Centers for Testing Advanced Technology

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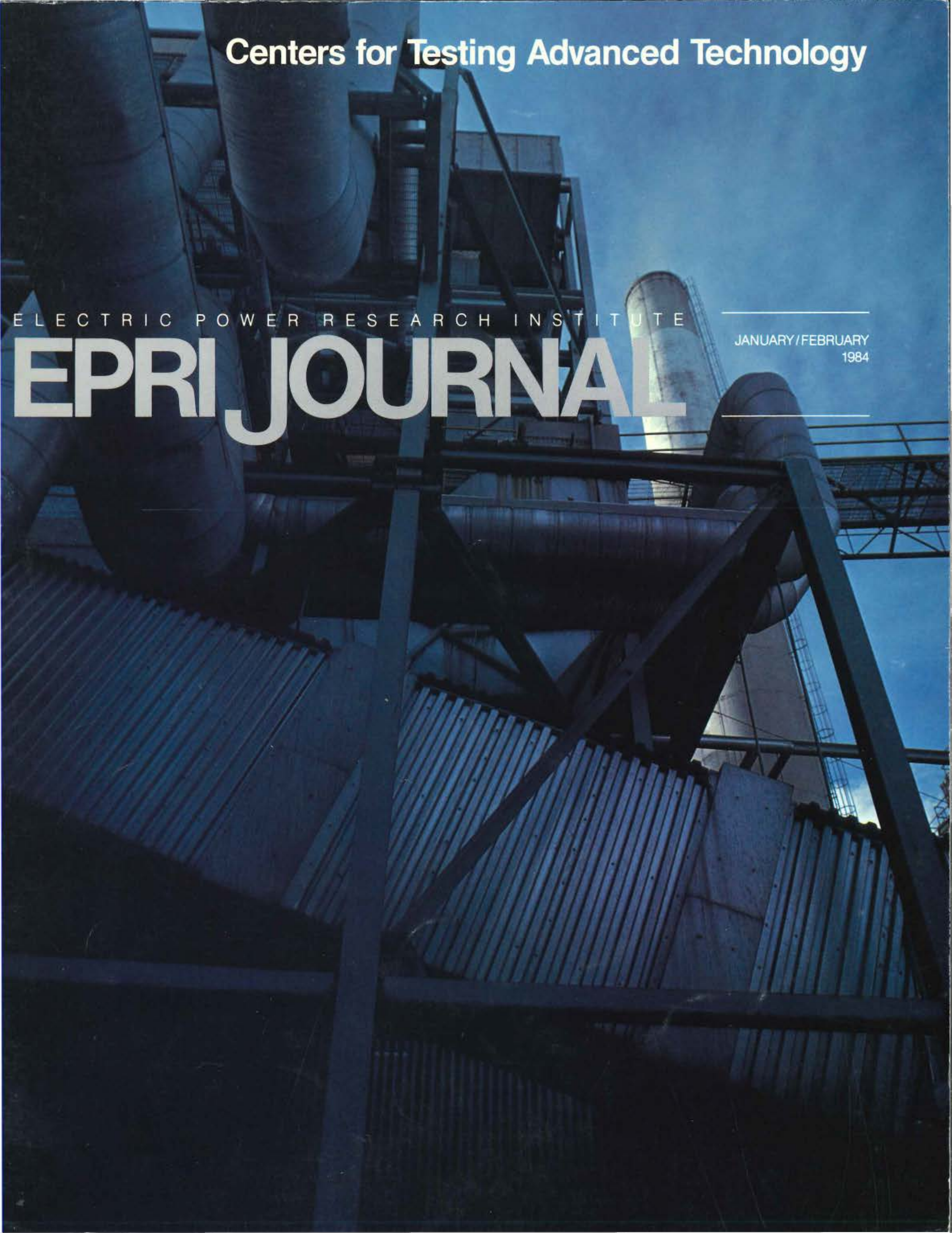

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Cover: The Arapahoe Test Facility, one of seven EPRI test centers, is the focal point for the development, testing, and transfer of emissions control technology. Located near Denver at the Arapahoe station of Public Service Co. of Colorado, it is operated under EPRI contract by Raymond Kaiser Engineers.

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Editorial

Features

Departments

R&D Status Reports

New Dimension for EPRI Test Centers

Something more than electric power technology has been under development at EPRI during the last 10 years. We are also finding ways to couple R&D more closely to its application. Nowhere is this more evident than in the work of EPRI's seven specialized R&D and test facilities. Clearly, the centers came into being to provide technical capabilities that existed nowhere else. But there is more than one dimension to their expertise. As stated at the beginning of this month's lead article, their main purpose today is for R&D results ''to be seen, to be wanted, and to take their place sooner and in more utilities than would otherwise be the case.'' This is a new and overarching realization and it therefore would not be amiss to call the facilities technology transfer centers.

Seen in this light, the main attributes of the EPRI centers are their realistic physical scale and operating environment. If advanced processes and hardware are to move from developmental to commercial status, they must be shown to work satisfactorily—and reliably—under representative operating conditions. This means simulating and resolving real-world problems. It means understanding and evaluating the integrated behavior of components and subsystems.

Going commercial also means devising and teaching new procedures for design, operation, inspection, and maintenance. Thus another major attribute of the centers is their accessibility to EPRI members. There is no substitute for the understanding that comes from one-on-one collaboration in cleaning 1000 tons of coal in Pennsylvania or testing a transmission structure in Texas, or from attending a hands-on class in HVDC design in Massachusetts or one in radiographic inspection in North Carolina.

Cosponsored efforts are a vital element and a unique opportunity at the centers, especially at the Transmission Line Mechanical Research Facility and the Coal

Cleaning Test Facility. Because full-scale towers and large coal samples are analyzed with instrumentation and procedures dictated by the needs of EPRI's research for the industry at large, the cost-sharing member utilities get unusually thorough test results.

Diagnostic capability has been a timely specialty of the pilot-scale baghouse unit at the Arapahoe Test Facility. We have greatly improved our understanding of the fundamentals of baghouse operation; and in the course of the research, we have gradually developed truly optimal operation and maintenance procedures.

Examples of a different sort come from the Nondestructive Evaluation Center, where much work deals with the in-service inspection of power plant components and subsystems. In one case, advanced interpretive skills for the ultrasonic inspection of BWR pipe welds were developed and taught to utility teams within a month of the request.

The plain fact is that research results do not automatically and inevitably find their way into use. Even the best new technology usually has to be packaged and delivered and called to the right person's attention. The all-important attractions are technical and economic feasibility. They are enhanced by pragmatic research efforts that best take place in a field environment—data base development, proof testing, human engineering, debugging, pilot or demonstration operation, application engineering, and user training. EPRI's field facilities are valuable for all these purposes—combining them in the name of authenticity for the timely transfer of technology.

Richard E. Balzhiser, Senior Vice President
Research and Development Group

Authors and Articles

Dedicated research and test centers for the U.S. electric utility industry began with the High-Voltage Transmission Research Facility in 1959. Six others have followed, and **EPRI Test Centers: Full-Scale Experience for New Technologies** (page 6) highlights how all of them help move new technology into utility practice just a little bit faster. Feature editor Ralph Whitaker turned to seven EPRI research managers for background information.

Clark Harrison is one of four on-site EPRI facility managers. He has headed operations at the Coal Cleaning Test Facility near Homer City, Pennsylvania, since May 1982. Harrison joined EPRI after two years as a marketing representative for Babcock & Wilcox Co. and seven years with Pennsylvania Power & Light Co., first in environmental and licensing studies and then in fuel supply planning and procurement.

Louis Rettenmaier, on-site manager of the Arapahoe Test Facility at Denver, Colorado, for the past three years, joined EPRI there as a project manager in January 1978. He was previously with the Buell Emissions Control Division of Envirotech Corp. for 18 years, where he worked in both equipment construction and sales.

Gary Dau, senior program manager for system integrity in the Nuclear Power Division, oversees the work of the Nondestructive Evaluation Center at Charlotte, North Carolina, whose establishment he first proposed. Dau joined the EPRI staff in April 1977. Before that he had been with Battelle, Pacific Northwest Laboratories since 1965.

John Dunlap manages most of the research conducted for EPRI at the High-Voltage Transmission Research Facility in Lenox, Massachusetts. Before coming to the Electrical Systems Division in February 1979, he spent 21 years with Florida Power & Light Co., ultimately serving as group supervisor for transmission facility upgrading.

John Shimshock is the third of EPRI's on-site research managers. Project responsibilities at the Waltz Mill Underground Cable Test Facility in Pennsylvania have occupied much of his time since he joined the Electrical Systems Division in October 1976. Shimshock was formerly with New Jersey's Public Service Electric and Gas Co. for 18 years, specializing in the design and operation of cable systems.

Paul Lyons, also of the Electrical Systems Division, is EPRI's fourth on-site R&D manager, responsible for projects at the Transmission Line Mechanical Research Facility at Haslet, Texas. Before joining EPRI in April 1982, Lyons was a senior project engineer at General Dynamics Corp., where he worked for 16 years in the field of aircraft and spacecraft structural dynamics.

William Spindler, EPRI's project manager for battery testing and evaluation since he joined the Institute in November 1976, oversees activities at the Battery Energy Storage Test Facility near Somerville, New Jersey. He previously worked in environmental and community health planning for six years. Still earlier, Spindler was with the Naval Ordnance Laboratory in Corona, California, for 13 years, eventually heading the electrochemistry branch.

■

Adapting existing technology to a new market application always involves technical refinement, testing, and economic analysis. **Pumping Heat Into Cold Water** (page 16) reviews how heat pumps are being adapted for the heating of domestic water supplies. William Nesbit, science writer, did the article with help from James Calm, EPRI's project manager for heat pump development.

Before he joined the Energy Management and Utilization Division in July 1981, Calm was with Argonne National Laboratory for five years, engaged in R&D on heat pumps and other technology for energy conservation. He served in the Air Force from 1971 to 1976, where he was responsible for the design, operation, and maintenance of a range of heating, air conditioning, and refrigeration systems.

■

Building a better mousetrap isn't enough these days. You also have to build the path to your door. **Inventions Licensed for the Marketplace** (page 22) explains the process of licensing, which helps take new technology to market. The author, science writer Adrienne Harris Cordova, was aided by EPRI's Don Erickson and Scott Taper.

Erickson, manager of patents and licensing for three years, came to EPRI as a contract attorney in December 1974. He was formerly a contract administrator with Four-Phase Systems, Inc., for four years and, still earlier, a systems programmer with IBM.

Scott Taper has been EPRI's licensing analyst since February 1982. Before that he was with Lockheed Missiles & Space Co., Inc., for two years, successively as a materials and processes engineer and as assistant proposal manager for advanced systems. Taper also was with General

Electric Co. for five years, much of that time in quality control/assurance for nuclear power components and facilities.

■

Above some threshold value, oscillations in torque on a generator shaft contribute to metal fatigue that shortens shaft life. How to detect, measure, and devise ways to avoid the problem are the subject of **Monitoring Stress in the Turbine Generator Shaft** (page 28), by science writer Stephen Tracy.

James Edmonds contributed technical background from his work as a project manager in EPRI's Rotating Electrical Machinery Program. From 1968 to 1977 Edmonds was with American Electric Power Service Corp., becoming the staff electrical engineer for all rotating electrical equipment on the AEP system.

CORRECTION

The vertical scale of the chart titled "Emission Densities" on pp. 18–19 of the November 1983 acid rain special issue was incorrectly labeled. Estimated values of SO_x and NO_x emission densities were overstated by a factor of 386. The relative state-to-state comparisons and the SO_x-to-NO_x comparisons remain valid, however. The chart can be corrected by multiplying each unit on the scale by 2.59 and striking thousands (10^3) from the unit expression so that it reads "tons per km^2 per year." For example, the SO_x density for Alabama, originally given as 2360 t/km^2 per year, is instead 6.1 t/km^2 per year.

Shimshock

Taper Erickson

Lyons

Calm

Harrison

Rettenmaier

Dau Dunlap Spindler

Edmonds

Focused purpose is the special attribute of seven EPRI facilities now operating in the United States. Their purpose is for R&D results to be seen, to be wanted, and to take their place sooner and in more utilities than would otherwise be the case.

Administered under the R&D programs of four EPRI technical divisions, the seven centers are scattered from Massachusetts to Texas and as far west as Colorado, with two in Pennsylvania and one each in New Jersey and North Carolina. Their R&D subject matter ranges from high-voltage dc line design to baghouse aerodynamics, from ultrasonic inspection of deep welds to proof tests of storage batteries for utility load leveling. Two of the centers began before EPRI existed; the newest went into business just last year. All are organized and positioned to refine, demonstrate, and test new technologies at the largest practical scale and, wherever possible, to train utility personnel along the way.

Seven centers, seven origins

Although such early authentication of new technology is the shared purpose of all the centers today, other factors had to do with their origins and locations. Most of the centers are functionally unique—built because there were no other facilities capable of doing the work. Site choices were influenced by the nature of the research, the proximity of related or support facilities, the climate, and the assistance of interested host utilities.

Climate, for example, figured in the Lenox, Massachusetts, siting of the High-Voltage Transmission Research Facility:

EPRI Test Centers: Full-Scale Experience for New Technologies

Bridging the gap between R&D and the real world are seven centers dedicated to the development, testing, and transfer of key technologies. Several of the centers offer utility personnel access for training and hands-on experience.

New England winters would assuredly freeze plenty of ice on conductors and insulators. Built by General Electric Co. in 1959, HVTRF had significant financial support from its owner for several years. At that time, it was a case of a manufacturer seeking to push technology along; today EPRI and its members are in the position of pulling it.

The Underground Cable Test Facility at Waltz Mill, Pennsylvania, followed in 1967. The stimulus here was different: without the results of accelerated-life tests of underground cable systems, utilities were understandably slow to accept the technology. Organized at that time under the Electric Research Council, a number of utilities shared in building the test facility on a Westinghouse Electric Corp. site. Westinghouse operates the center under contract to EPRI today.

The Arapahoe Test Facility in Denver, Colorado, was the first to originate in an EPRI research program. Host utility cooperation was all-important because the research and testing of combustion emission controls requires a supply of flue gas. Started up in 1977, the EPRI-owned facility is now a complex of five pilot-scale treatment systems that each draw flue gas streams equivalent to as much as 10 MW of capacity from the boiler of a 110-MW coal-fired unit at the Arapahoe station of Public Service Co. of Colorado.

The Nondestructive Evaluation Center owes its existence to the safety-related in-service inspections that must be performed on welded piping and on large vessels that are subject to high pressure in nuclear power plants. However, the applicability and cost-effectiveness of various NDE technologies has quickly carried this center's work into fossil fuel power plants and electrical machinery as well. Built and operated for EPRI since early 1981 by J. A. Jones Applied Research Co. in Charlotte, North Carolina, the NDE Center develops inspection methods and equipment that are precise and reproducible, and it teaches them to all comers.

The Battery Energy Storage Test Facility was conceived as a national focus for proving advanced concepts in batteries for utility load leveling. It shares the site of a Public Service Electric and Gas Co. substation in central New Jersey, and the two are interconnected so that test batteries can be discharged (dispatched) and then charged again as part of the utility's regular operations. Opened in 1981, the BEST Facility has undergone acceptance testing of its own systems and operation and is now beginning tests on the first advanced batteries installed.

The Coal Cleaning Test Facility, near Homer City, Pennsylvania, came into being in 1981, taking advantage of a common interest between EPRI's research managers and the utilities who jointly own and operate a nearby power station, coal-cleaning plant, and research-oriented analytic laboratory. Pennsylvania Electric Co. and New York State Electric & Gas Corp. are the two cosponsors of CCTF. The laboratory, now serving EPRI as well, has doubled its workload and its staff during the past two years.

The Transmission Line Mechanical Research Facility is near Fort Worth, Texas. Wide-open spaces for a planned two-mile test line are only one reason. Texas weather reasonably permits year-round work by the riggers and engineers who erect and instrument transmission structures for various load tests, sometimes to destruction. Completed late in 1982, TLMRF began its first full-scale tower tests just last summer.

Fuel for cheaper electricity

Chronology may be a convenient way to introduce the EPRI test centers. But utility industry priorities call for a different sequence in commenting on the service roles and methods of those centers. Perhaps most pervasive among near-term utility problems are those associated with coal-fired generation. Two particular concerns are coal quality and coal combustion emissions, so two of EPRI's special facilities focus on these topics.

The Coal Cleaning Test Facility came none too soon. Conceived at EPRI as far back as 1976, it was completed in 1981 and is now beginning its third full year of research and testing under the auspices of the Coal Combustion Systems Division.

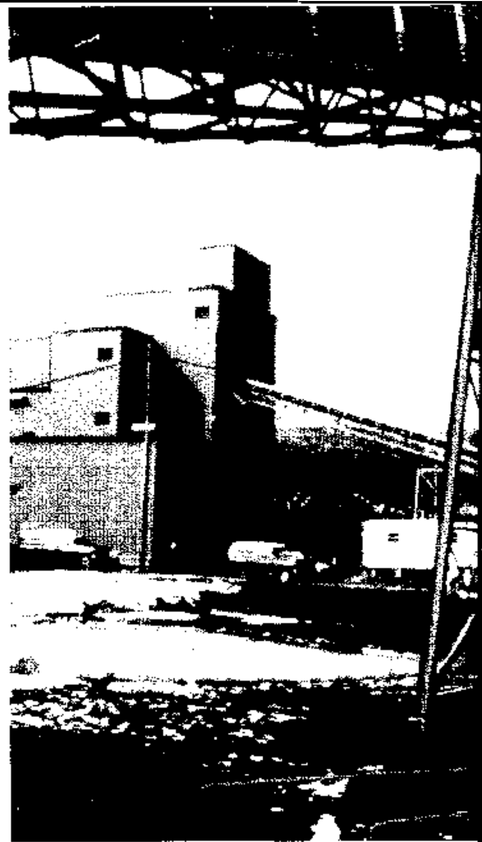
If backlog means success, then CCTF is successful, according to Clark Harrison, its manager. It is booked solid until the middle of 1985, a year and a half away. Seen only as a series of R&D tasks, the backlog is nothing out of the ordinary. But the coal for EPRI's test plant cleaning circuits is donated, 1000 t at a crack, by cosponsoring utilities who get answers to specific problems, such as slagging, low heating value, or high sulfur, while EPRI builds its data base on the cleanability of U.S. coals and develops new coal-cleaning technology.

Harrison therefore acknowledges that his full R&D agenda can be seen as a worrisome delay for the utility last in line. A dozen utilities are now in the queue, and the test program cooperatively devised with each of them will take from four to eight weeks in the cleaning facility itself and as much as five months overall, including data analysis and report preparation.

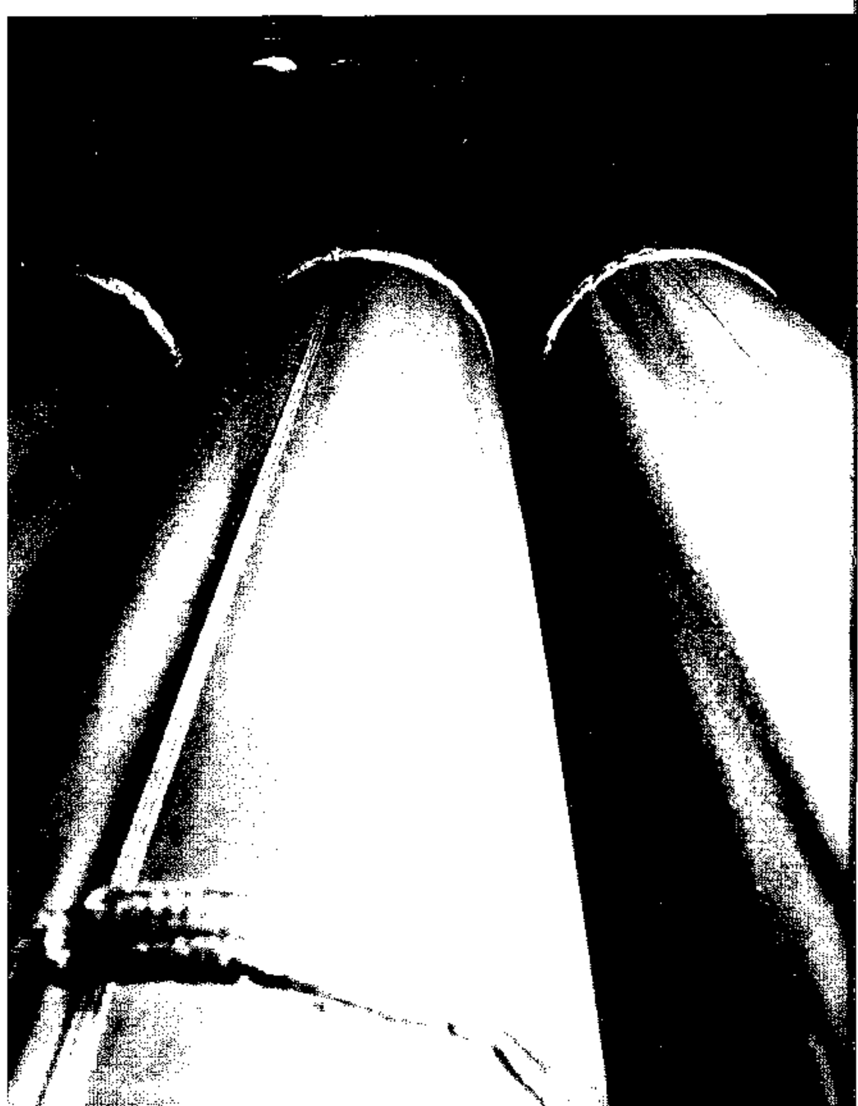
The means for doing all this are housed in half a dozen buildings connected by conveyors and surrounding a pair of water treatment ponds on a hilly 10-acre (4.05-ha) site served by both road and rail. CCTF is a test plant, rated at only 20 t/h throughput. But each item of equipment is commercial size, and there is sufficient variety to make up five basic cleaning sequences, known as flowsheets, plus valves and splitters and auxiliary conveyors that make possible another 50 configurations. All this represents an investment of about $15 million, plus $3 million in annual operating costs.

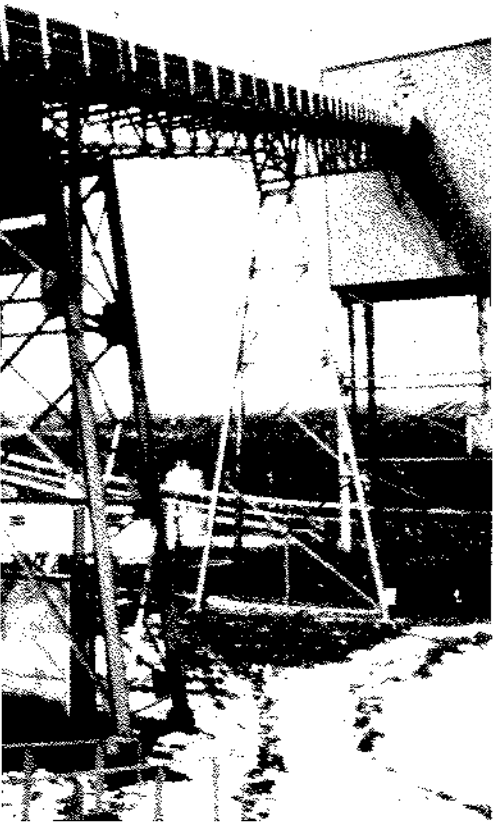
EPRI is building a data base for various degrees of coal cleaning, finding out how equipment performs on various coals, demonstrating new equipment and processes, advancing the instrumentation for plant control and automation, developing new sampling and analytic methods, and training people from all levels of the utility and coal industries, their consultants, and suppliers.

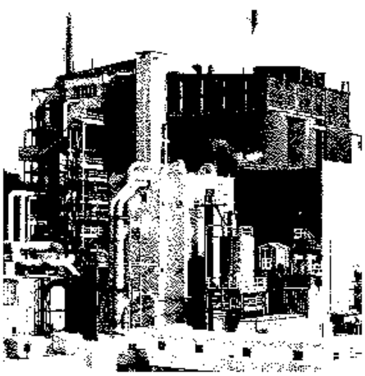
Cosponsoring utilities are encouraged to send engineers or consultants to CCTF for test programs on their coals. "If they don't," Harrison says flatly, "they get less out of it." In addition, the CCTF staff has included at least one loaned employee (a Babcock & Wilcox Co. chemical engineer for four months) and several engineering students from Pennsylvania State University.



Obtaining data on coal cleanability and optimal processing sequences is the shared research goal of the **Coal Cleaning Test Facility** and the utilities that furnish 1000-t samples. The center also fosters equipment development by evaluating prototypes of new equipment in the course of coal-cleaning tests.







Separate or combined operation of various emission control systems is a major capability of the **Arapahoe Test Facility,** where exhaust gas from a coal-fired utility boiler is diverted into any of five pilot lines. Arapahoe-based research has led to the adaptation and scale-up of baghouse technology for utility use.

It is a definite part of the CCTF agenda to bring utilities and coal suppliers to a closer understanding of each other's problems. Therefore, in addition to the utility members of a CCTF Advisory Committee in EPRI's Coal Quality Program advisory structure, Harrison and his staff also turn to a CCTF Technical Advisory Committee, whose members are drawn from coal companies, architect-engineers, manufacturers, universities, DOE, and EPA. Both groups have a hand in formulating and reviewing the CCTF annual test plan.

Getting the word out is at the same time CCTF's easiest and toughest task. Easy because there are plenty of people asking questions (Harrison logs some 50 or 60 visitors each month, from all professions, including perhaps 10 from abroad) but tough because there are not the hours to give a timely response to every query. CCTF has just begun to circulate a quarterly update to 150 interested individuals, plus all the appropriately categorized names on EPRI's industrywide mailing list.

There is a paradox about this attention to coal cleaning. Harrison points out that the amount of coal being cleaned for utilities is not increasing today. "For the moment, switching to low-sulfur coal accounts for more annual tonnage than does the turn to coal cleaning." Even so, reducing sulfur content and improving power plant performance are driving reasons for interest in the R&D programs of EPRI's CCTF. "And that," Harrison reminds himself, "is why we have an 18-month backlog."

Optimal emissions control

When proposals were sought for pilot-scale emission control equipment to outfit the Arapahoe Test Facility in the mid 1970s, a few of the established manufacturers did not even bid. EPRI's Walter Piulle was in charge of design and construction, and he recalls the circumstance as a way of emphasizing how recently the view persisted that electrostatic precipitators (ESPs) and fabric filters for fly ash were "essentially simple devices, adequately defined by their basic operating principles and really not worth research attention."

A lot of flue gas has passed through the Arapahoe Test Facility since then, and even the name of this R&D center has evolved. It was to be called the Advanced Particulate Control Facility, a place for upgrading precipitator design and gaining understanding of fabric filtration, the latter being inherently more efficient and well established in many industries but never scaled up to the flow rates of modern utility power plants.

Even before Arapahoe started up, it was renamed the Emissions Control and Test Facility, recognizing the broadened research scope that would bring flue gas SO_2 and NO_x controls under test and evaluation. Just last year the name officially became Arapahoe Test Facility—what everyone already called it—because pilot work on integrated control systems must take account of solid, water, and thermal waste streams, in addition to combustion emissions.

Today the plant investment is over $21 million and the annual operating cost is about $1.3 million. Arapahoe is operated for the Coal Combustion Systems Division by Raymond Kaiser Engineers, Inc., with a staff of about 20, and research contractor staffs vary according to their tasks. Currently on hand are some 25 personnel of Southern Research Institute, Radian Corp., and Brown & Caldwell. Louis Rettenmaier is EPRI's facility manager, and Richard Hooper is the resident R&D manager.

It might have been foreseen that Arapahoe's research findings would travel a fairly conventional, scholarly route into formal EPRI reports and thence to utilities (for procurement guidelines) and manufacturers (for equipment component and system design improvements). In fact, the work has attracted wide attention from utility plant operating managers. Rettenmaier reports that one or two visiting groups a week is not unusual. "They tour the facility, they get a complete set of our *Arapahoe Update,* and we answer questions—lots of questions.

"The reason people come out and want to talk," Rettenmaier emphasizes, "is to find out about operating problems. They want to know what not to do!" He cites the length of time that new particulate control equipment must operate before it becomes stable. "For an ESP it's more than 8 hours, maybe as many as 24. And for a baghouse, it may be months. The point is, you can't expect to make consistent performance measurements any sooner."

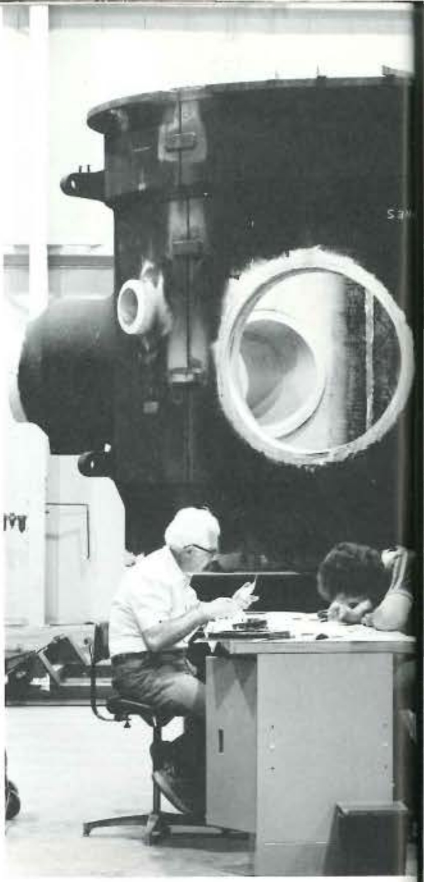
In one special way Arapahoe symbolizes more than the single facility in Denver. There is much related EPRI research elsewhere, not only laboratory studies and full-scale unit evaluations at various sites but also (since mid 1982) a pilot baghouse on a high-sulfur-coal combustion exhaust stream at Gulf Power Co.'s Scholz station in northwestern Florida. Interim reports from all of them are compiled three times a year in the *Arapahoe Update,* published since 1980 for interested individuals in the utility, manufacturing, research, and architect-engineer communities.

