimates of crack detection probability to assess the influence of preservice and in-service examinations in reducing the probability of pipe integrity loss. The sensitivity of the calculated results to the estimated values was assessed. The most influential factor in the analysis was the residual stress caused by welding. The contractor is Science Applications, Inc. *EPRI Project Manager: R. L. Jones*

Air-Water Countercurrent Annular Flow

NP-1165 Topical Report (RP443-2)

Countercurrent annular flow of air and water in circular tubes of diameters ranging from 6.4 to 152 mm is investigated. Experimental measurements include liquid fraction, pressure gradients, and countercurrent gas and liquid fluxes. Interfacial momentum transfer between the phases is characterized by empirical friction factors. The dependence of interfacial friction factors on tube diameter is demonstrated to provide a basis for extending the present results to larger tubes. The contractor is Dartmouth College. *EPRI Project Manager: K. H. Sun*

ARMA Sensor Response Time Analysis

NP-1166 Final Report (RP503-2)

The autoregressive moving average (ARMA) time series analysis method was investigated for application in measuring the time response of resistance temperature detectors and pressure sensors. The theoretical background, data acquisition method, and analysis results are presented and compared with expected values derived by other methods. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: D. G. Cain*

Chugging and Condensation Oscillation Tests

NP-1167 Final Report (RP1067)

Experimental studies of condensation oscillation induced by injection of steam into a pool of subcooled water are described. Experiments were performed in three facilities of different sizes; the facilities are described and compared. Data are presented in graphic and statistical form. Some theories are advanced concerning bubble collapse, appropriate statistical descriptors, and condensation oscillation frequencies. The contractor is SRI International. *EPRI Project Manager: J. P. Sursock*

Feedwater Heater Workshop Proceedings

WS-78-133 Workshop Proceedings

The design, operation, and maintenance problems encountered with nuclear feedwater heaters were the subject of an EPRI-sponsored workshop held March 13–14, 1979, in New Orleans, Louisiana. This report is a compilation of prepared papers, abstracts of group discussions, and special topic group presentations. All edited material of archival quality developed in this workshop is included. The contractor is Joseph Oat Corp. *EPRI Project Manager: Thomas Libs*

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