Arapahoe is not designed or operated as a hands-on training facility. But it is becoming increasingly clear that although better equipment can be bought, better procedures must be taught. Arapahoe's R&D goals, therefore, include both equipment specification guidelines and operating procedures for meeting today's—and tomorrow's—emission standards.

Inspection tools and training

Two facts set the EPRI Nondestructive Evaluation Center apart from the six other special Institute facilities. One is that for certain periodic inspections of nuclear plants, federal law has had the effect of mandating development of accurate and reproducible nondestructive examination techniques. Cutting into pipes, vessels, and welds is out of the question; their integrity is the whole point. Besides, many such components

Technology transfer was first stated as a test facility purpose when the **Nondestructive Evaluation Center** was established. Here inspection equipment and procedures are debugged for field use; but even more important, each year hundreds of utility inspection personnel get consistent, thorough hands-on training.



Methodical advance in electrical line design has been the role of the **High-Voltage Transmission Research Facility** since 1959. Texts and handbooks from the work are utility industry standards, and week-long seminars augment continuing research, which now covers the design of both ac and dc transmission facilities.

are radioactive from their operating environments.

The other fact is that the NDE Center is the first one established with the abstract phrase *technology transfer* as its primary stated goal. However subtly, this suggests an approach involving more than technology development alone. Gary Dau, program manager for system integrity in EPRI's Nuclear Power Division, puts it this way. "Researchers developing new technology bring motivations and skills to their work that are different from those of the people who will use the technology. Developers' hardware and procedures just may not be what are needed in the field. The point about the NDE Center," Dau adds, "is that it is created as a communications bridge, so that good technology takes fieldworthy form as fast as possible."

With this background of purpose, the NDE Center was built and is operated for EPRI by J. A. Jones Applied Research Co. Thomas Nemzek is president of the company and manager of the center, a 67,000-ft^2 (6225-m^2) facility on a 9-acre (3.6-ha) site in Charlotte, North Carolina.

The center and its staff of 75 draw new developments and new needs from many origins, forward data and components and procedures to the next R&D destination for needed refinement, route useful interim information in all directions, and ultimately approve new technology for field application, often by demonstrating that it meets regulatory requirements.

After less than four years of operation, it is clear that NDE Center qualification alone acts as a strong push to send new technology outward across the nationwide web. But the most pervasive technology transfer mechanism is the hands-on training provided for inspectors. Dau, who proposed the center more than six years ago and still oversees its operations today, illustrates the point with figures from just the first two years. "More than 500 people took part in our technology workshops or attended our classes on in-service inspection of nuclear plants. They came from 50 utilities, as well as from service contractors, R&D firms, and NRC." Dau points out that about 400 of these individuals attended sessions at the NDE Center. "But," he adds, "the other 100 trained at various plants and we supplied the materials."

Even two subordinate functions of the NDE Center illustrate how it contributes to the field of NDE technology, thereby transferring increments in yet different ways. As one example, the center has carefully built relationships with universities, even arranging a cooperative program under which a professor spent several weeks at Charlotte, working with utility representatives to develop a survey NDE course for senior engineering students at his own and other schools. Without such long-range action in NDE career development, there could be an awkward lag in technology capability just as the need takes off.

Another example is the center's function in characterizing and calibrating NDE hardware for utilities and inspection service contractors. The first category is that of ultrasonic equipment, and the NDE Center can now provide calibration services that satisfy NRC Regulatory Guide 1.150. This capability is a useful industry service and, in drawing clients, helps the NDE Center maintain its pivotal position in the technology.

Line design for the book

Three of EPRI's field R&D centers are projects of the Electrical Systems Division, and from the findings at two of these facilities, EPRI is writing the book on transmission line electrical design and transmission tower mechanical design.

Electrical design is the province of the High-Voltage Transmission Research Facility, built in 1959 when the accepted maximum ac transmission voltage was 345 kV. With guidance by the Electric Research Council until EPRI was established, research at HVTRF spearheaded successive advances to 500 kV and 765 kV (today's norm) and prepared the way for 1200 kV and 1500 kV when the occasion arises.

All this progress is distilled in a hard-covered EPRI report titled *Transmission Line Reference Book, 345 kV and Above.* Known in the power industry as the red book, 2500 copies were sold and were succeeded by 1000 copies in paperback, which also sold out. An updated second edition came out in 1982, and 2000 copies have been distributed.

But as early as 1979, its ac line research for the book completed, the HVTRF staff moved into HVDC and has since been compiling measurements and data for a book on HVDC line design up to ±1200 kV, planned for publication late in 1985.

These major research efforts, as well as a number of related projects, are sponsored predominantly (about 65%) by EPRI, with DOE (about 25%) also a major sponsor. EPRI and DOE, for example, are separately sponsoring research to calculate levels of human exposure to ac fields beneath transmission lines and to characterize dc environmental phenomena. An important point about HVTRF is its availability for individual utility research projects, such as a current study of a hybrid ac-dc transmission system for GPU Service Corp. Altogether, the HVTRF programs total about $1.5 million annually and are carried out by a General Electric Co. staff of 16, headed by Luciano Zaffanella, HVTRF director since 1972.

The major facilities are 500- and 150-m lengths of full-scale line, a fog chamber for insulation research, and the extensive instrumentation needed for corona research, electric field and ion current research, and evaluation of various environmental factors—wind, ice, rain, humidity, dust, and so on.

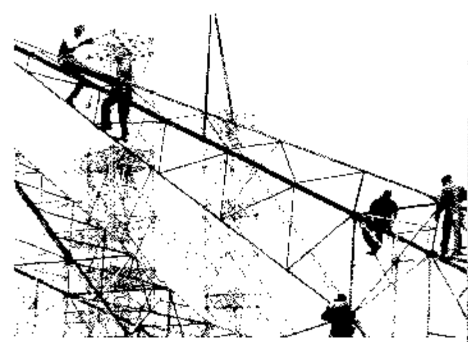
More compelling than the formal reports from HVTRF research are the design reference books. But real immediacy is found in the week-long seminars conducted by the HVTRF staff under EPRI sponsorship. Excerpts from an announcement brochure clearly explain why the seminars have been held for three years and are well regarded by transmission design managers of electric utilities: "communicate results of research . . . field experience and measurements with lectures and demonstrations . . . facilitate use of the *Transmission Line Reference Book* . . . methods to evaluate various conductor and insulation design considerations . . . direct exposure to tests and first-hand knowledge of measurement techniques."

A seminar lasts 4½ days (two-thirds in class, one-third in laboratory and field), and although the red book is the main text, findings from current HVDC research are continually added. John Dunlap, EPRI's project manager for HVTRF, observes that the HVDC content has proved to be a great attraction. "Several utilities have announced plans for HVDC lines, and we know of others being considered." Kenneth Lloyd, manager of HVTRF operations for General Electric, sees interest in the seminars from another angle. "We'll have a T&D manager in the class this year, and next year he'll see to it that some of his design staff attend."

Life stress for cable

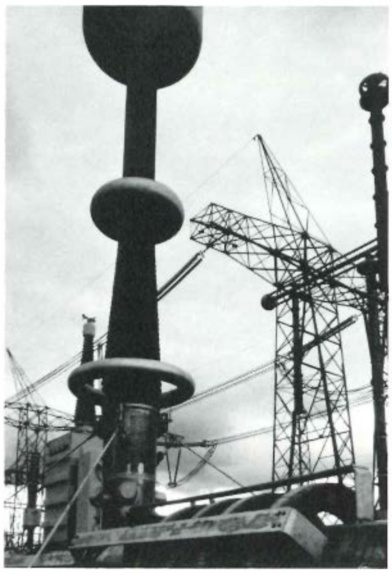
Probably EPRI's most specialized R&D center is the Underground Cable Test Facility at Waltz Mill, Pennsylvania. The Electrical Systems Division is sole sponsor of research at the site, occasionally calling for some tests of DOE-sponsored cable samples, in addition to EPRI work. The 29-acre (11.7-ha) facility lease and a staff of four entail operating costs of about $1.4 million annually, not including the costs of cable samples and installation.

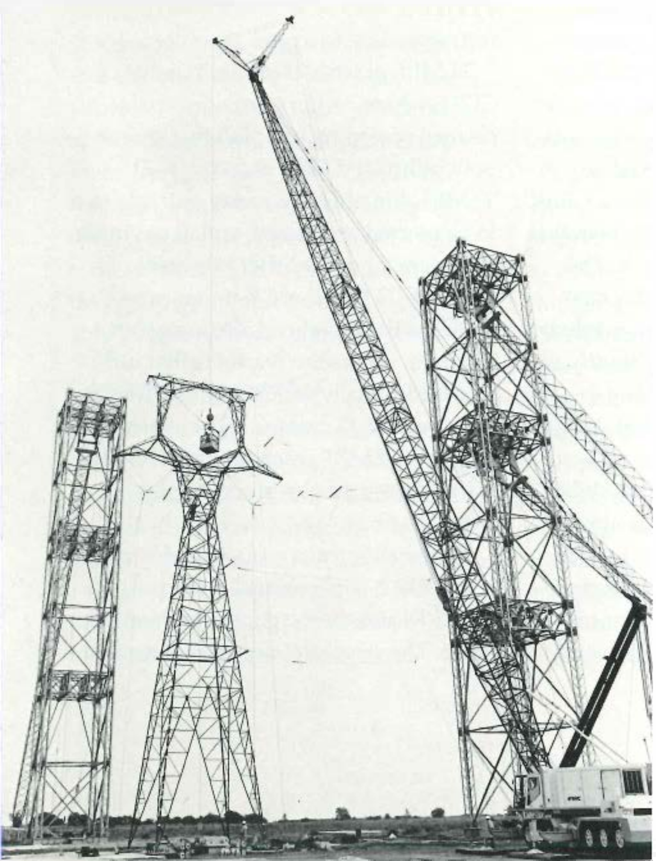
The main activity is accelerated-life testing (2 years simulate 40) of prototype cable systems. A wide variety of instrumentation is needed to document and analyze the performance of many cable configurations—pipe-type and self-contained, rigid and flexible gas-insulated, tape-wound and extruded-dielectric, self- and forced-cooled, and cable fitted with many novel accessories, splices, and ter-



Precise analysis of the structural design and performance of transmission towers, poles, and foundations is the research task of the highly instrumented **Transmission Line Mechanical Research Facility.** The research program features a constantly refined data base and computer control of stress tests on full-scale structures.

Life-test results are a key criterion of transmission and distribution cables that use new materials and configurations for more efficient power transfer and dielectric performance. The **Underground Cable Test Facility** is a 17-year-old proving ground for cables and their many specialized accessories.





minations. Also, since 1982 Waltz Mill has had the capability to test dc as well as ac cables.

John Shimshock, resident manager of EPRI's cable test projects, cites polypropylene-paper-type cable as having special potential in coming years, particularly where underground transmission ratings need to be increased. Because the cable features an insulating tape with very low losses and high dielectric strength, it should be possible to retrofit existing pipes with higher-voltage cables.

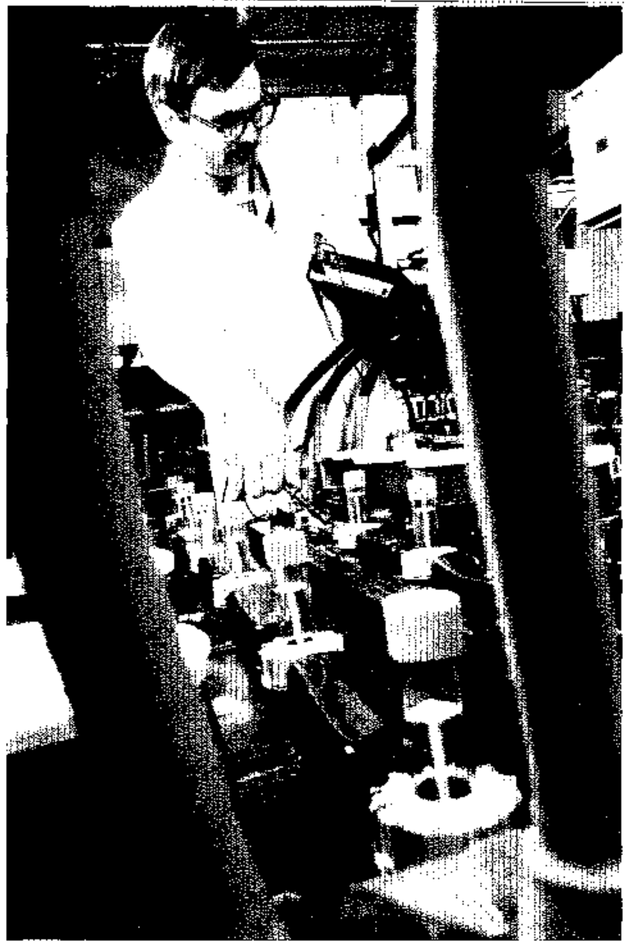
Although Waltz Mill research today, like that at HVTRF, addresses the design of new systems, this could change. Shimshock acknowledges, for example, that methods to locate dielectric fluid leaks from high-pressure oil-filled cable are likely to become a research topic at Waltz Mill. "You only have to think of a big-city utility like Consolidated Edison to realize how important this is."

Communication between Waltz Mill and its utility constituency is surprisingly simple, effective, and fast. "Word of mouth is the main way questions are asked and answered," says Shimshock. "And the key reason is that the worldwide community in cable technology is probably no more than a thousand individuals."

There are two principal channels in which word-of-mouth and more formal exchanges take place. One is the utility advisory task force for EPRI's Underground Transmission Program. The other is the Insulated Conductors Committee of the IEEE Power Engineering Society.

The EPRI advisers receive status reports three times a year. "These really are summaries," Shimshock emphasizes. "And that's what they want. The nitty-gritty detail is saved for the formal reports."

The Insulated Conductors Committee is a more diverse group, including manufacturers and consultants. It meets twice a year. "But no matter which committee develops information or receives it," Shimshock concludes, "it's around the world in a week."



Proof tests of two utility load-leveling battery system designs are under way at the **Battery Energy Storage Test Facility.** Utilities and manufacturers cooperated with EPRI in planning the test regimen, which features connection to a utility system for realistic cycling in response to daily load.

Full-scale tower tests

EPRI's newest R&D center has already had one failure—a computer-controlled mechanical load test to intentional destruction of a 345-kV lattice tower in May of last year. The occasion was an inaugural demonstration at the Transmission Line Mechanical Research Facility near Fort Worth, Texas. Since then, seven additional full-scale tests have been conducted in cooperation with cosponsoring utilities and fabricators.

Although transmission poles and towers are the major focus of research and testing, the 214-acre (86.6-ha) site will also be equipped and instrumented for foundation tests that use both native and imported soils. A two-mile test line is planned, which will permit various loads to be simulated on conductors and insulator strings.

The $10.5 million facility was designed and built by Adelphon-TLMRF, Inc., under the direction of Henry McGinnis. It is operated for EPRI's Electrical Systems Division by Sverdrup Technology, Inc. With a staff of about 25, Sverdrup also serves as research contractor. Paul Lyons is EPRI's resident project manager.

TLMRF research is aimed squarely at the twin criteria of cost and reliability in transmission lines. Lyons explains it this way. "There's good reason to believe that handbook design of structures has become overly conservative—redundant members, thicker sections than needed, and higher cost—but not consistently so. Mathematical models show this. Now we need to verify the models so that designs and safety factors are consistent. Then we'll have both economy and reliability."

EPRI's model development is already well under way. It has a design base of theoretical and empirical performance data. Combined with software for extensive computer-aided tower design and graphic display, it is called the EPRI Workstation. Cosponsored research at TLMRF is the key to continuing this effort, according to Lyons.

TLMRF practice is not unlike that of CCTF, where a utility provides coal to be cleaned according to a plan that meets both utility and EPRI objectives. At TLMRF, the utility provides a structure to be erected and tested, and, if anything, the interaction thereafter is even closer than at CCTF. Richard Kennon, who manages the Overhead Transmission Program, thinks the reason is that utilities traditionally are closely involved in their own T&D designs. "They gain benefit from TLMRF research right from the start because they're in on the planning," Kennon says.

In overall form, a research-oriented test is like a conventional proof test. But EPRI and the cosponsor learn much more. The structural design is computer-analyzed before the test and the results compared with the owner's original design analysis. This prepares observers for what to expect and when, and in at least one instance it led Sverdrup to suggest reinforcing a structural member so that stress testing would not be cut short. Actual testing may cover as many as 20 load cases (different combinations of stress), far more than the 3 or 4 of a conventional proof test, with as many as 80 strain gages providing data. Lyons summarizes, saying, "We learn how each member responds, not just whether the tower survives."

TLMRF's capacity for running 50 or more complete tests annually suggests how cosponsored research can rapidly move findings into the design practice of many utilities. But since an improved design capability is already in EPRI software, Sverdrup also conducts seminars for utility engineers—last year at Wisconsin Electric Power Co. in Milwaukee and at TLMRF; this year at Carolina Power & Light Co. in Raleigh, North Carolina, at Sverdrup in Tullahoma, Tennessee, and at TLMRF. Each seminar lasts three days and gives as many as 16 designers and managers a short course in use of the EPRI Workstation design package.

Kennon is watching tower research and seminars closely. He foresees that a future Workstation users group might speed the time when computer-aided tower design, firmly based in TLMRF findings, would be routine among utilities. "In fact," he muses, "EPRI's transmission electrical design handbooks from the high-voltage test facility will probably go into software someday, too."

On-line battery operation

Just last November the renaissance of batteries for utility energy storage and management came to the point where utilities could have hands-on experience with advanced units. The occasion was a workshop for utilities held at the Battery Energy Storage Test Facility in central New Jersey.

The workshop was a milestone on a development path that began in 1975. Since then, EPRI's Energy Management and Utilization Division, DOE, and New Jersey's Public Service Electric and Gas Co. have moved methodically to establish a unique center for testing prototypes of MW-scale battery systems in utility operation, thus improving the prospects for commercial battery success.

The $17 million BEST project features a $4 million, 33,000-ft^2 (3065-m^2) structure on a PSE&G substation site. It is fitted with three battery test bays, power conversion equipment, computer control and data acquisition, and the necessary shops, utilities, and offices. PSE&G owns and operates the facility, with a staff of 10 headed by Alois Pivec, project manager. William Spindler is his counterpart for EPRI.

More than any other facility sponsored by EPRI, this one seems to be plowing new ground, because (except for site-specific pumped hydro) energy storage has hardly figured at all in utility system capacity planning. The long-term strategic potential of dispersed storage by utilities is now supplemented by an even nearer one in which batteries owned by electricity users (e.g., large transit and industrial operations) could also be advantageous in load management.

Last year, therefore, saw an advanced zinc chloride battery and an improved, deep cycling lead-acid battery (both rated at 500 kWh) installed for testing. These are the systems demonstrated to planners and operations managers from 18 utilities during the November 1983 workshop jointly sponsored by EPRI, PSE&G, and DOE. EPRI's Spindler believes that the occasion brought together more utility people than any previous program on the topic.

In the years leading up to this point, technology development and information exchange have been conducted through a number of advisory and planning groups. First came the BEST Facility Planning Group, constituted under a joint contract for initiating the project. It includes members from EPRI, DOE, and PSE&G, and from other utilities—at the moment, Duke Power Co., Florida Power & Light Co., and Pennsylvania Power & Light Co. The Utility Battery Operations and Applications Team was later organized by EPRI, its six utility members providing detailed input on test program conduct, based on their analysis of probable system environments. Still more test planning criteria came from the Developer Users Group, organized by PSE&G.

With this kind of groundwork, the BEST Facility is beginning its career at a fast clip with two battery systems under test and an audience of at least two dozen utilities closely following developments.

R&D accessibility

Obviously, research is no longer the business of scientists alone. What was once a small institutional structure with a few narrow hallways of communication has been considerably remodeled by the industries that are often the major tenants. Basic and applied research now share space, and it is larger space. Technology research has expanded to become R&D.

EPRI symbolizes such a structure, with new hallways and stairways between the laboratories and new doorways to the neighbors on all sides. And the results of R&D are being adopted by utilities at an ever-faster pace. This is partly the natural outcome after 10 years, and it can be traced partly to the increasing tilt of EPRI work to near-term problems.

But partly also, the specialized R&D centers, not to mention many single developments hosted on utility sites and systems, are proving to be a way of organizing R&D in manageable portions, easily seen, easily accessed, and always in touch with the real world. ■

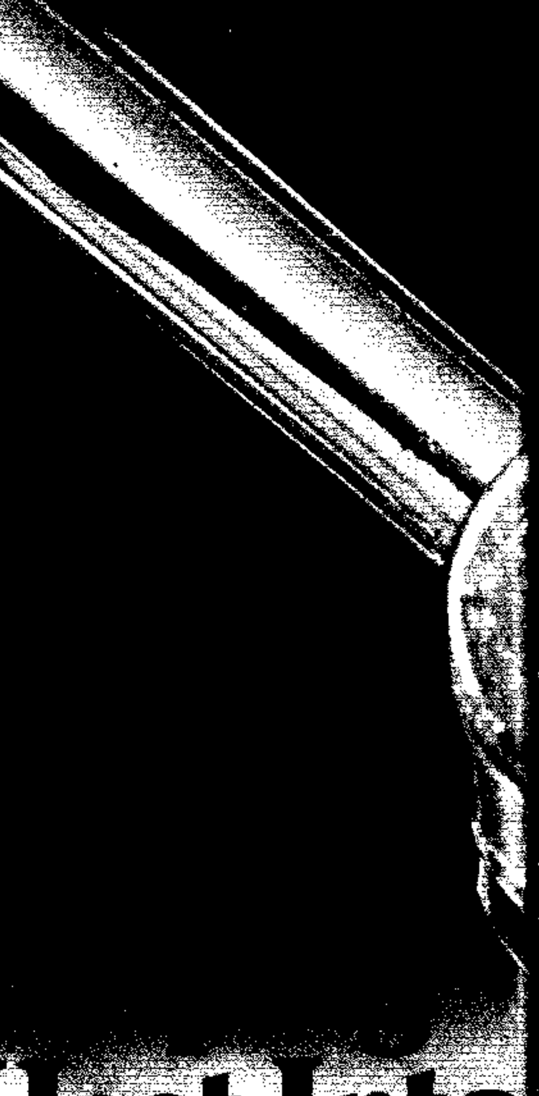
This article was written by Ralph Whitaker. Background information was supplied by Clark Harrison and Louis Rettenmaier, Coal Combustion Systems Division; John Dunlap, Paul Lyons, and John Shimshock, Electrical Systems Division; William Spindler, Energy Management and Utilization Division; and Gary Dau, Nuclear Power Division.

With the nation's move toward improved energy efficiency, heat pumps have emerged as the most significant commercially available option for improving the efficiency of electric heating. To date, most heat pump research has focused on space conditioning. But application of heat pumps in another important end-use area—water heating—is showing significant promise to reduce costs to utilities and their customers.

Water heating today accounts for approximately one-fifth of the energy used in a typical household, with 53% of in-place water heaters using natural gas and 45% using electric resistance heating. Propane, oil, and solar units account for most of the remaining 2% of the market, along with heat pump water heaters (HPWHs)—about 20,000 of which are now in use.

The attractiveness of the HPWH stems from its high efficiency. As a heat pump, it does not simply produce heat per se. Rather, the majority of the heat is transferred from its immediate environment to the water to be heated. Consequently, it uses half or less than half the energy of a conventional electric resistance water heater and increasingly represents a cost-competitive alternative to natural gas. Solar water heaters show energy savings roughly equivalent to those of the HPWH, but the HPWH has the advantages of a higher degree of reliability and a significantly lower capital cost. Moreover, in comparison with electric resistance water heaters, which have relatively low load factors and high demands, HPWHs have a higher load factor and a more consistent demand pattern that is attractive to utilities.

"Consumers and utilities alike have begun to express greater interest in heat pump water heating in recent years," says James M. Calm, project manager for heat pump development in EPRI's Energy Management and Utilization Division.



Heat Into Cold Water

"At least 50 utilities are now evaluating the technology in their service areas, and over 15 space conditioning and water heater equipment manufacturers are actively marketing such products. The key to the future for the technology, however, is energy price. High-efficiency HPWHs are already cost-competitive with gas-fired units in many regions of the country, and projected increases in energy prices should make them even more competitive."

The technology

The HPWH uses a vapor compression cycle, the same cycle used by refrigerators and air conditioners. In service, heat pumps use energy in the form of electricity to reverse the natural flow of energy from warmer to cooler locations; that is, they "pump" heat from cooler to warmer areas.

A typical heat pump uses a refrigerant to move heat from a source, most commonly air, to a higher-temperature use, which in water heating is water. This refrigerant circulates continuously in a closed cycle, picking up heat at the source via an evaporator and giving it up to the water (or air in space conditioning) via a condenser. At the evaporator, the refrigerant changes from a liquid to a vapor by absorbing heat from the ambient air. It then passes into an electric-motor-driven compressor that increases its pressure to drive the cycle. The compressor also raises the refrigerant's temperature to provide the temperature differential fundamental for transferring heat to the water. This transfer, which occurs in the condenser, results in the refrigerant's return to a liquid state. The refrigerant then passes through an expansion device where its pressure and temperature are reduced, and it completes the cycle by returning to the evaporator.

Two basic types of HPWHs are commercially available: remote and integral. Remote units (sometimes called retrofit, without-tank, or add-on) use a separate heat pump package that connects to an existing water tank. Integral units combine the heat pump and the tank in one device. Remote units cost less ($600–$1000 installed) than integral units ($1100–$1900) in residential applications, and because remote units are detachable, renters or families that move can take them along. In addition, the fact that remote units can use existing water tanks is an advantage.

History of development

Although the concept has been understood for over a century, HPWHs have been actively marketed in the United States only since the late 1970s. Internationally, a number of companies in Europe and Japan also manufacture HPWHs.

In the United States, the Hotpoint Co. (now the Hotpoint Division of General Electric Co.) developed the first HPWH designed for mass production in the 1950s, testing it in cooperation with Tampa Electric Co. The device worked well, but falling electric rates caused by an abundance

High efficiency is the reason for adapting heat pump technology for domestic water heating. With almost 20,000 units now in service, the heat pump water heater is coming on strong as an end-use conservation option.

HPWHs AND THE UTILITIES

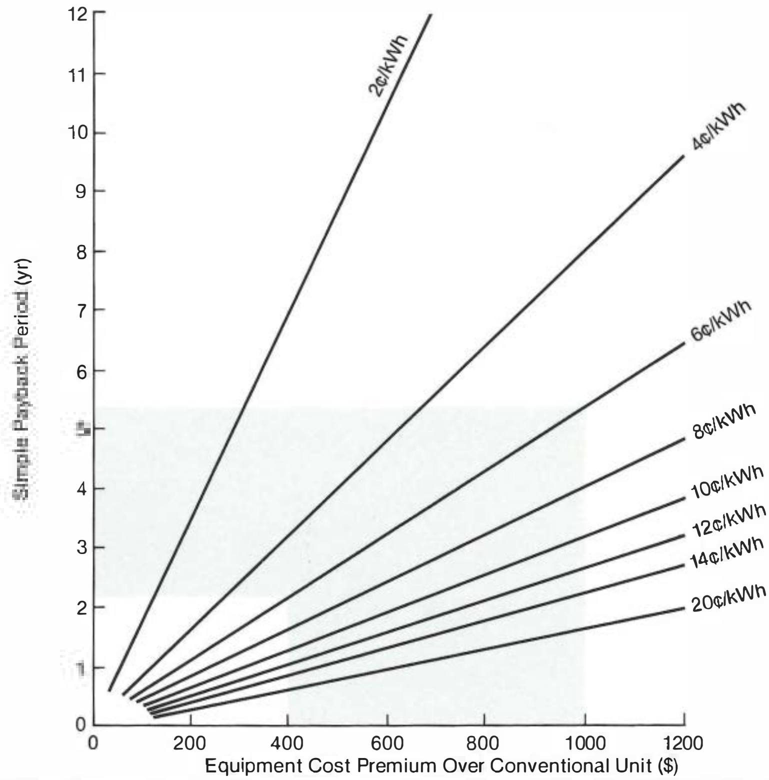
Given the energy efficiency and load-related benefits of HPWHs, a number of electric utilities are now actively involved in testing and promoting the devices in their service areas. This effort ranges from advertising and general publicity to research and monitoring programs and the offering of financial incentives.

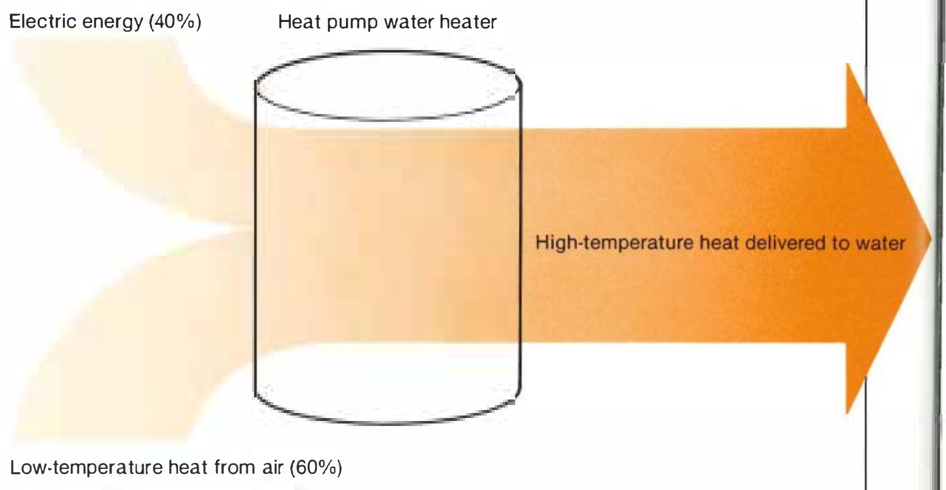
Public Service Electric and Gas Co., Newark, New Jersey, is monitoring the performance of 10 HPWHs and comparing it with conventional electric resistance heating and natural gas-fired units. Specific emphasis is on demonstrating the HPWH's energy savings potential and effect on space-heating demands and ambient indoor temperature. Testing began last year and is expected to continue into 1985.

In October of 1982, Tennessee Valley Authority added HPWHs to its energy conservation financing program. As a result, residential customers within TVA's service area are now eligible for zero-interest financing on the first $1200 of the cost of an HPWH. Over this $1200 level, $3800 in financing at TVA's cost of borrowing is also available.

Financial incentive programs to encourage customer use of HPWHs are also available. Portland General Electric Co., for example, pays $300 to customers who purchase and install the devices. To promote HPWHs inhouse, Georgia Power Co. and other utilities are offering financial incentives to employees. Through the Georgia Power program, both low-interest loans and a payroll deduction plan are available. □

Heat pump water heaters currently cost from $400 to $1000 more than conventional electric resistance water heaters. However, their significantly lower operating cost can lead to rapid payback of the initial investment, depending on the cost of electricity. In areas where electricity is 6¢ a kilowatthour, the unit will pay for itself in roughly two to five years; where electricity costs are higher, payback is even more rapid.





Using a much smaller amount of electric energy than would be required for resistance heating, heat pump water heaters boost the temperature of thermal energy extracted from air to heat water to a higher, usable temperature. This is accomplished by reversing the vapor compression cycle employed by refrigerators and air conditioners, allowing the HPWH to "pump heat uphill."

of low-cost generating fuels reduced its appeal, and development was halted.

National interest in HPWHs was rekindled in the mid 1970s as energy prices began to rise and recognition of the potential of heat pumps to conserve energy grew. One of the first to take another look at the technology was the National Rural Electric Cooperative Association (NRECA). Because gas pipelines are costly to install in sparsely populated rural regions, electric resistance water heating has predominated in those areas.

In 1975 NRECA provided a small grant to Energy Utilization Systems, Inc. (EUS), to develop a prototype HPWH as an alternative to electric resistance units. This effort was supplemented in 1977 by federal funding through DOE. In the expanded study, EUS manufactured 100 integral units for testing by 20 electric utilities. Eighty-five of these were fully assembled HPWHs (including water tanks); 15 were heat pump kits for field conversion of existing electric resistance water heaters into integral units. The conversion HPWHs proved unsuccessful, but the 85 complete units were tested for 25 months or longer. Twenty of these units were disassembled for internal inspection, but most of the remainder are still in use.

These tests revealed an average HPWH operating-cost savings of 48% over electric resistance water heating. In addition, the tests showed an expected useful life of 10 or more years for the units (versus an average of 7–11 years for conventional gas and electric devices) and identified a number of improvements to increase efficiency, reliability, and service life. Simultaneously, a consumer attitude survey showed that the vast majority of users participating in the study were satisfied with the operation of their HPWHs, especially with the energy savings realized.

More recently a number of electric utilities have independently undertaken programs in their service areas to evaluate HPWH performance and/or consumer attitudes toward the technology. A soon-to-be-published report sponsored by EPRI and conducted by Science Applications, Inc. (SAI), summarizes the results of 46 of these programs. It confirms that HPWHs provide energy savings of around 50% compared with electric resistance units in a large variety of climates and applications. Performance data, guidelines for economic analysis, and data on experimental designs and instrumentation devices found to be most effective by the utilities are also contained in the report.

Operating characteristics

Beyond their energy savings and load management benefits, HPWHs differ from conventional water heaters in a number of operating characteristics. The most important is the requirement that HPWHs be installed in locations where the ambient temperature does not ordinarily fall below 45°F (7°C). At this temperature and below, moisture from the air begins to freeze onto evaporator coils, reducing heat transfer capabilities and, therefore, unit efficiency. Also, at temperatures above 95°F (35°C) the compressor may overheat. Therefore, most manufacturers design HPWHs for the 45–95°F (7–35°C) range as most representative of typical application conditions. Units can be designed for more extreme conditions, however. For example, below 45°F a defrost mechanism can be installed at additional cost to maintain system efficiency.

Crawlspaces, garages, ventilated utility rooms, and basements generally provide suitable locations for HPWHs. Several utilities are now examining the effect of location on HPWH operation. Bonneville Power Administration, for example, is sponsoring research by Pacific Power & Light Co. that involves HPWHs in up to six locations in 48 test homes.

HPWHs also cool and dehumidify their surroundings as they pump ambient heat into the water tank. This effect can help cool and dehumidify indoor air if the units are indoors. During winter months, however, it might increase space-heating loads, offsetting the HPWH's energy savings. Various tests to assess this characteristic have been undertaken. One such test, conducted by Pennsylvania Power & Light Co., indicates that units located in basements (and, presumably, other unconditioned or partially conditioned spaces) do not materially affect space-heating loads.

The recovery rate (i.e., the rate at which cold water is heated after hot water is drawn from the tank) is an important operating characteristic of all water heaters. Per unit of power, the recovery rate of HPWHs exceeds that of conventional water heaters. However, lower output capabilities are generally selected for HPWHs to decrease equipment costs. Although this results in more continuous operation—thus increasing load management benefits—it also lowers the recovery rate. Using a larger storage tank or supplemental electric resistance heat can overcome the lower recovery rate during periods of very high hot water demand. However, supplemental electric resistance heating reduces (but does not eliminate) the HPWH's energy saving and load management benefits.

If HPWHs are improperly located, noise can be a problem. Fan and compressor operation typically produce sound at a level of approximately 65 decibels five feet from the unit—about the same as an average room air conditioner.

"Noise is not really an issue," says H. J. Reynolds, national accounts manager for E-Tech, Inc., the nation's largest manufacturer (in terms of market share) of HPWHs. "Placement of the unit in normally unoccupied areas, as recommended, should eliminate any concern."

Consumer acceptance

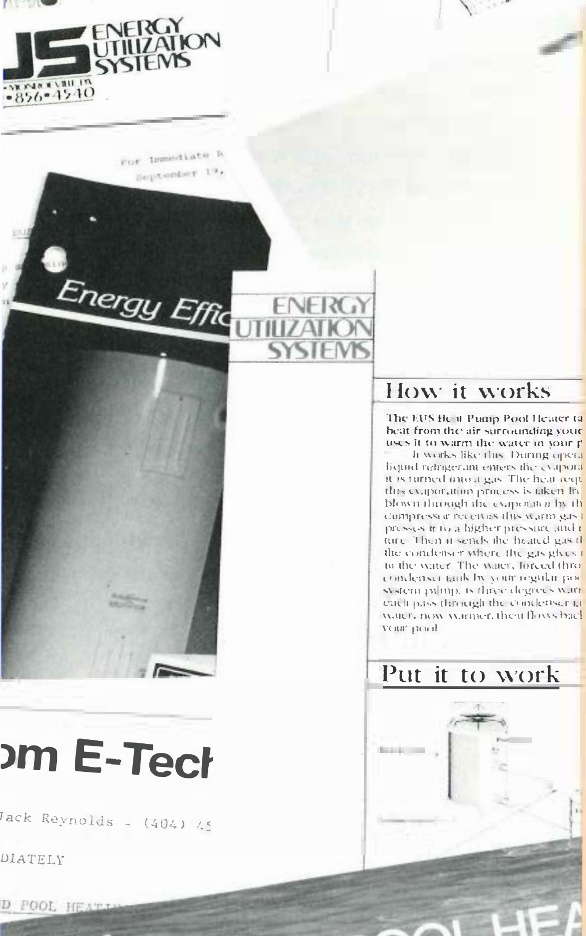
Lack of consumer familiarity with heat pump technology and concepts and the high initial cost of HPWH units (ranging two to four times as high as that of conventional water-heating devices) are important reasons for the relatively small number of units sold to date. In addition, at present there is no consensus standard for rating and comparing the devices.

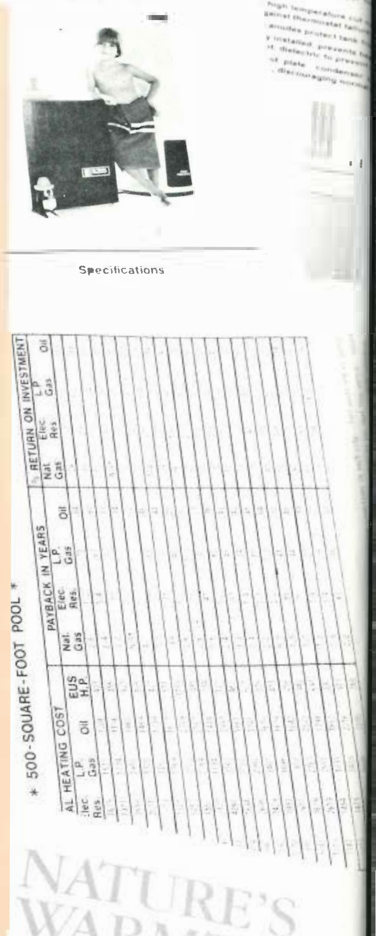
"Consumer acceptance of HPWHs

Heat pump water heaters are attractive commercially because they can cut energy use by as much as one-half. Some 50 utilities are now evaluating the technology, and over 15 manufacturers are actively marketing such products. Commercial barriers include high front-end cost and the public's lack of familiarity with the technology.

Commercially Available HPWHs

AquaTherm (Heat Controller, Inc.)
Carrier (Carrier Corp.)
Craftmaster (Craftmaster Water Heater Co.)
Daiken (International Energy Systems Corp.)
Duo-Therm (Motor Wheel Corp.)
E-Tech, Efficiency II (E-Tech, Inc.)
Fedders (Fedders Corp.)
Heatmate (Manoir International, Inc.)
Kenmore (Sears, Roebuck and Co., Inc.)
Lennox (Lennox Industries, Inc.)
Mor-Flo, American Appliance (Mor-Flo Industries, Inc.)
Northrup (Northrup, Inc.)
Oregon (Oregon Water Heater Co., Inc.)
Rheem, Ruud (Rheem Manufacturing Co.)
Temcor (Energy Utilization Systems, Inc.)
Therma-Stor (DEC International)
Thermo-Tec 1 (Reynolds Metals Co.)
York (Borg-Warner Central Environmental Systems, Inc.)





hinges to a large degree on the success manufacturers, dealers, utilities, and others can realize in educating the general public about the technology," says Morton Blatt, program manager in SAI's Energy Systems and Conservation Division. "The concept of pumping heat is alien to many people. But beyond this, and more important perhaps, the message must be put across that heat pump water heaters have a high payback potential in terms of cutting monthly energy bills. Because they are more complex than conventional equipment, they do have a higher initial cost. But the evidence is that they pay for themselves in a relatively short period of time—usually well under four years—depending on energy prices."

To address this concern, some utilities are now conducting promotional campaigns to familiarize the general public with the technology and its potential for energy savings. In addition, rebates and zero- or low-interest loans are being offered to customers to encourage purchase of the devices.

In one recent demonstration, Puget Sound Power & Light Co. installed HPWHs in the homes of 50 of its employees. A subsequent survey of these individuals and families showed that the units were generally well accepted, especially when the extent of the energy savings was realized. Two states have also given a boost to the technology: California, where a new building code allows only HPWHs in new buildings using electricity for water heating, and Oregon, where beginning in 1984 the state's energy conservation tax credit will extend to HPWHs.

In terms of HPWH comparisons, the Air-Conditioning and Refrigeration Institute (ARI), the Gas Appliance Manufacturers Association (GAMA), and the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) have each been involved in drafting rating standards for HPWHs. According to Calm, the ASHRAE standard is likely to be adopted within a year and become the consensus standard. For the present, a directory of water heater efficiency ratings is available from GAMA with listings of HPWH performance data based on GAMA's proposed test procedures. ARI has terminated its effort in this area.

Beyond education programs, financial enticements, and promulgation of product standards, however, installation of HPWHs in large numbers will probably depend on further improvement in the nation's economy, particularly in the housing market, and the establishment of a more effective marketing network.

"Sales of water heaters, like other major household appliances, track the building industry," says John Dobyns, senior engineer at SAI, "and of course the recession has hit this industry hard. Also, it was just as the heat pump water heater was making its market debut in the late 1970s that the housing market began its slowdown. In response, builders have chosen the lower capital cost option—conventional water heaters.

"Moreover," continues Dobyns, "in the replacement market high-volume sales have been delayed in part because equipment manufacturers initially did not employ the most effective distribution network. Instead of using plumbers they used heat pump dealers, individuals who usually deal in space-conditioning equipment. A consumer will generally call a plumber to fix or replace a broken water heater, and plumbers, being less familiar with HPWHs, would typically recommend a conventional replacement. Simply put, the units were not being effectively marketed."

This situation is now changing. Many HPWH manufacturers are using plumbers as dealers, and one major national retail store (Sears, Roebuck and Co.) has begun offering the devices.

Looking ahead

Because of the size of the residential water-heating market, the HPWH will most likely find its greatest application in this sector. However, units are available that produce 2000 gallons (7.6 m^3) and more of hot water per day, which is suitable for many commercial establishments.

The characteristic of HPWHs to cool their environment may also provide an added advantage in applications combining hot water demand with a year-round cooling load. Restaurant kitchens and office buildings, for example, may be ideal locations in this regard.

Commercially available models have also been designed for heating swimming pools and Jacuzzis and for other areas where hot water is required. HPWHs are especially economical in these applications because of their higher efficiencies at the required temperature conditions.

"Introduction of improved heat pump water heater designs and the entry of major manufacturers into the heat pump water heater market are evidence of increasing confidence by manufacturers in the product's future," comments EPRI's Calm. "They suggest growing awareness that heat pump water heaters offer an efficient end-use option to help consumers control their energy costs. The two key issues influencing product acceptance are energy and equipment prices. Right now the high first cost, or capital cost, of a heat pump water heater is a major impediment. This cost should decrease as penetration increases because of production economies and engineering improvements. The higher cost is, nevertheless, offset by the energy cost savings that can be realized by using the devices. As energy prices rise, the benefits to both consumers and utilities will increase." ■

Further reading

Heat Pump Water Heater. Final Report for RP2033-5, prepared by Science Applications, Inc. (in press).

Examination and Life Assessment of Field-Tested Heat Pump Water Heaters. Prepared by Energy Utilization Systems, Inc., for Oak Ridge National Laboratory, December 1982. ORNL/Sub-7321/5.

Demonstration of a Heat Pump Water Heater, 2 vols. Prepared by Energy Utilization Systems, Inc., for Oak Ridge National Laboratory, December 1979 (Vol. 1), June 1981 (Vol. 2). ORNL/Sub-7321/3&4.

This article was written by William Nesbit, science writer. Technical background information was provided by James M. Calm, Energy Management and Utilization Division.

Inventions Licensed for the Marketplace

EPRI is stepping up its efforts to move R&D products into the commercial mainstream. Licensing, which conveys the right to manufacture and sell, is a vital part of the technology transfer process.

Behind the scenes, EPRI's patents and licensing staff continuously assesses the many innovations emerging from contractors' laboratories and programmers' terminals. Many of these new technologies are licensable; that is, they are capable of being developed into products that can be manufactured and sold by another party through an agreement with EPRI. Ideally, such innovations will show potential to serve an emerging, vibrant utility market; to survive the costly patenting process; and to attract manufacturers interested in producing them. Some will not be picked up for licensing—more sophisticated technologies may overshadow them or the hoped-for market may appear nonexistent or remote.

Licensing is a vital part of technology transfer at EPRI, for the willingness of a reputable manufacturer to commercialize a new technology—a risky process that can cost 10 times the cost of R&D—can be a good indication of the technology's future. For many utilities, the licensing process is only one element of the technology transfer process that brings them practical solutions to their problems. For EPRI, licensing is an increasingly important part of the Institute's charter to make the results of its research available to the utility industry and the public.

A changing perspective

EPRI's view of licensing has undergone a gradual transformation in recent years that parallels a larger shift in the Institute's focus. When established in 1973, EPRI conducted its research without emphasizing target dates for commercial application. EPRI then relied on manufacturers to recognize the commercial potential of EPRI inventions and pursue them accordingly. However, as utilities faced the squeeze of uncertain fuel supplies and rising costs, the need for near-term solutions became more acute, and the Institute looked more closely at each research project for its timeliness and applicability to utility needs. As a result, as early as the project approval stage, project managers explicitly identify expected products and deliverables, potential immediate users, and the probability of technical and commercial success. Throughout the design, test, and demonstration stages, these criteria continue to be assessed and applied. The objective, of course, is to ensure productive responses to utilities' real-world concerns as soon as possible.

During this time, EPRI's patents and licensing staff (advised by project managers and contractors) scrutinizes work in progress for patentable products and technologies for which EPRI will obtain proprietary rights as incentives for future manufacturers. Scott Taper, licensing an-

alyst, states that EPRI is increasingly selective in applying for patents because of the high cost and length (an average of two years) of the patent process. EPRI seeks patents only if inventions are shown to have real commercial application or if a patent is necessary to prevent another producer from appropriating an invention. In cases in which the Institute seeks to distinguish EPRI-developed technology from other technologies, it may also apply for a trademark. Examples include the Scorpion, a self-propelled cable plow; Polysil, an innovative insulating material; NGH–SSR, a subsynchronous resonance damping scheme; and Chlor-n-Oil, a pocket testing kit for polychlorinated biphenyl (PCB).

Special status

EPRI's nonprofit status as a research institution brings with it special restrictions on how it handles the products of its work. Section 501 (C) (3) of the Internal Revenue Code requires that any organization conducting scientific research in the public interest must make the results of its research available to the public on a nondiscriminatory basis. Thus, unlike a commercial developer of a new technology, who can freely offer an exclusive license to one manufacturer, EPRI must offer nonexclusive licenses to all qualified licensees. In some very specific circumstances—when an exclusive license is the only way to get a product to the market, for example—EPRI's licensing staff and relevant project personnel can justify the need for an exclusive licensing arrangement to the Institute's Board of Directors. To date, the Board has granted only one such license.

Although many manufacturers might prefer exclusive licenses for a variety of competitive and other reasons, they can often benefit simply from being first in a new market and will pursue EPRI-developed technology on a nonexclusive basis. A number of manufacturers can achieve first-licensee status by entering the picture even earlier as R&D contractors to EPRI. From the utilities' point of view, nonexclusive licenses mean they need not ultimately rely on a single supplier for new EPRI-developed products.

Attracting licensees

Once the U.S. Patent and Trademark Office accepts a patent application from EPRI, the licensing office begins its efforts to match EPRI-developed technologies with potential licensees. The first step is a public announcement of the invention's availability in EPRI publications; currently the *EPRI Guide* is the publication of first record. From then on, the challenge is to get as much information as possible into the right hands so that a licensing arrangement might follow.

To interest prospective licensees, EPRI pulls together comprehensive information packages. Ideally, the licensing package includes as-built drawings and blueprints, a prototype, final R&D reports, fabrication procedures, component specification sheets, testing procedures, software listings, and technical assistance agreements. The first license granted for an invention becomes the standard for all agreements that follow.

SOFTWARE: NEW LICENSING CHALLENGE

The number of EPRI-developed software packages available for licensing has risen from 30 in 1982 to almost 80 in 1983, indicating the growing importance of this area to the Institute's research activity. Indeed, EPRI's software licensing efforts to date have been fruitful, bringing in almost $120,000 in royalties in 1982.

Because software and computer code manuals offer product and know-how in one package, licensing them is considerably easier than licensing hardware. Software licensing packages are easy to define and to assemble, and the Institute can license the programs directly to utilities and the public without the complications inherent in hardware licensing with an intervening third party.

To help improve access to licensable programs, EPRI has established the Electric Power Software Center in Dallas, Texas, to distribute all codes or programs developed at the Institute. Additional time-sharing arrangements are available through Control Data Corp., United Information Services in Arlington, Virginia, and Babcock & Wilcox Co.

As with hardware licensing, government agencies, universities, and other tax-exempt organizations pay no royalties to EPRI for software licenses. Industrial organizations, including utilities that are not EPRI members, pay royalties and a one-time distribution fee.

In paying their membership fees, EPRI members prepay all software-related royalties. In addition, EPRI has recently instituted a master licensing agreement that allows member utilities to obtain most EPRI-developed software programs under one license.

EPRI computer programs are generally provided in the form in which they were developed, and the Electric Power Software Center will assist utilities and others in basic installation. Additional support from the center is available to users interested in paid consulting arrangements. □

A number of EPRI publications, including the *EPRI Journal* and a series of "Off the Shelf" and "New Product Venture" flyers, get the news out about licensable inventions. Regular news releases and articles in trade journals supplement these publications, reaching wider and more-specialized audiences. In addition, EPRI's licensing personnel make direct contact with major suppliers to the utility industry at trade shows. On the agenda for 1984: the Energy Technology Conference in Washington, D.C.; the Dvorkavitz TECH EX '84 in Orlando, Florida; the IEEE Transmission and Distribution Conference in Kansas City, Missouri; the World Energy Engineering Conference in Atlanta, Georgia; and the ANS Nuclear Power Exhibits, being held in New Orleans, Louisiana, and Washington, D.C.

Given that the current *EPRI Guide* lists 286 available hardware inventions, processes, and techniques and 76 computer programs and data bases, matching manufacturers with the proper information is no small task. As a result, licensing personnel have developed special lists of manufacturers for given areas of technology and can target mailings accordingly.

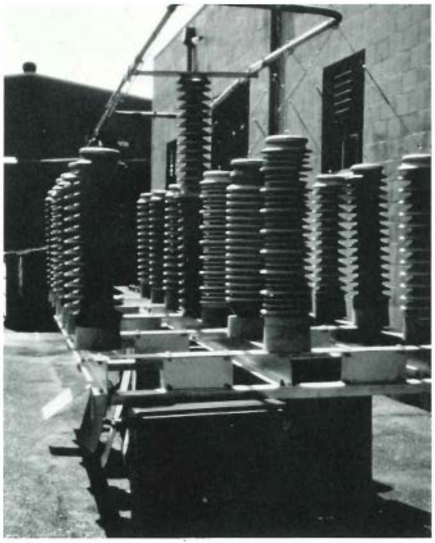
Whether or not one describes such efforts as marketing (an activity not generally attributed to nonprofit institutions), they certainly reflect EPRI's new seriousness about fostering timely, beneficial use of its research. Taper, who puts together licensing arrangements at EPRI, hopes to develop more comprehensive information packages than currently exist to attract potential licensees. "Ideally," he says, "we want to provide 'as built' drawings for hardware, final reports, fabrication instructions, and testing procedures." Taper and other members of the patents and licensing staff work closely with EPRI's project managers. As a team, they often meet with potential licensees to provide detailed information about licensable technologies and to lay the foundation for business arrangements.

The ball is then in the other court, for the candidate licensee must present its qualifications to EPRI. Generally, for publicly owned companies, EPRI evaluates product brochures and annual reports or Dun & Bradstreet reports to determine the licensee's engineering, marketing, and manufacturing capabilities. Startup companies must provide business plans and funding information.

When all qualifications are met, the parties develop a licensing agreement that specifies the amount and schedule of royalty payments to EPRI, the patent rights granted by EPRI, and related conditions. The first license granted for a given invention becomes the standard for all subsequent agreements for the technology; alternatively, if a later licensing modification becomes desirable, all previous licensees benefit as well.

As might be expected, many licensees are the original R&D contractors for EPRI's research projects. Many of these are large companies like General Electric Co., Westinghouse Electric Corp., and McGraw-Edison Co., which seek to enhance existing product lines or to build new ones. But a significant number are small (below $10 million) or medium-size ($50–$100 million) companies. Licensees for Polysil, for example, include Polytech, a small startup company; Lindsey Manufacturing, a small manufacturer; and Syntechnics and Tolley Industries, both medium-size companies.

Clearly, the steps to a licensing agreement will be less involved for R&D contractors or previous licensees. But all agreements specify that licensees must exercise due diligence in bringing a prod-


Polysil insulators

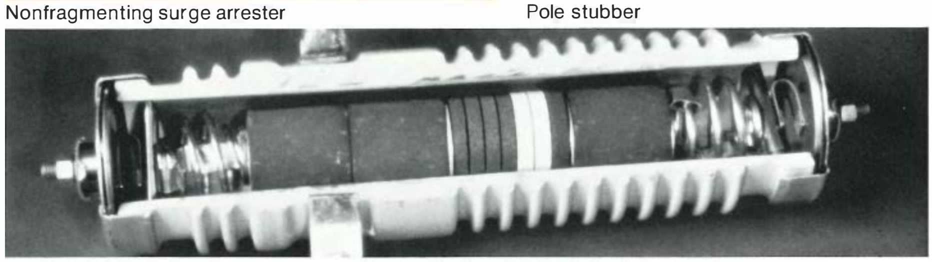

Cable follower


Pole stubber

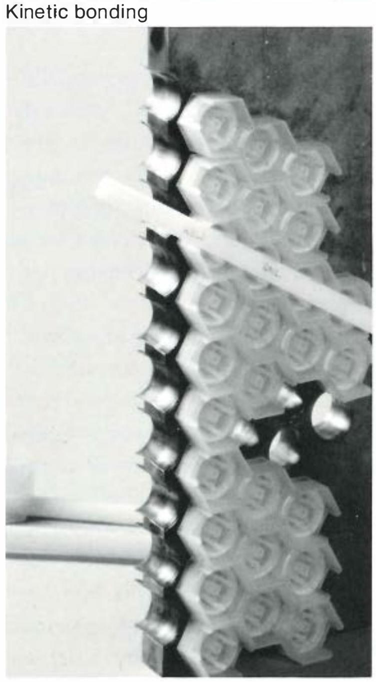

PCB-in-oil detector

The 37 hardware licenses EPRI has granted to date serve a wide variety of utility system needs. Over 250 other EPRI-sponsored inventions, processes, and techniques are also available for licensing.

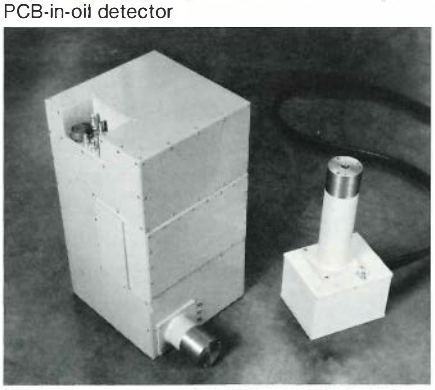
Nonfragmenting surge arrester



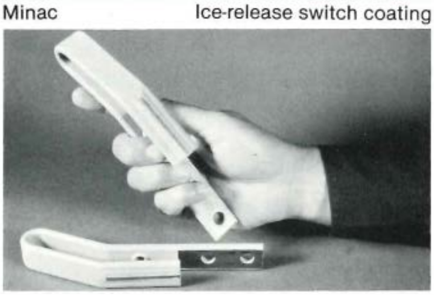
Kinetic bonding



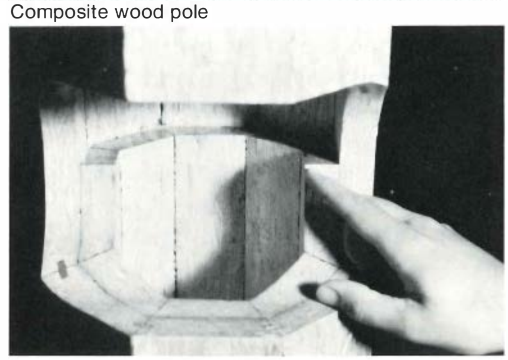
Cable plow


Minac

Ice-release switch coating



Composite wood pole



uct to market to retain their licenses, and call for quarterly reports to EPRI.

Beyond some monitoring of the commercialization process, EPRI's major licensing role is complete at the point the agreement takes effect, according to D. E. Erickson, EPRI's manager of patents and licensing. "As a research organization, EPRI is out of the picture once a commercial organization is willing to further develop the product, and this properly allows market forces to control the product's commercialization. Our role at that point is to let the utilities and the public know that the product is available for their use." In addition, to protect its research, EPRI will monitor possible infringements of the patents under which the licenses are granted and will control the dissemination of information to protect proprietary data.

Criteria for success

What is the ideal EPRI invention for licensing? According to Taper, it is one "supported by patents and technical know-how that can be transferred to a licensee with the skill and track record to forge commercial products out of raw R&D." In this category, he cites the Electric ARM, a remote sensor allowing appliance load monitoring by utilities without inconveniencing their customers; the solar voltaic cell; Polysil, with a potential $1 billion market; and the pole stubber and grouter, which allows utilities to salvage decaying poles and increase pole life 30–40 years.

Minac (a miniaturized linear accelerator capable of inspecting thick-wall vessels during nuclear power plant operation) is another recent success story. Licensed in October 1981 by Schonberg Radiation, Inc., its R&D manufacturer, Minac attracted its first sale scarcely two years later. Three or four other sales of this expensive technology ($250,000–$500,000) are pending. Interestingly, Minac, as a small-scale version of an existing technology, is not patentable. Thus, Schonberg has a proprietary data license that allows it to manufacture and market the technology, with a percentage of its sales returning to EPRI as royalties.

Those products that have less licensing appeal have so for a number of reasons, often stemming from the inherent risks of research into new terrain. The nonexclusive requirement has inhibited licensing of the optical temperature detector, for example, because the current market is not mature enough to support more than one manufacturer. Expected new applications may substantially expand the market for this device, however.

The time can be wrong for other products, either because the market is not yet ready for them, the market dries up, or economic conditions are unfavorable. Composite pole technology is one that may be ahead of its market. Japanese and West German companies have expressed interest in licensing it, but potential U.S. licensees have been less eager to investigate the technology because of the abundance of cheap wood made available by the slump in residential construction.

Another reason for low interest in a product may be that rapid advancements in the field outshine its contribution. The portable phase-angle meter is one such product that lost favor even after licensing in light of one manufacturer's assessment of safety and human factor drawbacks.

When all goes well, however, which is more often than not, both EPRI and its licensees benefit from the licensing arrangements. The licensees obtain a marketable product, and EPRI earns modest royalties. More important, EPRI recognizes that the real and beneficial use of its research results provides a clear measure of its success in serving utilities and the public.

To date, EPRI has granted 37 licenses for hardware; in the third quarter of 1983 alone, it granted 120 commercial licenses for software as well. Hardware royalty income in 1982 was around $30,000—the first ever generated by the Institute—all of which goes back into the general R&D fund. In keeping with EPRI's nonprofit status, it generally offers royalty-free licenses to domestic government agencies involved in regulatory and research activities, to universities that plan to use the research for teaching or their own research, and to other nonprofit institutions.

Thoughts for the future

With the increasing pressures to get technical solutions to the marketplace, it is clear that EPRI's licensing activity will continue to mature. In assessing future directions, Erickson emphasizes the need for EPRI to be attuned to its economic and technical environment. "We need to work hand in hand with the real world," he says. "It is important to continually evaluate economics and commercial feasibility."

Robert Whipple, a consultant to EPRI who brings both legal and business experience to his work with the licensing office, agrees that EPRI sometimes suffers from its somewhat ivory tower status. "EPRI is not set up to provide technical assistance to licensees along with its technology," he comments. "Many licensees would appreciate the kind of help offered by profit-oriented developers in commercializing new products."

Those involved in licensing at EPRI also see great value in close and early contact with potential licensees. Erickson explains, "The earlier we see a potential manufacturer, the better able we are to pave the way for commercialization." Moreover, utilities can benefit from an awareness of who is licensing EPRI's technology. It is here that research dollars come full circle.

EPRI's licensing objectives offer both challenges and concerns. But the current drive to transfer technology in shorter timeframes is already bringing results. The ultimate benefactor, of course, is the public: The inventions licensed today promise to bring more efficient delivery of electricity in the next decade. ■

This article was written by Adrienne Harris Cordova, science writer. Background information was provided by D. E. Erickson and Scott Taper, Patents and Licensing.

Monitoring Stress in the Turbine Generator Shaft

Severe electrical disturbances on the transmission network can bring strong physical forces to bear on utility generator shafts. Torsional vibration monitoring can provide early warning of shaft fatigue.

Conventional wisdom says, "If it isn't broken, don't fix it." In the utility industry, however, particularly with components as large and expensive as generator shafts, that sort of wisdom can mean unexpected and unnecessarily lengthy outages at a cost of over half a million dollars a day. It was specifically to avoid such costly maintenance that EPRI funded a research project with General Electric Co. to develop a shaft-monitoring system for turbine generators.

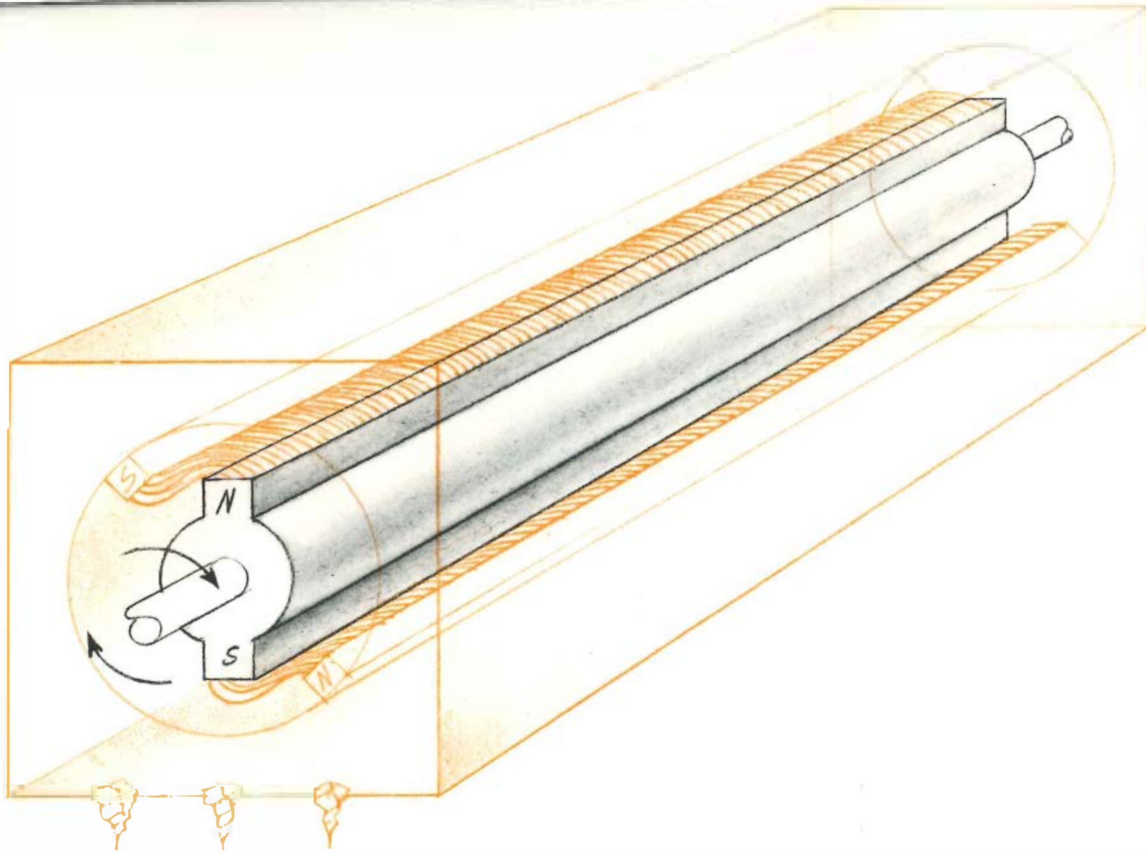
The project's impetus can be traced to events in 1970 and 1971, when Southern California Edison Co. (SCE) found major damage to two turbine generator shafts after electrical disturbances in the utility transmission network. Severe electrical disturbances can ripple through network-connected generators similarly to the way a still tuning fork picks up a resonance when touched to a vibrating one. Particularly susceptible to this effect are the long transmission lines in the West, where electric oscillations in the lines may match and reinforce the natural mechanical resonant frequency of a rapidly spinning generator shaft. In extreme cases, this subsynchronous resonance can even cause the shaft itself to break.

Similar effects can result from other electrical disturbances in more compact transmission networks. For example, a line fault may result in the high-speed reclosing of circuit breakers, which again may reinforce natural resonant oscillations in the generator shaft. The resultant torsional oscillations can cause shaft couplings to slip, coupling bolts to gall, and overall vibration levels to increase. Line-switching and out-of-phase synchronization are also sources of electrical disturbances. In all these cases, the shaft is subject to stress and fatigue. This and other damage can result in unplanned outages for repairs or extended turbine generator maintenance outages to machine distorted bolts and holes or rebalance the shaft. (A number of such incidents have been reported in the United States and abroad.)

Early warning of generator shaft problems clearly is desirable for avoiding damage and catastrophic failure, but, ultimately, avoiding subsynchronous resonance and preventing high-speed reclosing accidents will probably depend on new operating procedures. Thus, one of the goals of EPRI research is to develop a data base that will make possible effective guidelines for new procedures. In addition, the torsional monitoring system will help utilities validate the changes in system operations once they have been made. SCE is now monitoring turbine generator shaft life expenditure to verify that its new operating conditions are satisfactory.

Begun in 1980, the project consists of three phases. The first was the development of the prototype torsional vibration monitoring system, which was installed at the Mohave station in March 1982. The second phase involves the accumulation of data in a central data base from monitors all over the country. So far, three monitoring systems have been installed, and six more are planned. Analysis and assessment of the collected data will complete the third phase of the project.

The actual monitoring system, as installed, depends on two data acquisition



systems connected to a central computer system via an automatic telephone link. The first system continuously monitors the degree of shaft motion at each end of the generator shaft and also detects the level of electrically induced shaft-perturbing torsional forces. The second acquisition system continuously monitors voltage and current signals. These data will provide additional information about the nature of the fault and make it possible to deduce fault type, severity, duration, and approximate fault-clearing time. For both systems, data before and during the event are recorded on site; if the trigger circuit is activated by a disturbance, the data are transferred to the central computer via the automatic data communication system.

The accumulated data for any incident will allow three important calculations to be performed by the central computer: stress all along the shaft, loss of shaft life, and the turbine generator's response to a given disturbance. These calculations require the application of data to a custom model of the specific shaft involved. Within 30 minutes of the incident, these calculations are sent back to the utility's terminal through the telephone link and printed out. The report includes identification of the plant, time and date of the incident, and the calculations of per-incident and cumulative loss of shaft life. As James Edmonds, project manager, points out, the central computer has a basic advantage over systems that rely on individual, on-site minicomputers—although each utility's data are stored securely and separately, the amount of effort and time for a statistical analysis and summary of a broad range of data will be greatly reduced.

All in all, the turbine generator shaft torsional monitoring system is a powerful diagnostic tool. The system allows utilities to determine whether a shaft needs inspection after an electrical disturbance. SCE, for example, estimates that the system makes at least one inspection unnecessary every five years—a savings of $750,000 a year—so the new shaft torsional monitoring system's installed cost of $350,000 is justified quickly. The monitor also gives utilities an idea of just what kind of maintenance will be necessary during scheduled outages. Identifying problems in advance can ensure that the proper equipment and parts will be available during an outage. The continuous accumulation of data on remaining shaft life helps utilities decide whether a shaft needs to be replaced. (An unscheduled replacement would result in a minimum of two weeks in outage time.)

In the short term, the torsional vibration monitoring system means substantial savings in revenue requirements. In the long run, the system will provide the industry with an accurate statistical data base for establishing and validating operating procedures. But perhaps the longest-range benefit will be the system's data base, which will offer both utilities and manufacturers a valuable fund of refined information for planning future generation and transmission projects. ■

This article was written by Stephen Tracy, science writer. Technical background information was provided by James Edmonds, Electrical Systems Division.

NRC Research Supports Nuclear Safety Goals

In fulfilling its regulatory role, the Nuclear Regulatory Commission relies on a broad-based research program for technical support. There is close cooperation between NRC and EPRI in many program areas.

Ensuring safety in the operation of nuclear facilities and in the use of nuclear materials is the mission of the Nuclear Regulatory Commission (NRC). The commission fulfills this responsibility in a number of ways: It licenses nuclear facilities, makes rules governing their operation, and conducts inspections and takes action to ensure that these rules are followed. These are the regulatory responsibilities of NRC and the role for which it is best known.

There is, however, another side to NRC's work, which, though perhaps less familiar to the general public, nonetheless comprises a significant part of the agency's nuclear safety effort. This is the research side of NRC—a broad and extensive program that supports its regulatory work. "Our objective is to support the regulatory process by providing the necessary technical information to allow timely regulatory decisions to be made from a sound technical basis. Our emphasis is on safety," relates Robert Minogue, director of NRC's Office of Nuclear Regulatory Research (ONRR).

In fulfilling this objective, Minogue's office manages research in some 18 program areas, ranging from accident analysis and fission product behavior to seismic design and human factors. It includes some 500 separate contracts and accounts for nearly one-half of NRC's total budget. In FY84, NRC is spending $172 million (not including foreign contributions) for its research effort, and its long-range research plan calls for funding of about $800 million over the next five years. The program is, in fact, the federal government's primary force for nuclear safety research. Much of the work is cooperative with industry organizations, such as EPRI, and with governments of other countries.

Minogue places particular emphasis on NRC's working relationship with EPRI in the research area. "We are partners in our research programs in many ways. We exchange information and share research results; EPRI participates in the planning of our research program and we participate in the planning of theirs. We think of our programs as complementary," says Minogue, "but our research mission is narrower than EPRI's. As regulators, we are concerned primarily with public safety and not with questions of systems reliability or with the economics of nuclear power except as these issues affect safety. Also, our work tends to put more emphasis on extreme events—accidents that would cause extensive damage. EPRI, on the other hand, puts somewhat more emphasis on the lesser, more-likely accidents that may contaminate the plant and cause its inoperability and a loss of investment for the utility that operates it. Unlike us, EPRI is very much concerned with questions of plant reliability, on-line availability, and economics. We work closely with EPRI because we want our programs to mesh. This saves money for both parties."

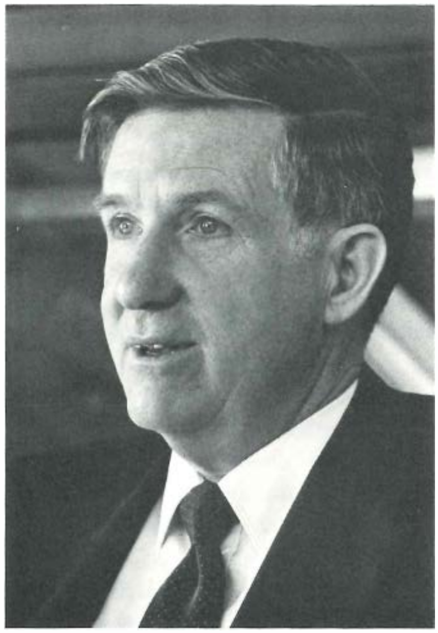
Research Priorities

EPRI and NRC also participate in jointly funded projects. Many of these are big-ticket items that are also funded by the reactor manufacturers or foreign governments. They involve research facilities that simulate nuclear accidents and test the response of safety systems or the behavior of damaged fuel. These programs are key NRC research priorities, explains Minogue. Some of the work dates back 10 years or more to the days of the Atomic Energy Commission, but much of it has changed as a result of the Three Mile Island (TMI) accident in 1979.

"We learned from TMI that the way in which we characterized severe accidents (those that involve damage to the core) was not very realistic," Minogue points out. "It was an approach that relied on some arbitrarily assumed accidents that we thought to be a limiting case—if you designed for them, everything else would be taken care of automatically. In fact, we learned that this was not true. Many of the things we observed at TMI didn't fall within the envelope of what had been previously thought." This finding particularly affected NRC's research in two areas: its work on thermal-hydraulic transients and its efforts on severe accidents.

Thermal-hydraulic transients are failures in the nuclear reactor cooling system (such as a pipe break, a pump failure, or a stuck-open valve) that would call into service the reactor's emergency core-cooling system and its backup systems. For the past decade, NRC has conducted tests at experimental facilities to validate the computer codes NRC uses to predict and understand the behavior of these cooling systems during such transients.

"The idea is to do accident tests," explains William Beach, technical assistant to the director of ONRR's Division of Accident Evaluation. "We build small-scale mock-ups of a reactor and then simulate broken pipes with quick-opening valves and do other kinds of mean things. The purpose is to check whether the computer code's prediction of what will happen during an accident is actually what does happen during the test. Another goal is to test the procedures that have



Minogue

been developed to help the plant operators respond to the accident."

Before the TMI accident, NRC's thermal-hydraulic research was dominated by large-break loss-of-coolant accidents (LOCAs)—those involving ruptures of very large pipes. Regulations required that nuclear plants be designed with emergency cooling systems that could function in the event that a large pipe broke. It was assumed that if the cooling system could function under these conditions, it could also function in the face of smaller-break accidents. A very extensive testing program on large breaks took place at a number of large experimental facilities across the United States.

The testing took place on "loops," which are configurations of piping that include all the major components of a reactor system. Different loops were used to study accidents that might occur in the different types of nuclear plants manufactured—that is, boiling water reactors (BWRs) or pressurized water reactors (PWRs). Some of the work was sponsored primarily by NRC and some was funded in conjunction with EPRI, the U.S. reactor manufacturers, and other countries.

The largest such facility—and the only one using a system powered by a nuclear core—was the Loss-of-Fluid Test (LOFT) Facility at the Idaho National Engineering Laboratory (INEL). For many years NRC was the major source of funding for LOFT and for the Semiscale Test Facility at INEL, which was powered by an electrically heated core. Both LOFT and Semiscale investigated large-break LOCAs as they would occur in PWRs manufactured by Westinghouse Electric Corp. and Combustion Engineering, Inc. (C–E).

Also examining postulated LOCAs in PWRs manufactured by these companies was a program called the full-length emergency cooling heat transfer—separate effects and system effects tests (FLECHT–SEASET), supported by NRC, EPRI, and Westinghouse at the Westinghouse facility in Monroeville, Pennsylvania. Similar work was under way for large-break LOCAs in BWRs at the two-loop test apparatus (TLTA) in San Jose, California, under the sponsorship of EPRI, NRC, and General Electric Co. In general, the large-break LOCA testing was successfully completed at these facilities and not only confirmed NRC's regulations dealing with emergency cooling for this kind of accident, but demonstrated the regulations' conservatism, Minogue explains.

However, after the TMI accident, it became clear that the large-break LOCA was not the only kind of accident that regulators should be worried about. The recognition resulted in some new tests, as well as the reorientation of work at some of the existing facilities. The TLTA facility, for example, was totally revamped to accommodate a new test program that will look at many types of transients occurring in BWRs, including small breaks. Called the fully integrated systems test (FIST), the program is under way with funding from the old TLTA partners.

The LOFT and Semiscale facilities and programs were also modified to broaden the testing in progress there on PWRs manufactured by Westinghouse and by C–E. NRC is no longer responsible for the LOFT program, but is part of a consortium of nine countries (led by DOE) that is sponsoring the testing here. Both NRC and EPRI contribute funds to the new international test program for the United States. Other countries represented are Austria, the Federal Republic of Germany, Finland, Italy, Japan, Sweden, Switzerland, and the United Kingdom.

New work was developed to test cooling responses to a wide range of transients in the kind of PWRs manufactured by Babcock & Wilcox Co. (B&W). The new test program is sponsored by NRC, EPRI, B&W, and the B&W Owners Group at B&W's Alliance (Ohio) facility. To accommodate the new program there, an existing loop called GERDA, which had been sponsored by Brown Boveri Corp., was upgraded to allow for testing in two phases: the once-through integral system (OTIS), which solely investigates the steam generator behavior, and the multiloop integral systems test (MIST), which will examine the rest of the system.

The TMI accident also affected the course of NRC's research on severe accidents—those involving extensive fuel damage and release of radioactive material from the nuclear core. Although the Atomic Energy Commission, the forerunner of NRC, had sponsored a program of research into fission product release and transport in the 1960s, the program was mostly completed during that decade. At the time of the TMI accident, work in this area was low-key and almost nonexistent, explains Beach. It has since become a top-priority research item, involving extensive experimentation at several key national laboratories, including INEL, Sandia, Oak Ridge, and Los Alamos.

The current program looks at the entire spectrum of events that might occur in a severe accident, such as the behavior of fuel damaged to the point of fuel melting. It also examines the nature of primary system failure and the quantities and the nature of fission products that might be released from the primary system during an accident, as well as the timing of their release, their transport into and beyond the containment, and their possible deposition on walls and other surfaces. This is the so-called source term, which is significant because it determines how severe the consequences of a nuclear accident would be in terms of its effect on public health and safety. Source term work is also a top research priority at EPRI, and NRC works closely with EPRI in this area.

One such cooperative project is the work begun this summer at the Marviken nuclear power plant in Sweden to simulate the transport of fission product aerosols through a reactor's primary cooling system. The work is sponsored by nine countries, with NRC representing the U.S. government and EPRI the U.S. private sector. "This is a very difficult experiment, but if fully successful, it would be very valuable," notes Minogue. "What the research is trying to do is to look at the behavior of aerosols that are generated when the core melts. The belief is that most of them will deposit out."

Other Research

In addition to the agency's research on such major items as severe accidents and thermal-hydraulic transients, NRC has work under way on a number of smaller-scale efforts that are nonetheless significant to NRC's safety objectives. Such work includes research on risk analysis, human factors, seismic design, plant aging, and equipment qualification.

In the risk analysis area, as Minogue explains, the goal is to improve the technique of probabilistic risk analysis (PRA) to the point where NRC can begin to make use of it in the licensing process. PRA is a technique by which the probabilities of occurrence of various types of accidents are quantified and the safety consequences assessed. The information is then used to set plant and equipment standards.

"PRA would be a very powerful tool that the commission could use in making licensing decisions if the methods were fully developed, if the operational data base were solid, and if the models were fully validated," states Minogue. "Unfortunately, none of these is in very good shape. The concept is attractive, but there are a lot of limitations, and the priority of the research budget is to eliminate the limitations as best we can. I think it's going to be quite some time before PRA will be sufficiently backed up to play a very extensive role in the design process."

Research on human factors is also part of Minogue's program. "The bottom line in human factors work is more careful attention to the role of human beings in the decision-making process of nuclear plant operation, particularly in accident situations," he states. "The goal is to provide better operator training, better design of control rooms and control systems, better diagnostics, and better displays of information. Much of this is applied research, and we work closely on it with the industry's Institute of Nuclear Power Operations."

Another key research effort is in the area of seismic design (i.e., the way nuclear plants are designed to withstand earthquakes). Minogue explains that one goal of this work is to allow seismic design to be simplified for future plants. "Many of us are convinced that the approach we have used to regulate seismic design is such as to be counterproductive to safety in other areas and perhaps to be counterproductive even to seismic response," he states.

An example of this is the question of whether to use stiff or flexible piping. Because earthquake shaking can lead to appreciable displacement of the piping in cooling systems, seismic design practices call for piping to be stiff and rigid. These constraints, however, could lead to high stress on the system because pipes also require flexibility in order to expand and contract as they are exposed to normal variances in heating conditions. This stress could lead to breaks in the system and to loss-of-coolant accidents. Overconservatism in seismic requirements, therefore, could result in reduced safety for the system as a whole.

Although designers have been able to accommodate the needs for both flexibility and rigidity in the past, they would like to do a better job of allowing for more flexibility. Therefore, NRC and EPRI are working cooperatively to identify overconservatism in seismic design. One joint effort was initiated in 1982, for example, to test three-dimensional piping in simulations of earthquake motions.

The goal of NRC's research into plant aging is to aid the staff in determining whether operating plants continue to meet the health and safety requirements that were in effect at the time the plants were licensed. "The nature of the industry has changed considerably in the last 10 years," notes Minogue. "We have a lot of plants in operation and they are getting older. As plant equipment is exposed to various service conditions over time, it begins to undergo deterioration or aging phenomena. We are trying to get a better handle on what phenomena are important and how to test to make sure that the plants remain functional."

Examples of work under way in this area include research on the structural integrity of pressure vessels as they are affected by irradiation embrittlement and the growth of assumed cracks in service; research dealing with corrosion, cracking, and degradation of steam generator tubing; and work on the effect of stress and temperature on electrical and mechanical components. Efforts are also in progress to validate the nondestructive examination techniques used to detect and characterize cracks and flaws in pressure vessels, pipes, and steam generator tubing. Work in this last area is closely coordinated with EPRI.

Closely related to plant aging is the equipment qualification work, which is directed toward evaluation of the testing methods used to qualify the electrical and mechanical equipment needed for safety functions during severe accident conditions.

NRC is part of the joint government-industry effort to extract R&D data from the recovery operation at TMI. "You might look at TMI as a big, complicated, and very expensive experiment in severe fuel damage. Certainly there is a lot of information that can be obtained by looking at specimens of the damaged core and by analyzing how fission products actually behaved in the containment," notes Minogue. "However, the ultimate importance of the data to NRC decreases as the years go by. We do our research to support regulatory decisions, and timing is very important. If the cleanup had gone faster, I think we would have relied a lot on the data from TMI. But it has gone very, very slowly and, in the meantime, decisions have had to be made on the data we obtain from our various experimental work. I see us using the data from TMI less and less."

Minogue comments that he is placing major emphasis on providing the technical basis to permit NRC to make good decisions in a timely manner. Decisions are needed in the near future on severe accident policy, on the source term, and on obtaining balance in seismic piping design. NRC research is dedicated to supporting the decision-making process, and Minogue is looking to EPRI research for contributing technical support. ■

This article was written by Marie Newman, a writer specializing in energy issues.

Starr Wins Nuclear Statesman Award

EPRI's founding president is honored for outstanding service in developing and guiding the use of nuclear energy.

Chauncey Starr, founding president of EPRI, received the 1983 Henry DeWolf Smyth Nuclear Statesman Award for his pioneering work in the field of nuclear energy. The award medal was presented to Starr in November, during the concurrent winter meeting of the Atomic Industrial Forum (AIF) and the American Nuclear Society (ANS) held in San Francisco.

The honor was established in 1972 by the two nuclear organizations to recognize outstanding service in developing and guiding the use of atomic energy in constructive channels. Smyth, best known for the Smyth Report—the first technical explanation of the wartime development of nuclear energy—was a member of the U.S. Atomic Energy Commission and ambassador to the United Nations International Atomic Energy Agency.

André Giraud, the architect of the French nuclear energy program, and Glenn T. Seaborg, a pioneer in the field of nuclear physics who received the 1951 Nobel Prize in chemistry, are among the previous recipients of the award.

In accepting the award, Starr commented, "The previous recipients of this award have all made outstanding contributions to the development of the peaceful uses of atomic fission worldwide. I am therefore very impressed and deeply grateful to my colleagues in the AIF and ANS that they considered my work worthy of such recognition."

Starr served as EPRI president from 1973 to 1979 and then assumed the title vice chairman. He is director of EPRI's Energy Study Center, where he is involved in the long-range issues of electric power generation and use.

From 1967 to 1973 Starr was dean of the UCLA School of Engineering and Applied Science. This followed an industrial career that included 20 years with Rockwell International, featuring service as president of its Atomic International Division.

Starr first became involved with nuclear energy in the early days of the Manhattan Project at the University of California at Berkeley and later served at Oak Ridge National Laboratory.

Among his many honors, Starr is a founder and past president of the ANS, and an officer of the French Legion of Honor in recognition of his efforts in promoting and furthering understanding between France and the United States in the field of scientific and industrial achievements. ■

First Source-Term Tests Under Way in Sweden

As part of its program to establish a more realistic value for the source term, EPRI is working with the Nuclear Regulatory Commission (NRC) and the nuclear research organizations of eight countries to carry out a series of tests at Sweden's Marviken test reactor. (Source term refers to the amount of fission products that would be released in the improbable event of a reactor accident resulting in core degradation.)

Overestimation in the prediction of accident consequences could lead to overreaction in emergency response planning, as well as to unnecessary public fears. The objective of the reactor safety community in addressing this concern is to return to the traditional engineering practice of doing realistic, rather than conservative, accident evaluations.

Work under way is testing EPRI's position—that the source term now used is exaggerated—through accumulation of additional experimental data. An important component of EPRI's source-term program is to study the transport of fission product aerosols through the reactor primary coolant system.

Marviken was an early, 200-MW (e) boiling (heavy) water reactor built for the Swedish State Power Board but never put into service. It is now used as a test facility. The current Marviken tests are studying the possible attenuation of aerosols in the primary system. High-concentration aerosols—those exceeding 100 g/m^3—will be studied in tests attempting to simulate, at nearly full scale, real accident scenarios.

Fissium, a nonradioactive substance that contains the elements typically found in fission products, and corium, a substance that contains the elements found in core material and fission products, will be vaporized and injected into the primary system of a light water reactor. The fissium will contain elements that have a high vapor pressure.

Tests will determine the behavior of the simulated fission products and core material during transport through full-scale reactor components. Core meltdown effects will be simulated by vaporizing the fissium and corium in an LWR reactor vessel. Other tests will study the retention of the volatile species by interactions with the less volatile aerosols.

A varied program of experiments, expected to continue through mid 1985, has been planned to cover numerous possible scenarios. The first of these tests—with a flow path configuration including the pressurizer and quench tank—has already been carried out. In subsequent tests the reactor vessel and upper plenum structures will be included in the flow path.

Working with EPRI and NRC in this program are utilities and/or agencies in Canada, England, Finland, France, Holland, Italy, Japan, and Sweden. ■

New Cost Study for CFB Retrofit

EPRI has awarded the Colorado-Ute Electric Association, Inc., a $180,000 contract to study the cost and feasibility of installing a utility-scale circulating fluidized-bed (CFB) boiler at its Nucla station in western Montrose County. The project is one of several sponsored by EPRI to complement research under way at the 20-MW (e) atmospheric fluidized-bed pilot plant at the Tennessee Valley Authority's Shawnee steam plant reservation near Paducah, Kentucky, and at the 6-by-6-ft test boiler at Babcock & Wilcox Co.'s Alliance (Ohio) Research Center.

Colorado-Ute's cost and feasibility study will include replacing the plant's stoker-fed coal boilers with a CFB boiler and adding another turbine generator. These steps would increase the plant's capacity from 36 to 100 MW (e).

The circulating-bed boiler design for the Nucla station would differ from the bubbling-bed boiler planned for the 160-MW (e) demonstration plant at Paducah. Construction of the commercial-size Paducah plant (sponsored jointly by EPRI, the Tennessee Valley Authority, Duke Power Co., and the state of Kentucky) is scheduled to begin in 1985.

In both the circulating-bed and the bubbling-bed processes, a mixture of air, crushed coal, and limestone is injected into the bottom of the boiler. In a circulating-bed boiler, the coal-limestone mixture is completely recirculated into the reactor, where it burns to completion; in a bubbling-bed boiler, the mixture burns while bubbling in the bed area. Both processes remove almost all SO_2 gas before it enters the smokestack. The proposed retrofit at Nucla is designed to determine whether the circulating-bed process can remove flue gases more efficiently than the bubbling-bed process.

Meanwhile, Northern States Power Co. is proceeding with plans to modify an existing boiler at its Black Dog plant near Minneapolis. EPRI is providing partial funding and technical support. Under a $414,000 contract with EPRI, NSP has tested a variety of fuels in an AFBC boiler at its French Island station at La Crosse, Wisconsin. Tests at the 15-MW (e) unit, designed to burn wood wastes, demonstrated how such low-grade fuel materials as discarded railroad ties, shredded rubber tires, refuse-derived fuel, sewage sludge, and peat can be burned successfully in a fluidized bed. ■

Artificial Reefs May Provide an Alternative for Waste Disposal

With land at a premium in most large cities, finding adequate space to store or dispose of the huge amounts of waste produced by emission control systems is no easy task for utilities. Especially in urban coastal areas, waste disposal problems can present a major obstacle to utilities planning conversion to coal combustion.

EPRI researchers have found that using blocks of coal waste to make reefs may be an attractive alternative to traditional disposal methods, and at the same time may provide new habitats for aquatic life. These conclusions are based on observations at a pilot reef constructed in 1980.

Before building the reef, laboratory and small-scale field tests were conducted for two years to determine the effects of coal waste blocks on a marine environment. Test results yielded no indication of toxic chemical damage.

Some 15,000 hardened blocks, manufactured from 500 tons of scrubber sludge and fly ash, were placed in the Atlantic Ocean off Long Island, New York, at a depth of 65 ft (20 m). The artificial reef rises about 5 ft (1.5 m) from the ocean floor and extends for 600 ft (183 m). Researchers then monitored the reef for three years to see whether fish and plant life would accept the artificial reef as a suitable habitat. Within one year, adult fish moved in. Within two years, a complete marine community was established.

A nearby reef, built earlier from conventional concrete blocks, served as a control site. After three years the marine populations at the two sites were essentially the same. A smaller coal waste reef constructed at a freshwater site (in Lake Ontario) also yielded positive results.

Although it demonstrates that environmental effects are negligible, the study does not prove the economic viability of building reefs from coal combustion by-products. Transportation costs, acceptance by regulatory agencies, and costs of traditional disposal methods must be considered by a utility in making a decision about waste disposal.

However, a hypothetical case study found that a reef construction system would cost about $45/t to build and operate. For urban areas where land is not available on site or nearby, this figure is comparable with land disposal costs. The economics of coal waste reefs may also be influenced by proposed congressional legislation providing tax credits for artificial reefs that increase fishery resources and fishing opportunities.

Funding for the ocean reef project (RP1341-1) was provided by the Department of Energy, Environmental Protection Agency, Power Authority of the State of New York (PASNY), Long Island Lighting Co., New York State Energy Research and Development Authority, and EPRI. The freshwater study (RP1341-2) was funded by PASNY and EPRI. ■

CALENDAR

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

FEBRUARY

9–10
Load Management Strategy Testing Model Users Group
Palo Alto, California
Contact: Victor Niemeyer (415) 855-2744

23–24
Heat Pump Research Update—Residential
New Orleans, Louisiana
Contact: James Calm (415) 855-8949

MARCH

6–7
Seminar: Indoor Air Quality
Atlanta, Georgia
Contact: Gary Purcell (415) 855-2168

14–16
Solar and Wind Power, 1984 Status and Outlook
San Diego, California
Contact: Edgar DeMeo (415) 855-2159

15–16
Residential Off-Peak Cooling
Tempe, Arizona
Contact: Veronika Rabl (415) 855-2401

APRIL

9–11
3d International RETRAN Meeting
Las Vegas, Nevada
Contact: Lance Agee (415) 855-2106

MAY

1–2
Seminar: Indoor Air Quality
Denver, Colorado
Contact: Gary Purcell (415) 855-2168

1–3
Annual Review of Demand and Conservation Program Research
Atlanta, Georgia
Contact: John Chamberlin (415) 855-2415

1–3
Seminar: Mutual Design of Transmission Lines and Pipelines
Palo Alto, California
Contact: John Dunlap (415) 855-2305

9–10
Meeting: 14th Semiannual ARMP Users Group
Jackson, Michigan
Contact: Walter Eich (415) 855-2090

15–17
Mutual Design of Transmission Lines and Railroads
Chicago, Illinois
Contact: John Dunlap (415) 855-2305

JUNE

4–7
Symposium: State of the Art of Feedwater Heater Technology
Washington, D.C.
Contact: Isidro Diaz-Tous (415) 855-2826

19–21
Mutual Design of Transmission Lines and Railroads
Washington, D.C.
Contact: John Dunlap (415) 855-2305

JULY

17–19
Annual Review of Demand and Conservation Program Research
Seattle, Washington
Contact: John Chamberlin (415) 855-2415

SEPTEMBER

11–13
Mutual Design of Transmission Lines and Railroads
Atlanta, Georgia
Contact: John Dunlap (415) 855-2305

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Vice President

COAL LIQUEFACTION RESEARCH

Significant advances in basic research have recently been made toward understanding the fundamental structure of coal and the chemistry involved during coal liquefaction. It is the chemistry that significantly affects, drives, or predetermines the yield of any process. In moving coal liquefaction from the laboratory to a process, many different process configurations have been pursued to achieve the desired chemical conversion of the coal into distillable liquids: one, two, or three stages; catalyst in none, one, or all stages; molecular hydrogen in none, one, or all stages; total or selective solvent recycle. It is the chemistry that will be discussed here, not the multitude of process configurations. Once the chemistry is understood, processes can be designed that optimally use the chemistry to achieve the desired products.

Coal liquefaction has been the subject of research for over a hundred years. Because of the complex, heterogeneous nature of coal, however, it is only recently that significant advances have been made toward understanding the true nature of coal and its chemistry. Progress has been slow for many reasons, such as the lack of adequate analytic techniques and incorrect fundamental assumptions. Another major difficulty is that most coal liquefaction research has been performed not on virgin coal but on retrograde coal materials that result from improper handling, such as oxidation, improper drying, aging, and so forth.

The misconceptions concerning coal structure have propagated to misconceptions regarding the chemical conversion of coal into distillable liquids. For example, the conventional theory of conversion is that it occurs in two distinct steps: dissolution and hydrogenation. Recent observations, however, indicate that this distinct, two-step concept is an inaccurate simplification of the true physical and chemical reactions that occur.

The nature and role of the liquefaction solvent are the keys to understanding liquefaction chemistry. Most liquefaction concepts employ some type of recycle solvent that serves many purposes. A possible mechanism for hydrogen donation from the liquefaction solvent will be postulated later. This mechanism for the very complex coal-solvent interaction is an outgrowth of several years of EPRI research that employed a specific type of solvent: basic nitrogen heterocyclic compounds. These solvents are unusually reactive and tend to amplify the chemistry in which coal participates.

Research work at EPRI began focusing on basic nitrogen solvents in late 1980 when both laboratory results and pilot plant operating results pointed to their disproportionate influence on coal liquefaction. Attempts to understand these results led to a number of speculations on the mechanisms of coal chemistry. To test these ideas, EPRI sponsored basic research and used the nitrogen solvents to illustrate the chemistry occurring during liquefaction. By employing these solvents, it is possible to achieve complete (100%) coal conversion to soluble material.

Having achieved complete coal conversion, EPRI looked to the next unknowns: solvent recovery and product quality. When laboratory experiments were performed that provided enough product to begin analytical work (Kerr-McGee Corp., RP1715-1, and University of Wyoming, RP2147-3), evaluation of the experimental results led to some rather startling chemistry. Attempted distillations of the product pointed to these observations: soluble products are not necessarily distillable (400–800°F, 200–430°C); solvents can be irreversibly lost to the coal-derived products and not necessarily as a result of retrogressive reactions; coal chemistry is even more complex than thought earlier.

In an effort to unravel the complex chemistry, EPRI's research focused on the following hypotheses.

- Coal may be a very reactive, easily damaged material.
- Coal may not be such a high-molecular-weight, refractoried material as previously thought.
- Low-temperature reaction may be important, perhaps critical, in determining the outcome of the liquefaction process.
- The basic nature of the solvent apparently catalyzes certain types of reactions at specific sites in the coal.
- Solvent incorporation into the dissolving coal plays some role in the chemistry.

Coal structure

EPRI's early liquefaction results were usually very erratic whenever the feedstock was a western subbituminous coal. Initially, it was thought that the erratic behavior resulted from oxidation of the coal. However, work at Gulf Research & Development Co. to study the behavior of dried and oxidized coals showed that any type of pretreatment, even drying under an inert gas, always gave lower coal conversions (EPRI AP-1625).

The evidence made EPRI question the traditional beliefs of coal as a refractoried, highly cross-linked, heavy aromatic structure. The fact that coal could be so easily damaged at very mild conditions, even during handling, preparation, and/or drying, pointed toward coal (subbituminous coal, at least) being a very reactive substance. Further, it was found that once the damage or degradation occurred to the coal, it could not be completely reversed, even with very severe liquefaction conditions.

To unravel the true nature of these very reactive materials, EPRI funded research at Rockwell International Corp. (RP2147-4) to study a typical western subbituminous coal (Wyodak, Rawhide Mine, Anderson seam). The coal was subjected to very mild solubilization reactions. The results gave a much clearer picture of coal as a relatively low-molecular-weight, easily solubilized material. A significant portion (50–70%) of the coal is subject to base-catalyzed reactions at very low temperatures (<572°F, 300°C). Further, these reactions involve the selective attack of oxygen functional groups, especially carbonyl and carboxyl oxygen.

In performing these low-temperature solubilizations, it was found that an extensive amount of the coal's oxygen can be removed as CO_2. With a clearer picture of coal and its reactive nature, EPRI realized the extreme importance of understanding what happens to the coal on the way to reaching liquefaction conditions (i.e., low-temperature coal reactions).

Coal reactions

In performing a series of low-temperature solubilizations, Rockwell found that at least three major reactions occur with this subbituminous coal long before liquefaction conditions are reached.

- <419°F (215°C)—hydrolysis of ester group
- <500°F (260°C)—decarboxylation
- <572°F (300°C)—hydrolysis of other-than-ester functionals

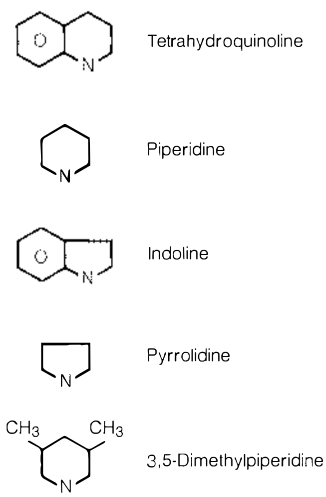


Figure 1 These basic nitrogen heterocyclic solvents catalyze reactions both at low temperatures and at liquefaction conditions.

All these reactions involve the base-catalyzed attack of oxygen functional groups. Coal's susceptibility to base-catalyzed reactions is not limited to low temperatures, however. The remarkable liquefaction conversions achieved with tetrahydroquinoline (THQ) and other basic nitrogen heterocycles indicate that these solvents are also catalysts for high-temperature liquefaction reactions (Figure 1). To investigate the liquefaction reactions that these solvents catalyze, research was funded with SRI International (RP2147-5).

The research at SRI has shown that these basic solvents do indeed catalyze high-temperature reactions, including cleavage of ether linkages, deoxygenation of polycyclic phenols, and hydrogenolysis of other linkages. Field ionization mass spectroscopy and gas chromatography analyses, however, have shown that these basic nitrogen solvents also incorporate with the dissolving coal. The coal-solvent bonds that are formed are actually stronger than those in the original coal. The incorporation takes place in a whole host of coal structures, at virtually every molecular weight from 200 to 800 (and, presumably, beyond). Both the solubilization and incorporation are extremely rapid (Figure 2).

Several relevant observations may be made from the basic nitrogen heterocyclic work.

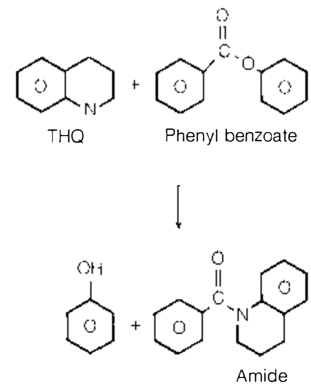
- Coal dissolution and conversion is extensively and rapidly base-catalyzed at both low and high temperatures.
- Solvent incorporates into the dissolving coal.
- Solvent incorporation occurs even at mild temperatures (<572°F, 300°C).
- Depending on the solvent, the incorporation may be irreversible.
- Also depending on the solvent, the newly formed solvent-coal bonds may be stronger than those in the original coal.
- Oxygen functionals are the prime sites for nucleophilic attack and may participate in electrophilic attack.

Because they seem to amplify the reactions in which the coal participates, the work using these basic nitrogen heterocyclic solvents has led to considerable insight in, and speculation on, solvent chemistry.

Solvent chemistry

Solvent apparently serves many purposes during the dissolution of coal, but two of the most significant are as a hydrogen transfer mechanism and as a catalyst. These two purposes are not necessarily separable.

Figure 2 The reaction of a secondary amine (such as THQ) with an ester (such as phenyl benzoate) produces an unconvertible amide.



In working with THQ at mild conditions (572°F, 300°C), some interesting phenomena have been observed. One is that solvent loses hydrogen. But the hydrogen is not added to the hydrogen-starved coal-derived products. At these mild conditions, coal is more reactive toward combination with the solvent than it is to accepting hydrogen from either the gas or the solvent. The coal reacts with the solvent to form solvent-coal complexes.

Solvent incorporation is not specific to basic solvents, however. All solvents apparently go through some initial period of incorporation. Solvent incorporation may be a necessary and critical step in the mechanism of coal dissolution (and, possibly, in hydrogen transfer). The nature of the solvent will determine whether the incorporation is reversible.

The sites of solvent incorporation in the coal are those that are highly functional. Because they are a catalyst, the basic nitrogen solvents accelerate solubilization and defunctionalization of the coal. They then combine with the highly reactive fragments. In the case of hydroaromatic solvents, the solubilization is slower and the incorporation less pronounced. The same mechanism, however, probably occurs.

It is only in the last few years that the heavier, higher-molecular-weight hydroaromatic solvents have been recognized as much superior hydrogen donors. Many reasons have been put forth as to why the heavier hydroaromatics are better solvents, including such speculations as their greater similarity to coal (like dissolves like); more donatable hydrogen; better equilibrium; more-labile hydrogen.

But the questions remain. What is a good hydrogen donor? Why is some hydrogen more labile? Why does solvent activity decline with repeated recycle?

Labile hydrogen donors

What is a hydrogen donor? By definition, a hydrogen donor is a chemical compound that gives up hydrogen to another species. This definition may be too simplistic when dealing with the interaction of coal and solvent. Mobil Research and Development Corp. found that under certain conditions almost any molecule containing hydrogen could donate it (EPRI AF-1298).

The differentiation between a good solvent and a bad solvent is not only the concentration of potential hydrogen donors but also the lability of the hydrogen. What is labile hydrogen? Again, a simple definition is hydrogen that moves facilely from one species to another.

Although the movement of hydrogen can be monitored analytically, the actual mechanism of hydrogen exchange is still unknown. Nevertheless, several observations can be made. Hydrogen exchange (not only donation) is critical. The preferred hydrogen exchange sites in solvents are very specific—the α-position. This position is more than three times as active as the next most active site (β-position).

This site-specific hydrogen exchange does not mean that hydrogen cannot be donated from other sites; obviously it can. However, apparently other sites are not as fast (not as labile) as the α-position. During coal dissolution, when speed is of the essence (time, <5 min), the β-hydrogen does not perform with the necessary speed or lability. If the solvent is deficient in α-hydrogen, retrogressive reactions will probably occur during coal dissolution. Unless care is taken with selective solvent recycle, bottoms recycle, or some other solvent adjustment, α-hydrogen tends to decrease and β-hydrogen tends to increase steadily with the number of the reaction cycles. Thus the solvent becomes less active.

Recent research implications

From the research performed over the last few years some preliminary observations may be made regarding coal (subbituminous) and coal liquefaction chemistry.

- Coal is a very reactive material, so reactive, in fact, that it can be easily damaged during handling, drying, or pretreatment.

- Coal dissolves easily and at mild temperatures.

- Bases catalyze both low-temperature dissolution reactions and higher-temperature liquefaction reactions.

- During the dissolution process, coal fragments attack both the solvent and the other coal fragments. Solvent incorporation occurs.

- If the solvent is a fairly high-molecular-weight hydroaromatic material with an abundance of α-hydrogen, the solvent will eventually disincorporate, leaving its α-hydrogen with the coal-derived product.

- If the solvent is a strong nucleophile, the highly functional coal fragments will undergo nucleophilic addition and form very stable bonds. In some cases, the newly formed bonds will be stronger than those in the original coal.

- If the solvent is a low-molecular-weight aromatic, it will participate in the incorporation/disincorporation reactions, but its deficiency in donatable α-hydrogen will give no net advantage. Retrogressive reactions will eventually occur.

- Repeated recycle of solvent eventually depletes α-hydrogen. The hydrogen becomes trapped in a slow or nondonating site. Thus, on recycle, solvent quality decreases unless it is upgraded (by hydrogenation or the addition of more-active hydroaromatics).

Based on a considerable amount of research over the last few years, some speculative observations may be made on the properties of a good solvent. Possibly the solvent would attach easily to dissolving coal ($T < 650°F$, 340°C); have a capping group on donatable hydrogen at the α-position; be capable of undergoing thermal cleavage; leave the capping group or hydrogen upon cleavage; and maintain its original aromatic structure.

Future research

Based on the results of the last year's research, the following areas have been identified as critical in the further fundamental understanding of coal and coal liquefaction: fundamental differences in coal; solvent-coal chemistry at mild conditions ($T < 650°F$, 340°C); chemistry of defunctionalized coal; and solvent equilibrium at mild and liquefaction temperatures. *Project Manager: Linda Atherton*

FUSION FUEL CYCLE RISK ANALYSIS

Any future fusion power generating station would be composed of a variety of interrelated systems. Although many of these would be similar or identical to those currently used in fission and fossil fuel plants, the systems directly related to the fusion reactor would be unique. Little detailed design work has been done on these systems to date. However, by using present perceptions of what an ultimate fusion power plant might be, technical performance requirements can be specified for many of the systems. Such work generally shows that much R&D is necessary to bring the systems' present state of the art to the required level. One important fusion element is the fuel cycle system. It is unique to fusion in the requirement that it must produce a major portion of the fuel (tritium) for the plant. Also, because only 5–20% of the fuel is burned on a once-through basis, the exhaust must be captured, purified, and reinjected by this system. The EPRI Fusion Power Systems Program has sponsored a technical risk analysis of the fuel cycle system to identify the R&D that is critical for meeting the expected ultimate performance requirements (RP1969).

It seemed appropriate to do a study on the fusion fuel cycle system at this time for two reasons. First, the federal program is conducting various research activities in this area—including a pilot fuel system called TSTA (tritium systems test assembly), now in its initial operational phase at Los Alamos National Laboratory. Second, there are several alternatives available for each of the fuel cycle subsystems. The objectives of the EPRI technical risk assessment were to define the most favorable options for development purposes, and to determine important technical risks that are not now being investigated but that need to be addressed in the R&D program. This article discusses the major elements of a fusion fuel cycle system, the methodology used in the risk analysis, and the results and conclusions relative to identified R&D needs. The project is documented in detail in the recently published report AP-3283.

Fuel cycle system

Figure 3 shows the major components proposed for a fusion fuel cycle system. The colored lines indicate the primary fuel flow. The fuel, a combination of deuterium and tritium, is injected into the plasma region from the fuel preparation and delivery unit. Then, after the burn, it continues to the plasma exhaust removal system. Approximately 90% of the fuel is unburned and must be recycled

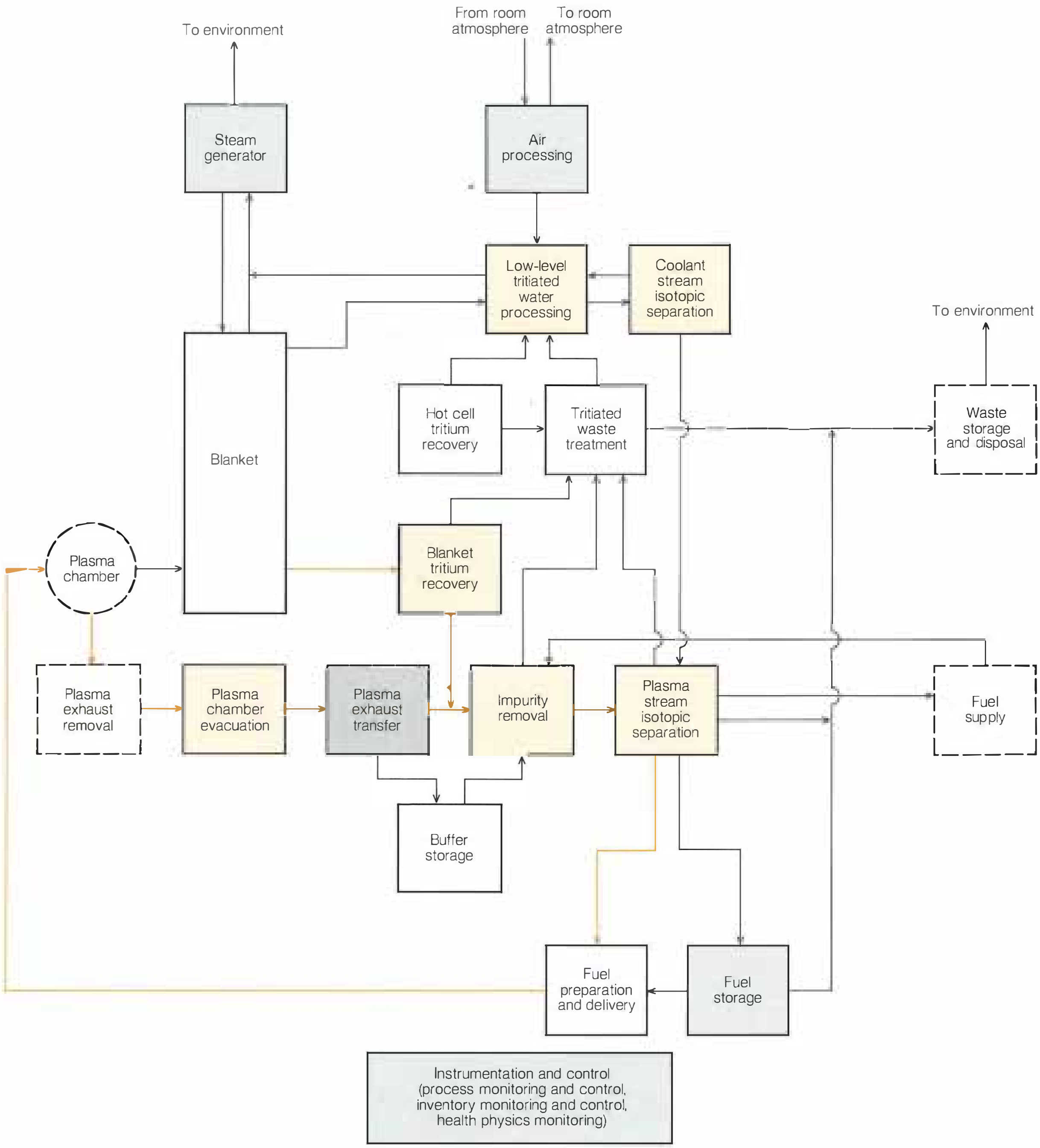


Figure 3 Fusion fuel cycle system. For the purposes of RP1969 the plasma and the units in the dashed boxes were assumed to lie outside the fuel system boundary. The colored lines indicate the primary fuel flow. The subsystems shaded in gray and in color—several mass-flow units plus the instrumentation and control subsystem—were selected for detailed design descriptions. On the basis of these descriptions, the units shown in color were then selected for the technical risk assessment.

and purified for reinjection. This process would require impurity removal, isotopic separation, and fuel preparation. Another source of fuel is the blanket, where tritium is bred from lithium. This fuel must also be purified. Initial impurity removal occurs in the blanket tritium recovery system; the fuel is then injected into the plasma exhaust stream for further impurity removal and isotopic separation.

Secondary to the major fuel reprocessing cycle would be the impurity streams and other exhausts. Because tritium is radioactive, accountability for it in the fuel cycle system is essential. This in turn requires systems of tritiated waste treatment, low-level tritiated water processing, and air processing; their purpose is to ensure that all radioactive tritium is recovered or is processed and disposed of in a way that will not endanger the environment.

There are three principal streams of the fuel cycle that interact with the environment and that must be included in a risk analysis: the coolant stream from the blanket to the steam generator, the exhaust from the tritiated waste treatment system, and the atmospheric exhausts from the air processing system. In addition to the functional waste processing systems, it would be necessary to have an instrumentation and monitoring system for recording all levels of radioactivity and the radiological interactions between the fuel cycle system and the environment.

In the development of fusion, there are several non-fuel-system decisions that could have a strong impact on fuel system design. Among these are the type of breeding system used in the blanket and the selection of the confinement configuration relative to the efficiency of the burn. The more efficient the burn, the smaller the size of the reprocessing system.

Project methodology

Under RP1969 EPRI sponsored an examination of the technical risks associated with the development of a fuel cycle system to satisfy the requirements of a commercial fusion power plant. The tasks entailed in this project were to:

- Define the technical performance requirements for a possible commercial fuel system
- Define the subsystems and options to be evaluated
- Determine key system and subsystem technical performance parameters
- Interview experts to obtain information on the past, current, and projected future performance of the alternative subsystems, as well as estimates of the funding levels required for development
- Conduct simulations with a Monte Carlo computer code to determine the overall fuel performance probability distribution for each reasonable set of subsystem options
- Select the combination of options that has the most favorable prospect of meeting the performance requirements of a commercial system through identifiable R&D tasks
- Rank technical risks and identify R&D tasks

Early in the project it was recognized that a complete fuel cycle technical risk assessment was beyond the scope and funding of this effort, so criteria were established for determining critical subsystems. Detailed design descriptions were developed for ten subsystems (see Figure 3), and five were then selected for the technical risk assessment: plasma chamber evacuation, impurity removal, isotopic separation, blanket tritium recovery, and low-level tritiated water processing. (The isotopic separation subsystem was later divided into two units, one for the plasma exhaust stream and one for the coolant stream.)

The following subsystems were excluded from detailed consideration—that is, from both the design description phase and the risk assessment—for various reasons discussed in the more detailed project documents: plasma exhaust removal, blanket, hot cell tritium recovery, tritiated waste treatment, buffer storage, fuel preparation and delivery, fuel supply, and waste storage and disposal.

Project results

Table 1 presents the performance and environmental requirements for a commercial fuel system that were defined in this study. It was necessary to use value ranges for these parameters; information on the factors that affect the ranges is presented in the project's final report.

For the five subsystems selected for the technical risk assessment, extensive consultations with the technical community, a workshop, and a comprehensive Monte Carlo analysis were conducted to determine preferred options. This assessment was limited to technical performance considerations and

Table 1
COMMERCIAL FUEL SYSTEM SPECIFICATIONS

Performance Parameter	Range
Total steady-state tritium inventory (excluding fuel storage requirements)	<30 kg (<3 × 10^8 Ci)
Tritium required for initial reactor startup (excluding fuel storage requirements)	<30 kg (<3 × 10^8 Ci)
Normal influx of tritium through first wall to water coolant	10–10^5 Ci/d (10^{-6} to 10^{-2} kg/d)
Tritium concentration in primary coolant (water)	0.1–10 Ci/L (10^{-8} to 10^{-6} kg/L)
Water leakage across steam generator	0.2–20 L/h
Fueling rate (tritium)	0.015–0.15 g/s
Plasma exhaust pumping rate (deuterium, tritium, helium)	20–200 Pa·m^3/s (150–1500 torr·L/s)
Purity of injected deuterium-tritium fuel	<1% hydrogen, <0.1% other
Accidental release of tritium to containment	0.1–1.0 kg
Tritium accounting accuracy	0.1–1.0% of inventory
Environmental Parameter	
Chronic tritium release	10–100 Ci/d (10^{-6} to 10^{-5} kg/d)
Chronic worker exposure	0.5–1.0 man-rem/MW (e)/yr
Chronic exposure to public	1–10 mrem/yr

did not address economic, safety, and environmental issues. These should be included in future assessments.

Two sets of options were selected, one on the basis of technology available in 1980 and one on the basis of technology projections for 2000. Here are the results by subsystem:

- Blanket tritium recovery: liquid lithium–molten salt technology preferred for both 1980 and 2000 (produces a lower tritium inventory and better fuel purity than a solid breeder with in situ gas purge)
- Plasma chamber evacuation: charcoal cryopump preferred for both 1980 and 2000 (has a larger helium pumping capacity and a shorter regeneration time than the argon cryopump)
- Isotopic separation (plasma exhaust stream): for 1980, cryogenic distillation (produces a lower tritium inventory than laser-induced separation); for 2000, laser-induced separation (produces better fuel purity than cryogenic distillation)
- Impurity removal: for 1980, molecular sieve (produces slightly poorer fuel purity than the palladium diffuser but has a lower tritium loss to the environment); for 2000, advanced molecular sieve (projected to have about the same removal efficiency as the diffuser while having a much lower tritium loss to the environment)

In the case of the options for low-level tritiated water processing and for coolant stream isotopic separation, it was not possible to identify technical preferences. Nontechnical factors will likely identify the preferred options for these subsystems.

It was concluded that for the five subsystems considered, there seems to be no generic obstacle to prevent the design and construction of a commercial fuel cycle system when it is required, assuming presently planned R&D efforts continue. There is at least one valid option available for each of these five subsystems, as well as a variety of long-term alternatives. In addition, six other subsystems are able to meet commercial fusion specifications with currently existing equipment and are judged to have very little technical risk: plasma exhaust transfer, fuel supply, fuel storage, buffer storage, air processing, and steam generators.

In general, it was the determination of the technical community that the funding levels for work on the five subsystems examined in the risk analysis are adequate to reach the long-term requirements of commercial operation.

Tritium inventories and leakages for commercial applications appear to be significantly lower than previously assumed in the conceptual designs of fusion power systems. Judging from the information gathered in this study, a maximum tritium requirement of under 20 kg seems possible for U.S. development units, and the first commercial reactor can be expected to require less than 10 kg of tritium for startup (the exact amount depending on how much on-site reserve is considered necessary).

The tritiated waste treatment subsystem was found to play a major role in preventing tritium loss to the environment. Although it unfortunately was not examined in the technical risk analysis, it should be included in future such analyses because of its economic and environmental significance in the fuel cycle system.

It was also concluded that as of now there are no viable options for monitoring the tritium inventory to the presently perceived specification of ±100 Ci. The design description effort for the instrumentation and control subsystem found that its functional requirements exceed current capabilities.

In the final project report, 20 critical R&D needs are identified, and a plan is presented to address these needs in a logical and timely manner. The methodology formulated in this project to assess the technical risks associated with fusion development appears to be generally useful for any advanced technology that can be quantified, that has clearly identifiable subsystem options, and that has an active R&D community for objective technical forecasting. *Program Manager: F. R. Scott*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Vice President

AFBC DEMONSTRATION

In the last five years, atmospheric fluidized-bed combustion (AFBC) has steadily gained acceptance among small boiler operators as an economical coal-fired boiler technology. Over 40 AFBC boilers are currently in operation or under construction in the United States. This acceptance has been due primarily to the boilers' ability to burn low-grade coals and waste fuels while meeting federal and local environmental emissions regulations. Although these initial AFBC designs adequately meet industrial use requirements for process steam and space heating, they cannot be directly scaled up to the size required for utility power generation (several hundred megawatts). EPRI's AFBC program is geared toward further developing the technology to make it suitable for utility application. Because scale-up is a major issue, EPRI's efforts have involved progressively larger test boilers: a 2-MW development unit, a 20-MW pilot plant, and now 100–200-MW full-scale demonstration units.

AFBC is an evolutionary improvement in coal-fired boiler design that offers several advantages over conventional pulverized-coal boilers equipped with flue gas desulfurization systems. (A fluidized bed is composed of granular particles that are vigorously mixed by up-flowing air; this gas-solid mixture percolates like a liquid, hence the term *fluidized bed.*) AFBC can meet stringent federal regulations on sulfur dioxide and nitrogen oxide emissions without the need for add-on flue gas treatment equipment. The relatively low combustion temperature—about 1500°F (816°C), as opposed to about 2500°F (1371°C) for pulverized-coal boilers—inhibits coal ash melting, thus greatly reducing slagging and fouling. On the basis of conceptual design studies for full-scale utility plants, a 10–15% savings in capital and operating costs is projected for AFBC in addition to the substantial site-specific savings associated with the use of lower-cost coals.

The scale-up process

When EPRI initiated its AFBC research program in the mid 1970s, there was little AFBC design information developed specifically for utility application. A 30-MW AFBC unit was being started up at Monongahela Power Co.'s Rivesville station, and its operation highlighted the critical issues for utility application; however, the unit did not serve as a test unit for developing design solutions. To meet this need, EPRI undertook the development of a 2-MW (e) AFBC facility at Babcock & Wilcox Co.'s Alliance (Ohio) Research Center. Construction was completed in 1977.

The 6-by-6-ft cross-sectional bed area and high freeboard of the 2-MW process development facility were designed to simulate the large bed area and long residence time that would be typical of utility units. An extensive parametric testing program, which was begun in 1978, led to design modifications for improving the process to meet utility efficiency requirements. The successful testing at the 6-by-6-ft facility provided the basis for proceeding to a larger utility design test unit.

In 1979 the Tennessee Valley Authority and EPRI developed plans for a 20-MW (e) AFBC pilot plant, a tenfold scale-up over the 6-by-6-ft facility. This engineering pilot unit, to be located at TVA's Shawnee steam plant in Paducah, Kentucky, was designed to simulate utility power plant operating conditions and mechanical features. Construction of the pilot plant was completed in May 1982 at a cost of $68 million.

Following startup, TVA and EPRI initiated a four-year, $28.5 million test program to verify process performance achieved at the smaller 6-by-6-ft facility, to test full-scale boiler components and auxiliary equipment, and to develop turndown and control philosophies for utility application. The success of initial testing at the 20-MW pilot plant provided the confidence necessary for taking the next step in the scale-up process: a 100–200-MW (e) full-scale demonstration plant.

Full-scale demonstration

In December 1981 EPRI solicited utility interest in hosting a full-scale AFBC demonstration. Industry response was strong, with 11 utilities proposing demonstration projects and many others indicating technical interest. After discussions with the interested utilities, EPRI requested formal proposals detailing the technical and economic aspects of the potential projects. Five proposals representing significantly different AFBC applications were received in February 1983. The proposed projects ranged from constructing grass roots plants to repowering existing turbines with an AFBC boiler to converting an existing pulverized-coal boiler into an AFBC boiler.

A detailed evaluation of the proposals was conducted, leading to a recommendation for selection. Industry advisory approvals were obtained, and in August 1983 EPRI's Board of Directors approved funding for a 160-MW demonstration jointly proposed by TVA, Duke Power Co., and the state of Kentucky. The project is to be located at TVA's Shawnee steam plant, the site of the 20-MW pilot unit, and is estimated to cost $220 million, which includes a four-year test program. EPRI's share will be $75 million.

In the Shawnee demonstration project, a 160-MW AFBC steam generator will be installed adjacent to the existing powerhouse, which contains 10 pulverized-coal boilers (1950s vintage) matched with 10 turbogenerators. Each boiler-turbogenerator set is nominally rated at 160-MW (e) output with steam conditions of 1800 psig (12.4 MPa), 1000°F (538°C) superheat, and 1000°F reheat. The AFBC unit will be designed to match the steam conditions for the existing turbogenerator No. 10 and will be installed in parallel with boiler No. 10. To minimize cost the project will make extensive use of existing plant systems, including the stack, baghouse, induced-draft fan, condensers, feedwater heaters, and coal-receiving equipment.

The project schedule calls for a request-for-proposal for the steam generator system to be issued in early 1984. Boiler vendor bids will be submitted in May, and on the basis of a final assessment of technical readiness, a selection is planned for October. Subsequent key project dates include release for fabrication in mid 1985, start of construction in the spring of 1986, and completion in mid 1989.

Following initial startup and shakedown, a nominal four-year test program will be initiated. The test program will consist of detailed boiler performance evaluations with the design fuel, operation over a range of load conditions to demonstrate turndown and control capabilities, and selected testing of alternative coals. The results from this test program, together with those from the detailed design and construction phase, are intended to provide a comprehensive technical and economic data base for the specification and purchase of subsequent commercial utility units. After the four-year test, the AFBC demonstration unit will be operated commercially for at least six more years. This long term commercial testing is intended to provide reliability and availability data on the boiler components and auxiliary systems.

The detailed design phase for the balance-of-plant systems will be conducted by Duke Power Co. EPRI, TVA, and Duke will participate in the boiler and balance-of-plant design review. The schedule is intended to provide for any design modifications considered necessary on the basis of test results from the 20-MW pilot plant.

Additional AFBC demonstration projects are receiving serious consideration by two other utilities. Northern States Power Co. (NSP) and Colorado-Ute Electric Association are currently developing projects that complement the TVA demonstration project.

NSP has proposed to convert an existing 100-MW pulverized-coal boiler into an AFBC boiler. Boiler No. 2 at its Black Dog station outside of Minneapolis was switched to firing a blend of bituminous coal and low-sulfur, subbituminous coal in the early 1970s to reduce SO_2 emissions. Since the fuel switch, the boiler has been derated to 85 MW and availability has been reduced. In the AFBC conversion, NSP plans not only to recapture the megawatts lost after fuel switching but also to increase the boiler capacity to 125 MW, with the intent of firing 100% with the lower-grade, lower-cost subbituminous coal.

EPRI is currently cosponsoring a design study with NSP to assess the technical feasibility and cost of this project. In this study, boiler conversion designs are being developed by Babcock & Wilcox, Combustion Engineering, Inc. (C–E), and Foster Wheeler Development Corp., and a balance-of-plant conversion design is being developed by Stone & Webster Engineering Corp. The study will be completed by early 1984. Further plans call for final selection of the boiler vendor by mid 1984 and completion of construction by early 1986. Both NSP's and EPRI's decision to proceed with the project will depend on the results of this design study. A preliminary survey of boilers in the United States indicates that up to about 150 boilers totaling 20,000 MW may be amenable to AFBC conversions similar to NSP's Black Dog project.

Colorado-Ute has proposed an AFBC demonstration using a significantly different fluidized-bed design—a circulating fluidized-bed (CFB) boiler. In a CFB the fluidizing velocity is typically 20 ft/s (6 m/s), or twice that of a (bubbling) AFBC. In addition, a CFB uses a very high rate of solids recirculation to the combustion zone, which results in a dilute fluidized bed throughout the combustor height rather than a dense fluidized bed at the base of the combustor, as in the bubbling-bed AFBC. In pilot tests the CFB design has been shown to improve carbon burnup, NO_x reduction, and limestone utilization. Questions still remain about the capital cost trade-off that may be required in achieving the higher efficiencies.

EPRI and Colorado-Ute are cosponsoring a design study to assess the application of a 100-MW CFB at Colorado-Ute's Nucla station in western Colorado. In addition to the new CFB boiler, Colorado-Ute plans to install additional turbine generator capacity to increase the plant output from the current 36 MW to 100 MW. The plant's three stoker-fired boilers will be retired. As part of this study, CFB boiler designs are being developed by two major CFB vendors—Pyropower Corp., which is using the Finnish Ahlstrom technology, and the team of C–E and Lurgi Corp. Colorado-Ute is designing the balance-of-plant modifications to support the station uprating. The design study will be completed in early 1984. Pending results of the study, Colorado-Ute intends to proceed with selection of the CFB boiler vendor by late 1984, start of construction by mid 1985, and initial startup by early 1988. *Project Manager: Callixtus Aulisio*

HEAT RATE IMPROVEMENT IN FOSSIL FUEL POWER PLANTS

The utility industry continues to emphasize improved plant heat rate as a major objective for fossil fuel power plants. This becomes particularly important as fuel costs escalate and as aging units and worsening coal quality take their toll of component efficiency. EPRI is devoting considerable attention to this issue. Major areas of effort include continuous plant performance monitoring and computer assessment, plant testing, plant modeling techniques, equipment efficiency improvements, and new plant designs for low heat rate. The goal is to improve the heat rate of existing plants by at least 3% and that of new plants by 10%. With over 1000 fossil fuel units larger than 100 MW currently in service in the United States, this effort offers important economic advantages to the utilities and has national significance for reducing fossil fuel consumption.

Improvement of fossil fuel power plant heat rate is perceived to be a major objective for most, if not all, U.S. utilities. The need to maintain or improve plant efficiency is brought about by rapidly escalating fuel costs; regulatory incentives for improved plant performance; and continual heat rate penalties due to backfitted environmental controls, worsening coal quality, and an increase in average plant age.

Additional gains to be realized by improving heat rate include reduced plant emissions, increased plant capacity, and reduced plant downtime. Further, there appears to be a definite relationship between efficiency and availability for fossil fuel plants. In fact, a sudden or gradual reduction in unit efficiency is often symptomatic of incipient component failure.

Heat rate trends

The average station heat rate decreased steadily until the early 1960s. Subsequently, there was little incentive to continue heat rate improvement efforts because of the expected increase in nuclear baseload generation and the availability of relatively inexpensive fossil fuels. At the same time, new environmental restrictions requiring flue gas treatment had a significant adverse effect on heat rate. A further negative impact resulted from the need to cycle many large fossil fuel plants. Compared with baseload operation, cycling typically results in lower component efficiencies and increased unit heat rate.

EPRI believes that it is important to reverse this trend toward higher heat rates and has recently carried out a two-year study on the design of advanced fossil fuel plants. As described below, a 10% improvement in heat rate over the most efficient plant now operating appears possible.

For existing units, efforts are under way toward a heat rate improvement goal of 3%. The ordering rate for new plants (essentially all fossil fuel units and primarily coal- or lignite-fired) indicates that system reserve margins may be eroded over the next 10 years. Considerable attention is likely to be focused on the performance of existing units, particularly aging units approaching the original design life. One impact of this scenario may be a trend toward extending fossil fuel plant life beyond 40 years, to perhaps 50–60 years of active operation. EPRI is working on guidelines for heat rate improvement in aging plants, as well as on plant performance monitoring, improved instrumentation and testing, and application of retrofit technology.

An indication of the importance of this overall program is provided by a recent study that considered the value of improved heat rate. Improved plant efficiency can be manifested in two ways: by reduced fuel consumption for a given MW output or by increased MW output for the same fuel consumption. Of course, the second option may or may not be possible, depending on other equipment design limitations. Using both scenarios, the study assessed the value of a 1% improvement in efficiency for baseload plants in the United States (cycling units were omitted). It was found that for fossil fuel baseload units alone, the second strategy leads to a potential $1.8 billion in savings and the first to a potential $0.7 billion.

This report discusses three major projects now under way in the heat rate improvement program. Designed to respond to primary utility needs and interests as defined in two recent EPRI seminars, these projects address heat rate improvement in aging fossil plants (RP1403-3), plant performance monitoring and instrumentation system development (RP1681), and advanced pulverized-coal power plant development (RP1403-4).

Heat rate improvement in aging plants

The maintenance of design heat rate as fossil fuel units age requires considerable attention to the following so-called controllable losses.

- Main steam temperature
- Reheat steam temperature
- Main steam pressure
- Condenser back pressure
- Dry gas loss
- Excess air
- Air preheater leakage
- Steam coil air heater steam needs
- Soot blower steam or air needs
- Boiler blowdown quantity
- Spray water quantity
- Condensate makeup quantity
- Condenser cooling water quantity
- Feedwater heater efficiency
- Boiler feed pump turbine efficiency
- High-, intermediate-, and low-pressure turbine efficiencies
- Station electric service
- Fuel quality

Many of these losses can be handled by plant operations personnel through routine maintenance and "tuning" of the plant, thus permitting the heat rate to be optimized while the unit is under load. Others may require scheduled downtime for component replacement or for removal of turbine and boiler deposits. Such procedures are followed by many of the leading utilities in the field of plant heat rate improvement, but many more companies are only now beginning to institute formal heat rate programs.

RP1403-3 seeks to quantify the key elements of existing heat rate programs for the benefit of the entire industry. To achieve this, two utility steering committees have been formed, one for western and one for eastern utilities. About 15 utility delegates form each committee.

The objective of RP1403-3 is to develop a generic planning tool that utilities can use in initiating and managing a formal, ongoing program to maintain heat rate. The project will cover heat rate program objectives, cost-benefit information, program management and organization concepts, key program activities and equipment needs, and program initiation activities.

The difference between the net heat rate of a plant as determined in initial acceptance testing and the actual net heat rate can be large. In a survey of utilities intent on pursuing plant heat rate improvement programs, the deviation of actual and design heat rates for 129 units averaged 1000 Btu/kWh and ranged from 100 to 3250 Btu/kWh. Of these losses the utilities estimated that, on average, 419 Btu/kWh could be salvaged (Figure 1). Clearly, when this limited sample is extended over the industry, the national gain in reduced fuel usage (or increased power output) is of major importance.

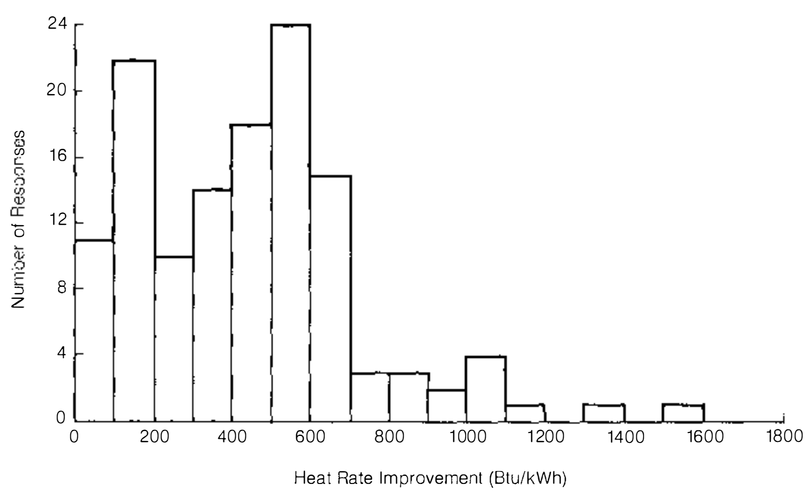


Figure 1 Utility estimates of potential heat rate gains for a sample of 129 fossil fuel units. For the average unit in this sample, the potential improvement is 419 Btu/kWh, which represents about 42% of the deterioration in heat rate since the unit went into service.

Plant performance monitoring and instrumentation system

Tools for improving the on-line monitoring of power plant performance are being developed by manufacturers, utilities, universities, and EPRI. These efforts involve advanced computer models and algorithms and improved instrumentation.

One area that is advancing quite rapidly is the on-line use of plant computer models (e.g., PEPSE, SYNTHA, THERM) in conjunction with continuously monitored instrumentation. By observing changes in performance and using the modeling codes to analyze the likely source of the deviation, performance losses and their causes can be identified quickly. This process goes one step beyond currently installed on-line systems by employing a calibrated computer model of the entire plant. Both the current and the advanced systems depend on accurate and reliable instrumentation, however, and it is here that much improvement is expected in the future.

RP1681 is designed to demonstrate a state-of-the-art performance monitoring system on the Morgantown-2 unit of Potomac Electric Power Co. (Pepco). This goal requires improved instrumentation in all areas of the plant, from coal feed lines to generator bus. For example, the absence of accurate devices for coal assaying and weighing makes continuous monitoring of coal plants difficult. Periodic coal sampling for constituent analysis and belt scales for coal weighing are the best systems now in operation. Because inaccuracies in these devices may mask plant component deterioration, utilities often resort to the method of losses—whereby feedwater flow to and steam flow from the boiler are measured, along with exhaust gas losses, to infer fuel Btu input.

Other areas of concern regarding instrumentation involve the ability to measure the following.

- Condenser conditions
- Wet steam enthalpies
- Drum liquid levels
- Combustion efficiencies
- Precipitator and scrubber losses
- Pulverized-coal feed rates
- Flue gas velocities and temperatures

The industry has to be able to measure these factors accurately and continuously, with reliable and repeatable results over long periods. This is a challenging task for instrument designers and manufacturers.

RP1681 will provide two benchmarks for the industry. First is the Mark I system, which will use available or soon-to-be-available instrumentation, new computer algorithms, and state-of-the-art display devices to advance Pepco's Morgantown unit to a new standard in performance monitoring. Included in this package will be permanently installed flue gas flow and temperature sensors, turbine cycle instrumentation, and monitors for all plant auxiliary equipment. Use of a plant computer model will permit performance diagnostics to be carried out on-line. Completion is scheduled for 1985.

The second benchmark is the Mark II system. Incorporating a low-excess-air boiler, individual burner tuning, on-line measurement of coal flow and coal heating value, and improved incremental power dispatch algorithms, the Mark II system will enhance Pepco system efficiency perhaps 1–2%. It will be in operation by 1988.

RP1681 is guided by a 20-member utility steering committee composed of both plant performance engineers and system dispatch personnel.

Advanced-plant development

Two independent research teams—each consisting of a turbine generator manufacturer, a boiler manufacturer, an architect-engineer, and a utility—have clarified the prospects for the next generation of coal-fired power plants (RP1403). The objectives of the project were to identify the limits of current fossil fuel plant technology and to develop conceptual designs and specifications for an advanced plant (Table 1).

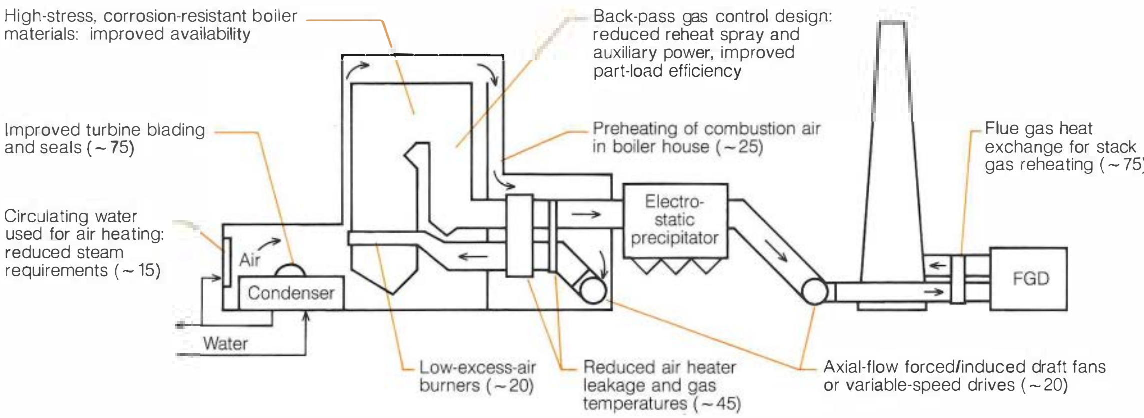
Heat rate improvements have been identified in the areas of cycle and design improvements and retrofit technology (Figure 2), and overall plant savings of from $74 million to $159 million for a new 750-MW plant were estimated. The required development work for the advanced plant has begun and is aimed at the new coal-fired power plants currently planned for the 1990s. Retrofits of advanced innovations to the more than 1000 existing fossil fuel units over next five years are also a key part of the program.

An important related conclusion was that the availability of new advanced plants can be as high as, or higher than, that of existing plants. Despite the advanced steam conditions, this is achievable through careful equipment design, component and subassembly pretesting, and adequate design margins for the expected duty. Plant availability can be further enhanced by effective use of redundant components, design for ease of maintenance, comprehensive spare parts practices, and new on-line diagnostic monitoring techniques.

Table 1
GENERAL SPECIFICATIONS FOR AN ADVANCED PLANT

	General Electric, Babcock & Wilcox Team	Westinghouse, Combustion Engineering Team
Gross rating	725 MW	824 MW
Net rating	674 MW	773 MW
Net heat rate	8875 Btu/kWh	8330 Btu/kWh
Net thermal efficiency	38.5%	41%
Steam throttle pressure	4500 psig (31 MPa)	4500 psig (31 MPa)
Steam throttle temperature	1050°F (566°C)	1100°F (593°C)
Steam reheat temperatures	1075°F (579°C) and 1100°F (593°C)	1050°F (566°C) for both
Final feedwater temperature	580°F (304°C)	604°F (318°C)
No. of feedwater heaters (including deaerator)	9	9
Condenser back pressure	1.5 in Hg	2.5 in Hg
Excess combustion air	17%	15%
Air preheater exit gas temperature	300°F (149°C)	270°F (132°C)
FGD inlet gas temperature	235°F (113°C)	220°F (104°C)
FGD exit gas temperature	120°F (49°C)	120°F (49°C)
Stack gas temperature	170°F (77°C)	170°F (77°C)

Figure 2 These are examples of the more than 50 possible retrofits for improving plant heat rate that have been identified in an ongoing EPRI advanced-plant planning project. The numbers in parentheses indicate potential heat rate improvements in Btu/kWh.



Outlook for the future

Fossil fuel power plants will, in the future, reflect the renewed emphasis on plant heat rate. One of the first effects is likely to be the introduction of on-line performance monitoring systems at more plants. Data from these systems will be used to pinpoint deteriorating components and areas of efficiency loss, as well as to optimize system dispatch procedures.

Along with improved monitoring systems will come improved computer software featuring new trending and analysis algorithms. Microprocessors will enable all stations to have adequate computing capability to handle this new demand at moderate cost. One area that utilities will need to address involves the training and skills of station personnel assigned to monitor and update this capability.

New plant additions are likely to show a return to supercritical steam conditions, with an emphasis on higher steam temperatures and pressures than currently employed. Stricter environmental legislation may penalize new plants even more in terms of heat rate and will require more attention to improved back-end designs and waste heat recovery devices.

Extension of the operating life of existing power plants will encourage the addition of retrofit measures to improve heat rate, along with other component modernization. As components in these aging plants are changed out, the replacements will be selected with optimized efficiency and reliability in mind.

To maintain the reliability of more advanced cycles and of new component designs, the use of on-line diagnostic monitoring tools will become more prevalent. These predictive maintenance systems will be able to anticipate the occurrence of failures, allowing plant personnel to schedule outages, order spare parts, and provide manpower in an optimal manner. Along with the diagnostic systems will come a further change in control room practices, as the additional diagnostic information is fed to suitable display devices. *Project Manager: Anthony F. Armor*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Vice President

UNDERGROUND TRANSMISSION

Partial discharge and fault location systems for gas-insulated transmission lines

Locating faults in cables has always been a challenge. The introduction and growing acceptance of SF_6 gas-insulated cables put a new wrinkle into this age-old problem. Recognizing that there were no proven methods to detect and accurately locate faults within gas-insulated transmission lines, in early 1979 EPRI initiated a project with Ontario Hydro to develop suitable instrumentation for gas cable diagnostics (RP7875-1). This instrumentation was to address two types of problems: faults and partial discharges that may eventually lead to faults.

Even though both the fault detection and partial discharge detection instrumentation seek to compare the arrival time of a transient traveling in opposite directions from the fault, the two methods are significantly different and were developed as two independent systems.

The gas cable fault location system consists of a high voltage to digital logic electrooptical interface, a timing logic system, and a microcomputer-based data acquisition and analysis system. The principle of operation is very simple. At one end of the cable, coaxial dividers within the cable couple high-voltage transients to the electrooptical interface system (Figure 1). At the other end, similar couplers are used to interconnect the three phases. A breakdown within one phase of the cable generates high-voltage transients, which propagate away from the arc in both directions. In one direction, the transient arrives at the instrumented terminal of the cable and is coupled to the interface system. The transient that propagates in the other direction is coupled from the faulted phase to the two unfaulted phases and returns to the instrumented terminal by an unfaulted phase. The fault position can be determined from the time difference between the first two transients arriving at the instrumented terminal.

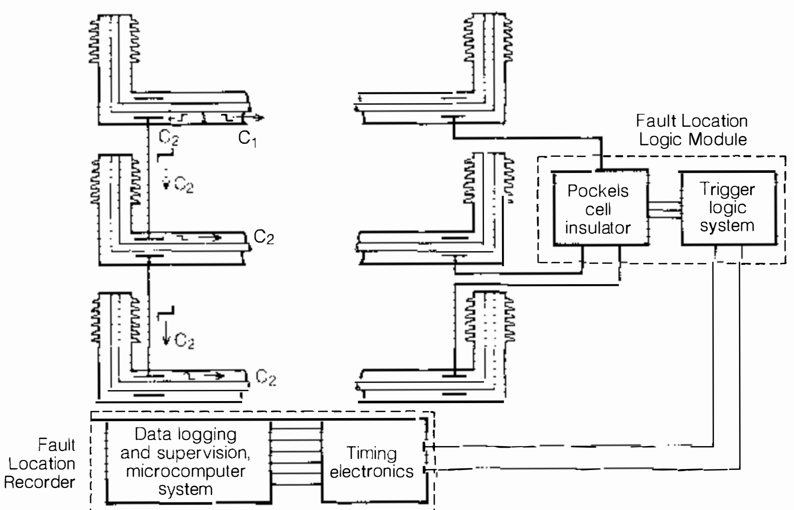
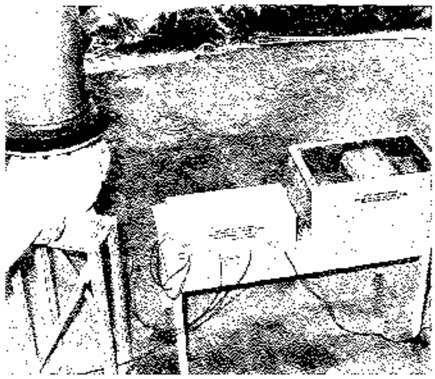


Figure 1 Gas cable fault location system. Fault generates transient waves that propagate away from the fault in both directions (C_1 and C_2). One wave (C_1) is received directly; the other (C_2) is coupled to the adjacent phases and reaches the fault location system through the unfaulted phases.

The system is housed in electromagnetically shielded enclosures with well-filtered power and has been tested under the electromagnetic conditions likely to be encountered during a fault (Figure 2). The system is now ready for field testing; as yet, however, a volunteer host utility has not been selected.

The partial discharge location system also depends on precision timing. The basic concept of the system is simple and is similar to that of the fault location system. Just as in the case of a fault, a partial discharge transient propagates away from its source in both directions. The location system can be used in either of two modes. In one mode a coaxial coupler at each end of the cable couples the partial discharge–induced transient to the location system. This is appropriate for short cable systems. In the other mode there is a single coupler at one terminal, and one of the partial discharge pulses is detected after it bounces off the remote terminal. In both cases the time between the two pulses locates the source of the discharge. This time is displayed as a correlation function (i.e., as a histogram of the number of pulses with a given time difference versus the observed time difference). The partial discharge location correlator, which was built by ESL, Inc., of Sunnyvale, Cali-

Figure 2 Fault location system being tested on a gas cable section in the laboratory.



fornia, achieves a time resolution of 2 ns, which corresponds to a location accuracy in the range of 0.5 m.

Partial discharge pulses in gas-insulated cable can have a rise-time in the range of 0.5 ns with a pulse width in the range of 1.5 ns. Ontario Hydro, as a host utility, has recently completed some modifications that have increased the detection speed of the instrument by a factor of 5—to the point that any signal that can occur will be detected.

The partial discharge location correlator is a computer-controlled instrument with keyboard and display terminal; to isolate the operator from any ground rises that might occur during testing, the keyboard and terminal are connected to the high-speed processor by a fiber-optic cable (Figure 3). The instrument is highly flexible, with about 80 commands and a wide range of operating modes and adjustments. Basic operation of the instrument is easily learned. A HELP command gives a summary of the command definitions. Ontario Hydro is attempting to extend the use of the correlator to locate partial discharges in gas-insulated substations.

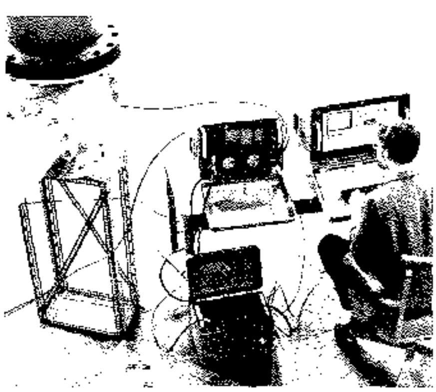


Figure 3 Correlator and power supply modules of the partial discharge location system.

This project has come to a successful conclusion with the testing of the fault and partial discharge location systems. Under test conditions the fault location system has proved capable of locating flashovers in gas-insulated cable to within much less than a meter. In actual applications the accuracy of location is likely to be determined more by knowledge of circuit length parameters than by the timing accuracy of the location system. The partial discharge location system has been tested in an electromagnetically unshielded environment in an urban setting near radio and television transmitters. Under such conditions, free conducting particles bouncing in the bus were detected easily with an accuracy of much less than a meter. The discharge magnitudes detected were in the range of 10–50 pC. These systems are now ready for utility use. However, using the two systems developed through this project will require installation of coupling devices in the gas cable. Because the incremental cost for these coupling devices is quite low, utilities interested in exploiting this newly developed technology may consider it a prudent investment. *Project Manager: Vasu Tahiliani*

Thermal stability of cable backfill materials

Rating an underground transmission cable requires extensive knowledge of the cable design, ac losses, and the thermal characteristics of the surrounding soil, of which the cable is an integral part. The thermal resistivity of the surrounding soil is measured to ascertain the heat transfer out of the cable under normal operating conditions. Conservative practice is usually followed to ensure low cable temperatures and reduce the possibility of insulation damage. Although some backfills (sandy soils) have good thermal resistivities, they are dependent on moisture to avoid exceeding their thermal stability limit, which prompts a question on what will happen to the thermal stability if periodic load fluctuations increase the cable's temperature and drive the moisture away.

A way of quantifying the soil's thermal stability limit is needed. This problem is part of the work being done by Georgia Institute of Technology (RP7883-1). Not only must a quantity defining soil thermal stability be found but a means of measuring this quantity and applying it to cable circuits must be determined.

Critical moisture content has been used in the past for defining the thermal stability limit of soil. The critical moisture content is not only hard to measure but this measurement leaves much to be desired during load fluctuations. Georgia Tech's approach is to measure the time of soil dryout under defined operating conditions. This can be measured quickly with a thermal probe, which is the same probe used for thermal resistivity measurements. To relate these measurements to cables already buried, correlation factors had to be determined.

Fortunately, very simple correlation factors were discovered and verified experimentally, and an accurate algorithm for calculating drying time from the temperature-vs-log time curve obtained from a thermal probe was developed. Ongoing work is taking these results one step further by modeling the actual performance of three single-phase cables in a laboratory; their performance will be measured by single probes, which can then be correlated with measurements taken in the field.

By using the information coming out of this project, one should be able to determine whether a cable circuit can operate safely during emergencies when larger overloads can occur. These measurements will then determine how long an overload condition can continue before thermal instability and cable damage become a serious problem.

Background information on soil measurements, additives, and measuring techniques is contained in two final reports, EL-506 and EL-1894. For information on time of drying and how it relates to cable loading, a Phase 1 report, EL-2595, prepared by Georgia Tech, is available. *Project Manager: Thomas J. Rodenbaugh*

Backfill materials for underground power cables

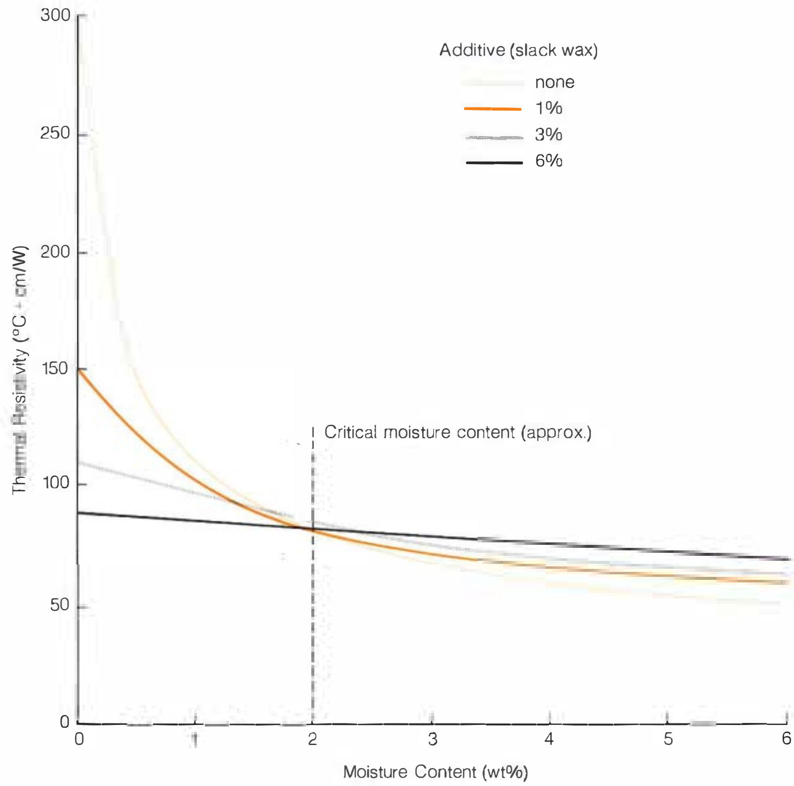
For several years, thermal backfills and soil additives used to enhance thermal backfills have performed well during tests at the University of California at Berkeley (RP7841). The most prominent additive, slack wax, has performed extremely well in full-size trenches without degrading, even though severe weather conditions have been encountered during the last two years.

Conclusions reached to date indicate that wax could be a viable additive to backfills prior to their placement in a trench. Wax not only reduces the thermal resistivity of soils but also reduces the soil's dependency on moisture content to maintain a stable thermal resistivity. Evaluation of the test trenches shows no leaching of the additive, no biodegradation, and no shifts in concentration levels around the buried pipes. In the laboratory, freeze-thaw cyclic tests produced no measurable change in the wax parameters in both poor and good backfill sands. Figure 4 shows the stabilizing effect wax can have on a thermal sand as moisture is driven away.

Current research at UCB is aimed at determining the effect of pipe size on both temperature and heat flux (proportional to temperature gradient) and the effects this has on thermal stability and thermal resistivity of the surrounding soil. Three new fully instrumented trenches have been constructed that contain three different sizes of cable pipe. Surge sand will be used as the backfill medium because it exhibits extreme differences in thermal resistivity for small changes in moisture flow. Thermal instability thus can be detected well in advance of thermal runaway, which can destroy the sensors and pipe heaters.

Results on the laboratory performance of various additives are given in EL-506; field tests and trench arrangements are presented in EL-1894. A Phase 3 final report for RP7841, discussing all the field test results and the new work started this year, will be available in the fall of 1984. *Project Manager: Thomas J. Rodenbaugh*

Figure 4 As moisture in Monterey No. 0 uniform sand is decreased adjacent to a power cable because of heat input, a wax additive could prevent thermal instability and eventual cable failure. Note that more-accurate heat transfer ratings for a circuit can be made because the additive gives a moderately flat curve.



OVERHEAD TRANSMISSION

HVDC insulator tests

Researchers from General Electric Co.'s High-Voltage Transmission Research Facility (HVTRF) recently tested 16 different types of dc insulators to determine their flashover characteristics (RP1282). The tests were designed to have features that are important for the dc case.

- Insulators were contaminated because clean insulators rarely flashover.
- Contamination patterns simulated those found on insulators in the field.
- Similar test conditions were maintained for all insulators.
- Insulator wetting conditions represented natural conditions.
- Full string lengths were tested at 400 kV.

This way the test results should be as close as possible to the actual field performance.

Although conventional tests on clean insulators, both dry and in simulated rain, are desirable from the tester's viewpoint, they are of limited value to the line designer, who must know the performance of the insulator when the fog rolls in or the dew forms on dirty insulators. Performance of contaminated insulators is especially important to engineers working on new lines in urban areas, near industrial plants, or near the sea; but there is very little operating experience on dc lines in contaminated environments. There is reason to suspect that such commonplace items as agricultural fertilizers or brush fires are important considerations in dc insulator design and application.

EPRI would like to have included more than 16 insulators in the testing program, but budget restrictions limited the selection to a few representative samples of different shapes, types, and materials drawn from available dc insulators. Comparisons can be made with field data and previous tests because the HVTRF team included insulator types used on existing dc lines. To represent different environmental areas, they selected three levels of contamination for the insulators. A few highlights of the test results follow.

- For dc, the contamination on both the top and bottom surfaces must be considered. (For ac, the bottom surface contamination largely determines the flashover voltage.)
- Shape is important, and leakage distance alone does not determine the insulator's performance.
- When comparing insulators of the same overall length, composite insulators generally far exceed a suspension insulator's flashover voltage.
- The tests demonstrate that typical ac insulator design criteria cannot be applied to dc insulator design.
- Small-diameter insulators generally outperform larger-diameter insulators of equal leakage distance, as observed in tests of long rod designs.
- Leakage currents appear to be highly dependent on insulator diameter.

A paper giving the details of the tests and performance of the insulators can be obtained by contacting the EPRI project manager. *Project Manager: John Dunlap*

POWER SYSTEM PLANNING AND OPERATIONS

Analyzing harmonics problems

Harmonics are voltages and currents at frequencies above 60 Hz that cause distortion of the standard utility sine wave. They cause losses, metering errors, and, if severe, insulation degradation, flashover, and overheating and failure of utility equipment. Harmonics are created by such nonlinear loads as rectifiers, variable speed motor drives, saturated transformers, and HVDC terminals—types of devices existing today and becoming more prevalent.

Utilities are concerned with the increasing cost of damaged equipment resulting from harmonics. Hence, there is a need to model the generation and spread of harmonics so that problems with insulation coordination, protection coordination, and HVDC filter design and operation can be anticipated and solved before they occur.

Research at Purdue University has developed a computer program to simulate and analyze harmonics in the bulk power systems (RP1764-7). This program, HARMFLO, is an extension and generalization of the conventional power flow method (balanced, single-phase) to include harmonics caused by nonlinear loads. HARMFLO is a significant improvement over other methods used for harmonic analysis because only power demand and load type (such as rectifier, dc motor, constant power) have to be specified, which means that harmonic content does not have to be known before modeling the system. Also, HARMFLO calculates not only the harmonics and how they spread but also how they affect each other. This breakthrough was made by using simultaneous solution rather than the much simpler, but less accurate, superposition method of solving equations. The current version of the program is capable of modeling up to 30 buses.

Users are cautioned that the results and programs produced have some restrictions because the scope of this project was intentionally limited. Most important, because the models used for transmission lines, transformers, motors, generators, and loads are simple (low frequency only), we recommend the program for the frequency range between 60 and 1140 Hz (19th harmonic). Balanced networks are assumed, simplifying the method through single-phase analysis. Zero sequence quantities from balanced harmonic-causing loads are also calculated, but only odd harmonics are so treated.

The first version of HARMFLO is available free to EPRI member utilities from the Institute's Electric Power Software Center (214-655-8883). We would like to learn of successful user experience with the program, as well as any application difficulties and limitations. A follow-on EPRI project (RP2444-1) will improve program efficiency and user input by adding HVDC models and performing a series of validation field tests. If received in time, user suggestions for modifications will be incorporated in the second program version. *Project Manager: James V. Mitsche*

DISTRIBUTION

Lightning flash density

Lightning is recognized as a major cause of electric distribution line failure and, consequently, customer service interruptions. A project completed in 1982 outlined the research necessary to reduce such interruptions (EL-2289). One of the topics recommended for future research effort was to ascertain how often lightning strikes the earth. This information can then be used to determine how often lightning strikes a power line, which is a parameter fundamental to the design of surge protective practices and the calculation of expected outage rates. Up until now, this parameter has been derived by a questionable relationship to the number of thunderstorm days experienced in the area of interest.

One might wonder why better data should be sought if adequate data, inaccurate as they might be, have served until now. The reason is that no other data were available. In Europe, Africa, Australia, and Asia the mapping of ground flash density has been in progress for as long as 10 years in some countries, and research to develop the necessary instrumentation and measuring techniques has been conducted for twice that length of time. This research was initiated by overseas electric supply companies for the same reasons that we are initiating similar work in the United States—to obtain realistic data for use in optimizing the cost-effectiveness of surge protection practices.

EPRI has undertaken the first step toward mapping ground flash density on a national scale in this country (RP2431). A contract has been signed with The Research Foundation of State University of New York at Albany (SUNYA) to map the eastern region of the United States.

Not surprisingly, interest in ground flash location is not totally restricted to power utilities. Although the development of appropriate instrumentation in other countries resulted in relatively simple flash counters suitable for power industry needs, development in this country took a different turn.

The overall advantage of designing equipment capable of doing more than simply counting flashes was perceived. Advanced electronic technology made it possible to design moderate-cost equipment that can geographically locate ground flashes with reasonable accuracy, count strokes per flash, and determine polarity, among other things.

By the time EPRI entered the scene, SUNYA was operating a lightning location network that covered the east coast roughly from the Canadian border to North Carolina and from the Atlantic coast west to a north-south line through western Pennsylvania. The existence of this network is an indication of the interest in lightning ground flashes displayed by others.

In this project, EPRI will not only produce ground flash density maps of the area now under surveillance but will also obtain data on stroke multiplicity and polarity. EPRI also plans to complete coverage of the east coast region in the northeast and the southeast by expanding the present SUNYA network this year. The ultimate aim is to have the entire United States under surveillance within the next few years and to continue collecting data until they are statistically valid. For this reason, EPRI will further review and evaluate other methods of determining ground flash density that could be used in the midsection of the country not now covered by an extensive existing system.

One feature of the more sophisticated equipment that is available (and included in the SUNYA network) affords utilities the ability to track storms approaching and passing over their service areas. Some utilities already have their own systems in operation. Tampa Electric Co. (*Electrical World,* May 1982, p. 111) and Detroit Edison Co. are two such utilities. As the network expands to reach the areas now under surveillance by existing equipment, EPRI hopes to arrange with its owners to use their data, thus avoiding duplication of equipment and minimizing the overall cost of the research effort. *Project Manager: Herbert Songster*

ROTATING ELECTRICAL MACHINERY

Optimization of induction motor efficiency

In an attempt to reduce motor costs over the years, suppliers have refined motor design and fabrication techniques, with the result that both single- and three-phase motors operate at lower-than-optimal efficiencies. The nation's increased interest in conserving energy now makes it important to improve the efficiencies of motors and drives. A recently funded project is directed toward satisfying this need (RP1944).

There has been relatively little advancement in the theory of design and analysis of induction motors in the past two decades. Existing design and analysis techniques rely on linearization of an inherently nonlinear system, with attendant inaccuracies. In this project, nonlinear models for single- and three-phase induction motors are being developed. These models are used with advanced computer methods of design optimization, resulting in the best achievable induction motor efficiency. The analytic methods will then be confirmed by tests on several different motors.

The results of this project will apply to all motors, from the smallest to the very largest. Because more than 60% of all generated electric power in this country is consumed in motor drives, even a modest improvement in motor efficiency could result in a significant reduction in operation costs in today's high-cost-of-energy environment. This is of direct concern to the utilities as well because 9% of all power generated in this country is consumed by power plant motors. The greatest impact will occur in small motors, which historically have been of relatively low efficiency. Even large motors, however, can be designed for sufficiently greater efficiency (when evaluated on the basis of lifetime cost) to justify the additional cost over the supplier's standard offering.

The three-phase portion of the project has been completed. The single-phase work will be completed by the end of 1984. Both final reports will be in the form of handbooks to provide suppliers and users with information that will help them optimize motor and drive efficiencies. *Project Manager: J C. White*

TRANSMISSION SUBSTATIONS

Transmission line transients

Traditionally, engineers use analytic tools such as an electromagnetic transients program or transient network analyzers for study of power system transients. Field data from actual power system transient conditions are used to verify analytic tools, but these data have generally come from staged switching tests, as opposed to naturally occurring disturbances. The importance of having naturally occurring data, especially fault data, was recently recognized by the utility industry, and a project with Westinghouse Electric Corp. was funded to design, build, and operate two transient recording systems (RP751); these were installed in two Florida Power & Light Co. substations.

One system operated in a 138-kV substation from 1979 through 1981. The other system was used in a 500-kV substation from 1980 through 1982. Each instrumentation system comprises the following major components.

- Three 500-kV high-frequency current transducers
- Six 500-kV capacitive voltage dividers
- Three 5-A high-frequency current transducers to measure current in current transformer secondaries
- Three 115-V high-frequency transducers to measure voltage in potential transformer secondaries or coupling-capacitor voltage transformer secondaries
- One 15-channel digital recording system for the transducers mentioned above

The instrumentation system, which has been built for unattended operation, is capable of recording transients with a frequency content from about 2 Hz to over 100 kHz. A surge automatically triggers the recorder, which then stores 8192 samples per channel during each recording interval.

Table 1 provides a summary of the events captured by the two recording systems. The term *primary line* used in the table refers to events occurring on the monitored line; and *secondary line* is any other line connected to the same substation switchyard.

The two transient-monitoring laboratories have been operated for a combined period of over 25,000 hours. Of the 341 events shown in the table, 114 were caused by lightning, 37 were caused by faults, and 190 were from switching.

Eight of the lightning events were caused by either shielding failure or back flashovers, and four of these resulted in faults. One of the events listed in Table 1 is depicted in Figure 5; it is particularly intriguing because it apparently caused a flashover and established a power arc. However, the short circuit extinguished itself after about 2.5 ms. No protective relays and no breaker operated to clear the fault.

This event contains the highest magnitude lightning surge recorded with the laboratories and has a measured magnitude of about 500 kV (incoming surge was probably 1000 kV) and a rise time of 4.5 μs or less. The struck point was estimated to be 8 km from the substation.

The event is one of six recorded on the 500-kV system. The question is how often this type of event might occur. The answer is very important to protective relaying devel-

Table 1
SUMMARY OF TRANSIENT EVENTS

Type of Event	Number of Events: 500-kV System	138-kV System
Lightning		
Backflash or shielding failure	6	2
Induced lightning surge	44	62
Switching		
Energize primary line	11	26
Reclose primary line	3	0
Deenergize primary line	6	7
Energize secondary line	44	83
Deenergize secondary line	5	5
Faults		
Primary line	5	4
Secondary line	17	11
Total	141	200

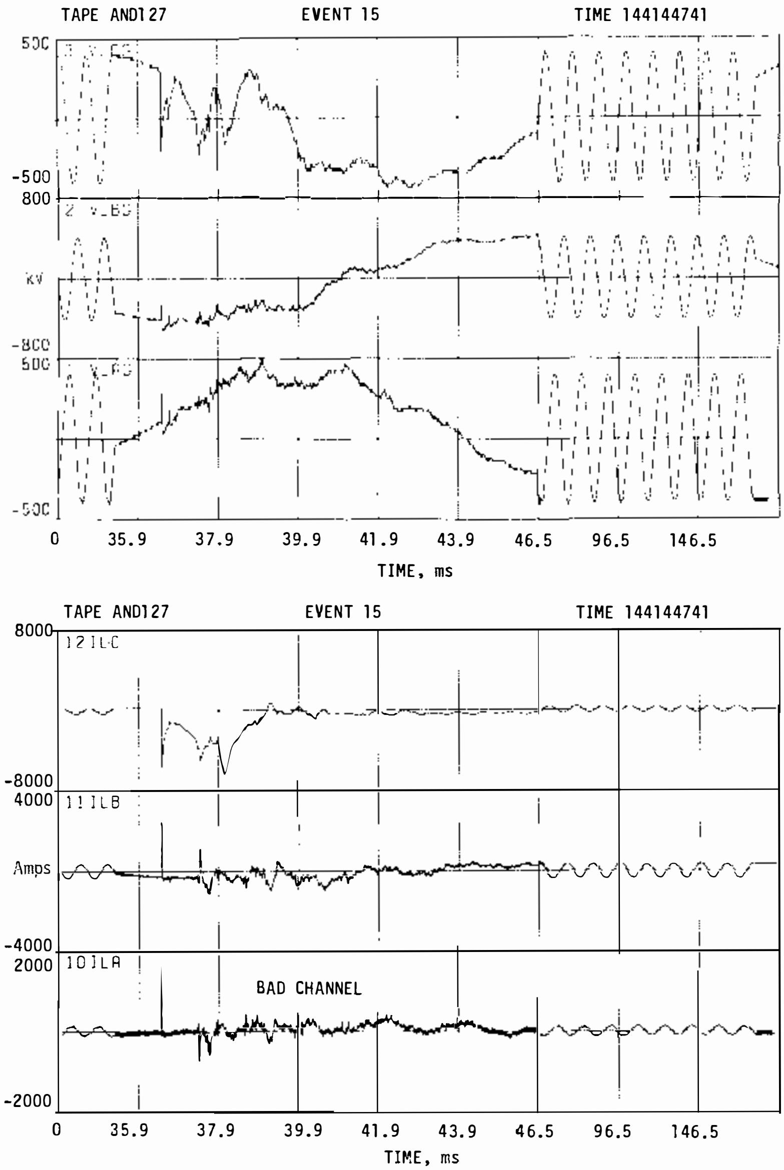


Figure 5 The lightning surge transient voltage as recorded at the end of a 500-kV line (top). A recording of the line currents for the same event (bottom). The recordings show a self-extinguishing lightning-surge-induced fault on the line. The figures illustrate the dual sampling rate capability of the recorders. A low, memory-conserving sampling rate is used when there is no high-frequency content in the input signals to the recorders. However, when there is a transient, the recorders automatically switch to high-speed sampling to capture the transient. This appears as expanded parts of the record.

opment because with increasingly short operating time of the relays, the probability becomes high that the relay will operate for an event like this, thus creating a larger disturbance than necessary. This increased outage rate must be balanced against the benefits of high-speed fault clearing. The recorded data unfortunately do not permit any statistical evaluation, which is needed for establishment of a probability figure for self-extinguishing faults. Hence, we are really not able to assess the importance of the event, but it is probably a significant event. This type of information could not have been obtained by anything but an automatically operated, high-frequency recording system because conventional fault recorders, normally installed in key substations, would not have the needed bandwidth and triggering system for recording events like this.

The bulk of lightning events (106) were caused by induced lightning surges and are generally considered to be of little significance.

The 37 fault events provide a useful data base for studies of ultrahigh-speed relaying algorithms or other equipment-related work that requires field data for evaluation purposes. The majority of faults were caused by a dielectric breakdown of insulation from various causes (e.g., pollution, fires, tree limbs, bucket trucks), while lightning only caused four of the recorded faults.

No significant overvoltages were found among the 190 switching events. However, this is to be expected because we were dealing with relatively strong systems and, on the 500-kV system, were recording only the voltages on the source end of the line being switched.

Although there has been no real surprise in the recorded data, this by itself is of value because it indicates that our understanding of the transient phenomena is relatively good. One must, of course, not expect to obtain information from a relatively short monitoring period that will make the existing knowledge and practices obsolete. Data collection of this type can only supplement other existing knowledge. EPRI plans to make the data available to other researchers eventually. *Project Manager: Stig Nilsson*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Vice President

FUEL SUPPLY ANALYSIS

The hallmark of fuel supply analysis is uncertainty. Research on fuels frequently raises more questions in some areas than were present originally; yet, in this process, the questions become more focused and the uncertainties better understood or redefined. The scope of EPRI's fuel supply analysis research reflects a combination of an earlier emphasis on the fundamentals of fuel supply modeling and a more recent emphasis on providing analytic insights into topics of current concern. For example, because uranium supply questions have receded with declining nuclear power projections, uranium resource assessment has been discontinued. Natural gas availability and the residual fuel oil outlook, on the other hand, have become important topics as restrictions on utility gas use have been lifted, as higher gas prices have altered perceptions about resource exhaustion, and as new price relationships have emerged in response to the combined effects of proposed price deregulation, declining industrial demand, and falling oil prices. Most recently, coal research emphases have shifted as scenarios for acidic precipitation legislation have redirected generic coal market analyses toward information needs specific to proposed legislation.

Utility gas availability

One view emerging from a completed study of natural gas availability (EPRI EA-2840) is that gas supply is hinged to geologic considerations over the long run, whereas market dynamics, and in particular the role of alternative fuels, are much more important in the near to intermediate term. Research projects are in progress in both these areas.

On the geologic side, EPRI and the Gas Research Institute are cosponsoring projections of the development cost of natural gas resources (RP1367-2). Conducted at the Colorado School of Mines, this project should help to narrow the divergence of different views about long-run gas availability. Whereas many studies have reached an apparent consensus on declining productivity of conventional gas fields in the 48 conterminous states, the possible cost factors for this gas are controversial and poorly understood. Further, the distinction between conventional and tight gas deposits is by no means clear-cut. This project is designed to inject new information into these debates, hopefully moving them closer to resolution.

The key contributor to success of the research is the Potential Gas Committee, whose members have been asked to provide additional details on gas field size, depth, and difficulty of exploration and development for each producing region. The analytic task is to assemble and interpret this information in such a way that the economic assumptions can be separated from the physical concepts, permitting the project results to serve as a data base and primary reference for further, more sophisticated interpretation. Figure 1 shows the type of information obtained for one of the many study regions.

Interfuel competition

On the market side, a recently published report (EPRI EA-3210) centering on the Gulf Coast region presents a new direction for fuel supply analysis research. Prepared by Charles River Associates, Inc., and a large group of contributing consultants, the report reflects the information needs of utility fuel planners. Over 20 individuals from eight utilities provided insights to the study team. Interfuel competition between gas and oil in utility markets is the principal focus, although coal and lignite availability is also reviewed. Subsequent research, also under the guidance of Charles River Associates, is investigating the California and Northeast utility fuel markets; future work is proposed for the midcontinent area (RP2369-30).

This first regional market study takes a somewhat broader perspective than its name would suggest, because the residual fuel oil and natural gas markets discussed in the report are in many respects subject to national or international considerations. An overriding conclusion, suspected but not documented at the start of the project, is that utility fuel markets have important regional characteristics that reflect differences in utility systems and access to fuels within the eight-state area (Texas, Louisiana, Mississippi, Alabama, Florida, Oklahoma, Arkansas, and Georgia). Because of this heterogeneity the patterns of fuel use, price, and availability are projected to continue to differ across subregions in this area.

Throughout the Gulf Coast region, coal and lignite have a clear economic advantage over oil and gas for new generation capacity. Moreover, for legislative reasons, new baseload capacity probably cannot use oil and possibly not gas. While the impact of rising rail prices has yet to be fully played out, at least for the present delivered coal costs fall in a narrow range of $1.75–$2.25 per million Btu. It is not possible to speak meaningfully of interfuel competition involving coal except for power sales of coal-by-wire by The Southern Company system, which are backing out gas (Gulf States Utilities Co.) and oil (Florida Power & Light Co.). The penetration of coal is taking place not through the retirement or replacement of existing gas- or oil-fired capacity based on fuel cost considerations, but through economic dispatch, as new coal units are built to meet new load growth. This trend contrasts with the situation in areas such as the Northeast and

Middle Atlantic regions, where more static load growth conditions prevail.

The major features of the oil and gas markets are described in the project report, and the extent and role of interfuel competition are examined. The authors underscore the great uncertainty in world oil prices and gas abundance, but nevertheless develop quantitative guidelines for interpreting price relationships between residual fuel oil and world crude oil prices and between natural gas and residual fuel oil prices. The analysis is conducted from the perspective that gas prices are effectively deregulated.

The governing logic is that gas prices will be set in competition with residual fuel oil at the burner tip in the most distant markets. This logic—together with its implications for gas prices, improved gas availability, and shorter-term gas market transactions—is developed in detail. Interfuel competition will have an enormous moderating influence, since, in the authors' estimate, one-third of utility generating capacity in the Gulf Coast region can burn either fuel. Within this region, the outlook for gas availability and price is generally better for utilities in Oklahoma, Texas, and Louisiana simply because they can afford to outbid more distant users on the basis of pipeline cost advantages. The factors governing residual fuel oil outlook are analyzed, including world oil prices and the petroleum industry's actions to shut down or upgrade refineries. Residual oil prices are forecast to remain depressed relative to crude oil prices at least until 1990.

A final project (RP2369-40) has the objective of integrating much of what has been learned about the availability of gas to utilities. Conducted by Applied Decision Analysis, Inc., this project seeks to derive a framework that utilities can use in identifying critical uncertainties in their gas supply outlook and in incorporating these concerns into the formulation of fuel strategies. The research involves considerable contact with fuel planners and energy analysts from producing and distributing companies as well as from government and academia. While the political issues surrounding gas pricing have not been resolved, the analytic insights developed in this project should be of use in interpreting the utility gas availability outlook under a variety of scenarios. Both long-run concerns (e.g., geologic uncertainties) and short-run concerns (e.g., policies and alternative fuel costs) are addressed.

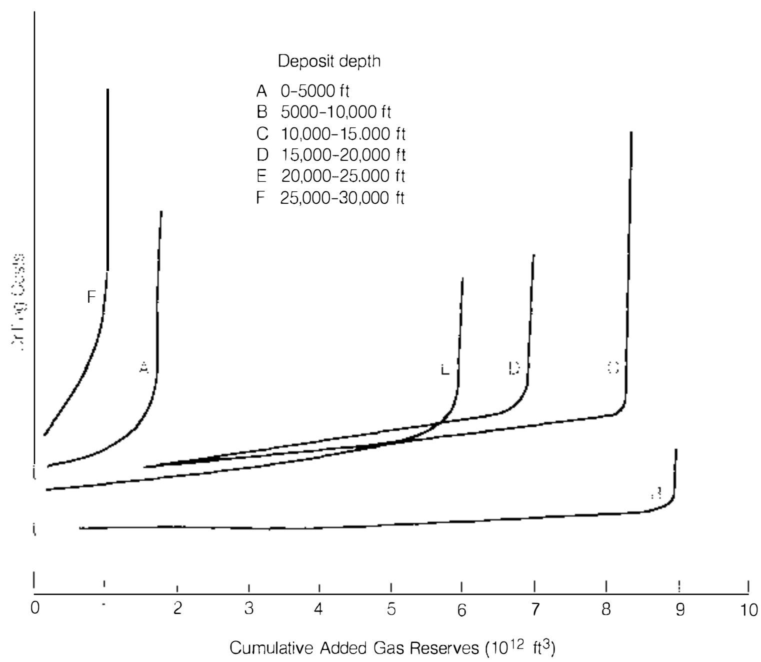


Figure 1 The costs and quantities of gas reserves in the Permian Basin classified as "possible" show a general pattern of increasing cost with depth. Similar information developed for all categories of gas in all regions is the key to understanding long-run gas availability.

Coal market analysis

Over the past year, the debate about acidic precipitation legislation has been watched with increasing interest, not just by utility spokesmen and environmental specialists but also by utility fuel managers. Utilities are concerned about how coal markets will be affected by acidic precipitation legislation. A great deal of uncertainty revolves around what form the legislation will take and, in particular, whether nonscrubbing alternatives for reducing emissions will be allowed. This decision could have a large influence on what qualities of coal or lignite are consumed. An additional, and by no means insignificant, uncertainty is just how much high-quality coal can be obtained and what it will cost if utilities attempt to switch fuels.

Research pertaining to these questions has been under way in EPRI's Energy Resources Program for a number of years. Two successive studies to develop better analytic tools and better coal supply data were initiated under RP1431 by ICF, Inc. The first project was an early attempt to identify and link short-term coal market developments (such as coal contracts data and unit construction data) with methodologies for long-term coal supply forecasting. In addition to creating or enhancing the capability to make more realistic projections, the researchers assessed the sensitivities of coal prices and movements to critical but uncertain assumptions: electricity demand, the rate of conversions to coal, transportation costs, mining costs, and (in one of the first of many such studies) scenarios of acidic precipitation legislation. While the projections themselves soon became out-of-date because of significant changes in nearly all of the above assumptions, the value of the insights and methodologies has multiplied through subsequent analyses and presentations by EPRI, EPA, and others.

The second project was primarily an expanded analysis of the sensitivity of coal prices to coal resource uncertainties and cost assumptions. These data assumptions form the technical backbone of most coal market assessments conducted to date. The coal price trajectory must at the very least reflect the influence of coal depletion. This is not to say that the United States is running out of coal, but rather that the long-run trend is toward thinner, deeper, lower-quality coal seams that are more costly to mine and market. The extent of this effect on minemouth prices is shown in Table 1. The premise of this research project was that constraints on coal availability would affect coal prices, although the extent was unclear. After an initial assessment based on hypothetical (but conceivable) constraints demonstrated that the effects were quite large, experts from mining companies and federal and state agencies were interviewed to develop a more realistic assessment of the coal data.

It was concluded that a somewhat more pessimistic view was warranted than the original base case had assumed. Yet the effect of supply limitations on delivered coal prices appears to be minimal, since utilities are expected to continue to shift from more expensive to less expensive sources, thus moderating the demand for the coals that are in short supply. This projection, however, does not take into account the effect of proposed acidic precipitation legislation.

A workshop held earlier this year in Atlanta confirmed that the great uncertainty in coal demand created by the possibility of such legislation is moving to the forefront of industry concerns. To address this and other upcoming issues, Temple, Barker & Sloane, Inc., is conducting a research scoping study that assesses what we currently know about coal markets and what research studies would best meet future needs for better understanding (RP2369-50). The research recommendations span a number of topics, including the controversy over coal transportation pricing, but they center on how utility coal demand under acidic precipitation controls can be better understood and on the surprising divergence of views on premium coal availability.

Research projects to implement the recommendations of this scoping effort will be closely coordinated with parallel work under way in the Coal Combustion Systems Division. That work places a stronger emphasis on emission control technology costs, while the related research activities in the Energy Resources Program emphasize coal market issues. *Project Manager: Jeremy Platt*

LAKE ACIDIFICATION MITIGATION

EPRI's Ecological Studies Program has been conducting research to assess the effects of acidic deposition on aquatic ecosystems since 1979. The initial effort was the integrated lake watershed acidification study (ILWAS; RP1109). Follow-on studies, such as the regional integrated lake watershed study (RILWAS; RP2174) and the lake acidification and fisheries study (RP2346), began the task of examining water quality as related to acidification and effects on fish. The development of a program to evaluate techniques for managing water quality was a natural outgrowth of EPRI research on the effects of acidic deposition. This report describes work that is under way to assess the use of liming to mitigate lake acidification.

The management of soil and lake pH by the application of liming agents is not a new practice. The use of lime was described in a Roman book on farm management published in 45 A.D. Farmers in the United States use over 30 million tons of limestone each year to manage soil acidification caused by nitrogen fertilizers. Liming has been used since the 1940s to enhance the fish production of bog waters in midwestern states. It has also been used to treat waters affected by acid mine drainage.

More recently, the Swedish government has adopted a massive program to restore acidic lakes. More than 1000 lakes have been treated to date, and the objective is to treat 20,000 by the end of 1986. The 1983 budget of this program is $8.3 million. More modest programs to counteract the effects of acidity have been initiated in Norway, Canada, and the eastern United States. Approximately 100 U.S. lakes have been treated with liming agents to reduce surface water acidity.

Most U.S. freshwater fisheries are managed in one way or another. State and local agencies use a variety of approaches, including controlled access (fishing licenses, catch limits), stocking, and habitat manipulation. The application of liming agents to raise the pH of lakes to preserve or restore fishery habitats has been practiced in New York since the late 1950s by state agencies and private organizations.

The first step in the EPRI effort to assess liming as a mitigation technique was to review the status of current research. An extensive literature review was conducted, as well as site visits to Canada, Sweden,

Table 1
IMPACT OF DEPLETION ON MINEMOUTH COAL PRICE GROWTH RATES (1990–2000)

			Price Increase (%/yr)		
Region	Coal Type	Sulfur Content	Initial Base Estimate	With Hypothetical Constraints	Revised Base Estimate
Western Pennsylvania	Bituminous	High–medium	0.8	1.6	0.8
Southern West Virginia	Bituminous	Low	0.8	1.8	1.3
Southern West Virginia	Bituminous	Medium	0.9	1.9	1.4
Illinois	Bituminous	Very high	1.1	1.8	0.2
North Dakota	Lignite	Medium	0.7	1.0	0
Wyoming (Powder River Basin)	Subbituminous	Low	0.8	1.8	0.9
Texas	Lignite	Medium	1.8	2.3	2.7
Central Utah	Bituminous	Low	0.5	2.5	0.5
New Mexico (San Juan Basin)	Subbituminous	Low–medium	1.7	2.1	0.6

and Norway. The investigators found that a number of techniques and liming materials are being used. They also identified several unresolved questions and information needs that could affect the feasibility of a long-term pH management program based on liming; these include the following.

- Lack of reliable dose-estimating techniques for base addition
- Effects of liming on carbon, phosphorus, and other nutrients
- Changes in metal speciation that might increase short-term toxicity
- Effects on fish caused by rapid changes in pH
- Interaction of buffered waters in limed lakes with low-pH waters during spring snowmelt

The results of this review are presented in EPRI EA-2362. The next step was a workshop sponsored by EPRI, the U.S. Fish and Wildlife Service, the American Petroleum Institute, and the Department of Energy to develop a research strategy to address the critical uncertainties. Scientists from Canada, Norway, Sweden, the United Kingdom, and the United States participated. A report outlining the recommendations developed in the workshop was published by the U.S. Fish and Wildlife Service.

EPRI's lake acidification mitigation project (LAMP; RP2337), in large part, incorporates the key recommendations of the workshop participants. The overall objective of LAMP is to develop the information needed to implement a water quality and fishery management program for acidic waters. LAMP is a three-year effort that will address both fishery management (i.e., the protection, enhancement, and/or rehabilitation of fisheries affected or threatened by acidification) and fundamental scientific issues associated with the response of sediment, water chemistry, and biota after base addition.

The LAMP research team is being coordinated by General Research Corp. Subcontractors include Cornell University, Syracuse University, Clarkson College of Technology, and the U.S. Geological Survey. The New York State Department of Environmental Conservation is supporting the project by providing services and also fish to stock the lakes. The project comprises two major tasks. The first is to evaluate existing data; the second is to conduct field and laboratory studies.

Task 1 involves the collection, synthesis, and analysis of historical and international data on lake liming. General Research Corp. is primarily responsible for this task, which builds on the earlier work reported above. The project team researchers will work cooperatively with foreign investigators to compile and analyze data on the biologic and chemical response of lakes to liming. Specific hypotheses will be tested, including these: (1) calcium carbonate addition affects the concentrations of toxic metals in water in a predictable way; and (2) shoreline application of calcium carbonate is as effective as whole lake liming in neutralization and aluminum reduction. The data gathered will also be used to test existing models of the reacidification of lakes after liming and the dissolution rate of calcium carbonate.

Task 2 entails both field and laboratory studies of lake liming. The field program will involve three lakes in New York's Adirondacks. One, Woods Lake, was studied in the ILWAS program; the other sites are Cranberry Pond and Little Simon Pond. Three sets of conditions will be imposed in the experiment.

- Liming of an acid lake to permit the establishment of a stocked fish population, followed by natural reacidification to examine population responses
- Liming and maintenance of an acid lake to permit the reestablishment of a self-reproducing fish population
- Maintenance liming of an acid lake where extant fish populations exhibit stress symptoms

Clarkson College of Technology will be responsible for these subtasks: developing a dose calculation model and selecting appropriate application doses and techniques; predicting and monitoring lake reacidification; assessing the effects of liming on lake sediments; and investigating the effects of liming on the phosphorus and carbon cycles.

Syracuse University will be responsible for evaluating the temporal and spatial variations in lake water quality after liming and for investigating the effects of liming on the behavior of trace metals (including aluminum, iron, manganese, zinc, and lead). Cornell University will develop optimal restocking strategies for brook trout and will determine the acute and chronic effects of liming on fish, zooplankton, and macrobenthos.

Although a complete understanding of the long-term consequences of lake pH management will require a longer period of investigation than currently contracted, the LAMP effort will provide answers to a number of the questions discussed earlier. The improved dose assessment techniques to be developed, as well as the information on liming's chemical and biologic effects, will provide fishery managers and others with a firm basis for evaluating the effectiveness of liming as a management tool. *Project Manager: Robert Kawaratani*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Vice President

ZINC BROMIDE BATTERY ENERGY STORAGE

The zinc bromide battery is under development by several companies in various countries. There are two general approaches, each based on electrolyte flowing through stacks of bipolar cells. Applications include electric utility energy storage for load leveling and electric vehicles. Engineering prototypes of stand-alone systems have been built and successfully tested in 1–10-kW sizes for 1–5-h operation. An 80-kWh system, including a dc-ac converter, has been installed at Duke Power Co. as a feasibility test of a utility load-leveling battery system. Prototype 20- and 30-kWh batteries for electric vehicles are being developed under contracts with Sandia National Laboratories for testing this year. EPRI and DOE intend to issue a request-for-proposal early in 1984 for continued R&D and the fabrication of a 500-kWh load-leveling system for evaluation at the Battery Energy Storage Test (BEST) Facility, possibly in 1987.

As reported in a feature article in the October 1981 *Journal,* EPRI is developing three advanced battery systems for electric utility application: the sodium-sulfur, the zinc chloride, and the zinc bromide. These systems employ low-cost materials and reversible, long-life electrodes. The zinc bromide and zinc chloride technologies fall into a category called flowing-electrolyte systems and offer the advantages of ambient temperature operation and physical access to the electrochemical components. These features should translate into ease of maintenance and repair. The chief disadvantage of flowing-electrolyte systems is their inherent complexity in that pumps, valves, and other plumbing are required.

At this time there are three major zinc bromide development programs in this country: Exxon Research and Engineering Co., supported by DOE; GEL, Inc., supported privately; and Energy Research Corp. (ERC), supported by EPRI. ERC acquired technology developed by Gould Inc. when the latter organization concluded its program in 1981. In 1983 DOE and EPRI funding for zinc bromide battery development was approximately $3 million, most of which went to Exxon.

The battery designs of ERC and Exxon are similar conceptually, having carbon-based electrodes contained within plastic frames and stacked adjacent to one another (Figure 1). The electrodes are bipolar; that is, on one side the zinc reaction takes place, and on the other, the bromine reaction. Current flows through the stack perpendicular to the electrodes. Each cell stack is a replaceable battery submodule. The substantial differences between the zinc bromide battery programs are that the Exxon and ERC systems

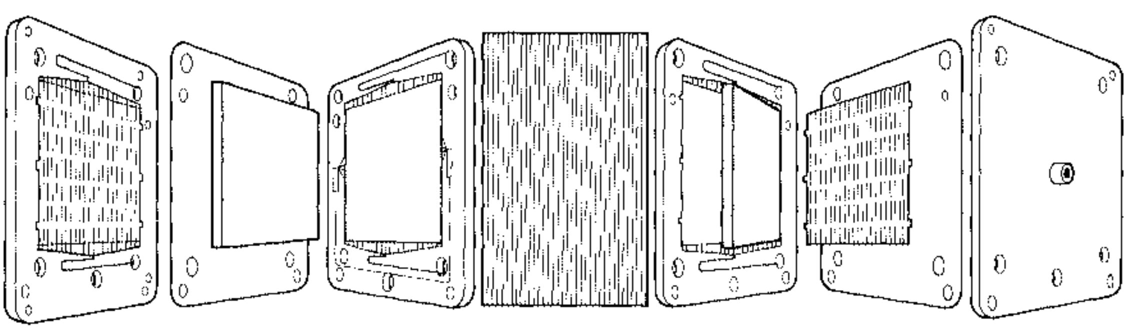


Figure 1 Cell stack components. The electrode frame assemblies are interspersed with separators and clamped between the end plates.

have two separate electrolytes and store the bromine in a separate organic liquid phase external to the cell, whereas GEL has only one electrolyte and stores the bromine within the cell in a porous electrode structure.

Battery design

ERC (through its parent company, Fluor Engineers, Inc.) has designed a 500-kWh battery suitable for testing at the BEST Facility. Fluor has completed a preliminary engineering design of a truckable, self-contained pallet system. This 100-kW, 500-kWh zinc bromide battery has thirty 3.3-kW submodules (40 A, 83 V each) in a common electrolyte flow (hydraulic) and electrical system. The following criteria guided the overall design.

- The battery arrangement (parallel-series connection) to provide suitable voltage and current rating for operation into a utility grid
- A design and equipment layout based on a skid-mounted unit for installation indoors at the BEST Facility
- Maximal use of proven technology in components
- All module components readily accessible for repair or replacement

Figure 2 is a simplified process flow diagram of the battery system, illustrating specifically the Gould-ERC design technology. The submodules are connected hydraulically in parallel. There are two nearly identical flow systems. The negative electrolyte system includes a heat exchanger and a hydrogen-bromine recombiner; the positive electrolyte system incorporates a static mixer and the bromine storage facility. Electrolyte is pumped through the submodules by circulation pumps that draw the liquid from storage tanks. Electrolyte is returned to the same storage tanks, thus forming a closed-loop system. During the charge cycle, zinc is deposited on the negative electrode and bromine is evolved at the positive electrode. The bromine formed is stored as a liquid polybromide complex solution in the positive electrolyte tank. The polybromide, circulated by a third pump, is dispersed as fine droplets in the electrolyte, which absorbs bromine on the charge cycle and releases it on the discharge cycle. Flow on the negative side also provides for uniform thermal management of the submodules.

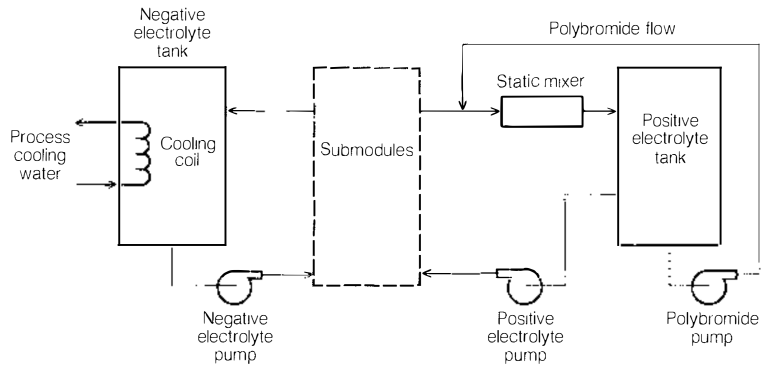
Submodule description and performance

The submodule is the part of the system in which the electrochemical reactions occur. In the Gould-ERC design (Figure 1), the submodule consists of a stack of carbon electrodes bonded into plastic frames together with carbon felt cathode substrates, negative electrode spacers, and separator layers. The injection-molded plastic frames contain flow channels that deliver electrolyte to the carbon electrodes. On one side of each carbon electrode a high-surface-area carbon felt is used as a bromine reaction substrate. The flat surface of the opposite side of the electrode is used for zinc deposition. The zinc and bromine electrodes of adjacent plates are kept apart from each other by a microporous plastic separator. A spacer grid is used on the negative (zinc) side to keep the separator from collapsing against the electrode surface. The separators extend to the outside of the stack and are used as gaskets to seal the flow channels. At each end of the stack a thick end plate is used to direct flow to the proper manifolds. The end plate also contains the end electrode, which is a thicker, more-conductive electrode for distributing current evenly over the working area of the stack. The stack is held together by compression between metal end plates placed on each end of the stack and bolted.

The ability of the zinc bromide cell to deliver power and energy is shown in Figure 3. This is representative of a typical large-cell design that is still in a relatively early stage of development and does not represent optimal performance. In the range of 20–40 mA/cm^2, the energy efficiency of the cell is expected to be between 70 and 75%. For initial bipolar module assemblies of 40 cells, the module energy efficiency has been within 2–3% of single-cell efficiency.

Cell performance improvements are expected to be achieved by reducing ohmic losses in the separator and voltage loss at the bromine electrode and by higher and more uniform zinc loading on the negative electrode. In addition to the work by ERC on these problems, EPRI is supporting studies by Stonehart Associates, Inc., in zinc deposition, electrode kinetics, and plastic carbon electrodes for use in both bromide and chloride electrolytes.

Figure 2 Module flow system. The separately stored electrolyte solutions are pumped through the submodule cell structures to provide for the reversible storage of electric to chemical energy.

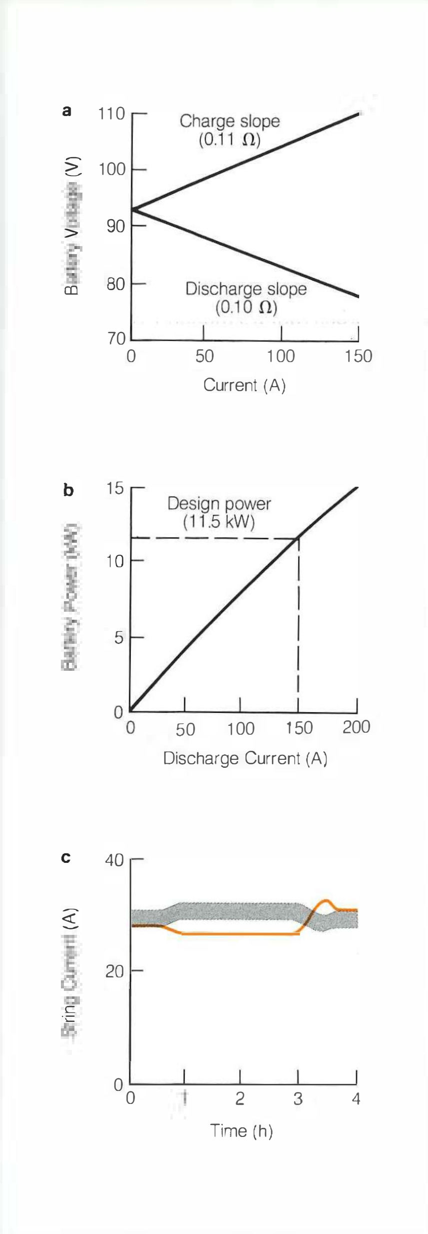


Component R&D

Separators are a critical component in most batteries. One function of the separator is to limit bromine diffusion from the positive to the negative side of the cell, where it would react with the zinc deposit and reduce the coulombic efficiency. The Gould studies found a microporous material to be most desirable. Commercially available, low-cost Daramic, which is produced for the lead-acid battery industry, has been used extensively. However, the organic complexing agents that Gould developed to form the polybromide tend to become absorbed in the separator, increasing its ionic resistance and causing excessive voltage loss. ERC is evaluating several commercial sources of microporous separators to optimize a design specification for both physical and chemical properties. It has equipment to produce separators for its various alkaline batteries, and some experimental work has been done for the zinc bromide project. Ion-exchange membranes have been tested by both Exxon and Gould but were found to be unsuitable and too costly.

Electrodes for these bipolar cells must meet several strict requirements. They must

Figure 3 (**a**) Voltage-current performance of Gould 80-kWh battery. Note the predominantly linear, or ohmic, behavior. (**b**) Power-current performance. The discharge power is nearly linear with current to at least 200 A. (**c**) Module string current distribution. The higher impedance in String 1 (color) resulted in a depressed string current during most of the discharge period until the submodules in the other strings (Strings 2–5, gray) polarized near the end of discharge.



have low electrical resistance, be impermeable to the electrolyte and bromine solutions, be invariant in surface properties throughout the battery's life, and be suitable for zinc deposition on the negative side and for bromine reaction on the positive side. The surface for bromine reaction controls the current at which the battery can be efficiently operated. The Gould design uses carbon felt bonded to the rigid carbon plate so that a flow-through electrode is created. The Exxon design depends on an enhancement process to modify the reactivity of the electrode surface so that a flow-by electrode operation is able to sustain the required level of current. The GEL design is a porous, activated-carbon structure that absorbs and retains the bromine during charge and then releases it on discharge.

All the developers expect to be able to manufacture a low-cost carbon plastic composite electrode. In the work of both ERC and Exxon, a manufacturing process that yields a combined bipolar electrode and flow frame is considered essential to the control of quality and cost. ERC is attempting to mold a composite electrode of two layers, one dense for the zinc side and one porous for the bromine side. Exxon has a low-cost, continuously extruded material that has tended to degrade in long-term tests. A simple increase in thickness may resolve the problem. ERC, which has its own facilities for making carbon plastic fuel cell electrodes, has not yet obtained a bromine-stable formula. Corrosion effects are severe and are different for various solutions of electrolytes with or without bromine or bromine oil complexes.

The most stable electrode thus far is the rigid carbon plate developed by Gould, which is still being cycled successfully by ERC in long-term submodule testing. This plate is a variation of a fuel cell electrode, with final processing modified to alter graphitization. Proof of a stable, low-cost electrode is a main problem to be solved before a commercial product can be demonstrated.

Materials stability is important for all the components in the electrolyte flow paths. Commercial polypropylene and polyvinylchloride pipe and fittings have been used in virtually all work to date, and long-term stability may be adequate. There is an initial absorption of bromine in these materials, but this stabilizes to a relatively small change in weight or volume. Kynar is the least affected, but it is expensive. Flow frames pose special problems because of the need for molding in large sizes and incorporating many fine details to provide for the electrolyte flow paths.

Battery performance

Several small zinc bromide batteries have been built and successfully tested over the past two or three years. Most noteworthy is the 40-module, 20-kW, 80-kWh GEL battery that was delivered with a dc-ac converter fabricated by Firing Circuits, Inc., to Duke Power in September 1983. This experimental installation and testing study is being cofunded by the North Carolina Alternate Energy Corp. Exxon and Gould have delivered several smaller multikilowatthour batteries for test at Sandia. GEL also supplied two modules to Research Triangle Institute for independent test and evaluation under EPRI contract. Gould fabricated and tested an 80-kWh battery in its own laboratory in 1981.

Results from the various battery tests have been mixed. On the positive side, life of several hundred cycles has been demonstrated, integration of submodules has been successfully accomplished, and performance stability has been achieved. However, repeatability and reliability have varied from very good to poor, and degradation of materials is evident after long periods of operation. From the test results, a conclusion is that the technology has progressed rapidly but significant technical problems remain. Recognizing that development costs for zinc bromide batteries have been about an order of magnitude smaller than those of the sodium-sulfur and zinc chloride systems, the technical status and prospects are very good.

In light of the prospects for low cost, rapid laboratory progress, and potential user interest, the opportunity exists for near-term scaling of the technology to 100 kW and 500 kWh for evaluation in the BEST Facility. Design, qualification, and fabrication will probably take a year for each step—thus leading to BEST Facility testing in 1987. *Project Manager: William Spindler*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Vice President

STRUCTURAL RESPONSE OF CONCRETE CONTAINMENTS

One of the important issues in the degraded-core scenario evaluations since the TMI-2 accident is the load-carrying capability of reactor containment buildings if overpressurized beyond design-basis levels. To reevaluate risk with the benefit of knowledge gained from the TMI incident and post-TMI research, utilities need a greater understanding of how containments actually behave as they experience large, nonlinear deformations, in contrast to the oversimplified assumptions about containment capacity and failure modes that have been used in past assessments of risk. This status report gives an overview of current views on containment behavior and describes the experimental and analytic efforts being sponsored by EPRI toward resolution of this issue.

The concrete containment building surrounding nuclear reactor systems is a major barrier against release of radioactive material during accidents. Because of the importance of containments in the defense-in-depth philosophy used for plant design, they are designed as pressure vessels in accordance with ASME code provisions to withstand internal design pressures from postulated loss-of-coolant accidents. However, the accident at TMI-2 focused attention on the very unlikely "what if" scenarios known as degraded-core accidents. Such accidents go beyond design-basis accidents and have been addressed in probabilistic risk assessments (PRA) like the *Reactor Safety Study* (WASH-1400).

One of the most important steps in predicting radioactive releases in a PRA is to determine when the containment may be breached during an accident scenario and the rate of effluent produced by the breach. The effluent would consist of air and other gases and would carry with it aerosols, such as entrained water (steam) and suspended solid particles (including radioactive debris from the degraded core). Clearly, if the entire inventory of the containment atmosphere is assumed to be ejected suddenly (as in the *Reactor Safety Study*), the later the release occurs the smaller are the consequences because more time is available for the settling of aerosols out of the atmosphere onto containment walls and floors, radioactive decay, and emergency evacuation. If, instead, the containment inventory is released gradually via a leak, the resultant pressure relief would delay the occurrence of rapid releases and diminish (via plate out) the long-term release, thereby reducing consequences. The picture is further complicated by the fact that aerosols will tend to deposit along crack walls, reducing the release by blocking leak paths.

Containment failure modes

Concrete containments are designed to be leak-tight mainly by (1) special design of penetrations for cabling, piping, and personnel/equipment entry, and (2) provision of a $\frac{1}{4}$–$\frac{3}{8}$-in (6–10-mm) steel liner plate. Anchored to the inner surface of a reinforced or prestressed concrete wall, the liner prevents leakage through cracks in the concrete. In accordance with various industry codes, containments have been designed to withstand pressures from a design-basis accident that range from 15 psig (103 kN/m^2) to 70 psig (480 kN/m^2), depending on containment type (e.g., PWR, BWR, size). Prior to commercial operation, the containments are proof-tested at 1.15 times the design pressure. On the basis of analyses by architect-engineers, these containments can withstand from 1.7 to 5 times the design pressures before yielding of the main reinforcement or tendons occurs. From the design point of view, this yielding is considered to be failure because relatively small increases in pressure lead to a large deformation of the containment building.

In response to the risk assessor's need for establishing levels of containment capacity, the assumption has been made by architect-engineers that the liner acts as a membrane and maintains leak tightness well into the large-deformation region. This assumed liner behavior induces a sudden, gross rupture of the containment wall at or near the ultimate strength of the containment, as if it were a balloon. (Indeed, some tests of containment models performed with the concrete structure lined by a rubber bladder have demonstrated gross rupture modes.) This assumed failure mode has led the risk analyst to further assume a sudden and total release of containment volume inventory.

These oversimplified assumptions, based on linear design concepts, are almost certain to be in error. In actuality, as the containment grows into the nonlinear, large-deformation region, local liner failure can occur at corners, penetrations, anchors, and other areas of strain concentrations. Also, large deformations will warp penetration openings, allowing leakage through seals and gaskets. Significant leakage is likely to occur during yielding of the main reinforcement. An overall hoop strain of only 1.5% allows the building to expand radially by about 1 ft (30 cm). Local failures and leaks may also occur at hard spots where wall movement is restrained by stiff, attached structures, such as piping, floors, or exterior walls. It has been calculated that a total leak area of only 10 in^2 (645 cm^2) is sufficient to limit peak pressure in a containment under degraded-core conditions and thereby prevent gross failure modes.

Experimental data base

The only existing data on containment integrity come from scale-model tests in Japan and Canada, in which, as mentioned above, the mode of gross tensile failure was induced by the bladder used to load the structures. Also, because models were loaded hydraulically, no data on leakage rates were obtained. Some leakage data are available from Canadian and French testing, but these are for cracked concrete without a liner plate.

Pressurization tests of prestressed concrete reactor vessels by several organizations have exhibited premature failure by leakage at pressures well below the ultimate tensile capacity of the vessel walls. Typically, the vessels failed by the tearing of their steel liners near the welded joints at the intersections between the cylindrical walls and the flat roof or base.

In a related NRC-sponsored program, plans are being made by Sandia National Laboratories to pressurize a $\frac{1}{6}$-scale model of a reinforced concrete containment with a steel liner. (The concept of pressurizing a decommissioned containment building was rejected by NRC after an unsuccessful attempt to identify a candidate test site.) Scheduled for 1985, the pneumatic testing of the model will include measurements of leakage as a function of pressure. Attempts are being made to model penetrations and other areas of discontinuity as accurately as possible at the reduced scale. The NRC program also includes leak-testing of cable penetrations and hatches, as well as pressurization of scale-model steel containments.

EPRI research

The EPRI concrete containment integrity research is aimed at establishing the true failure modes and load-carrying capability of reinforced and prestressed containments under internal pressures beyond those for which they were designed (RP2172). The immediate goal is to provide utilities with a test-verified analytic tool for evaluation of containment integrity. The ultimate goal, in conjunction with overall risk studies, is to characterize leak rates and radioactive releases as functions of pressure and time under various postulated severe accident scenarios. These scenarios involve such loadings as steam surges and hydrogen combustion, which can be treated as static because they vary slowly with respect to the dynamic response time of containments. Dynamic loads from potential hydrogen detonations or steam explosions have been hypothesized, but technical arguments have been advanced by the Industry Degraded-Core Program that such phenomena cannot occur in real-world situations.

The approach of EPRI's structural integrity research has been to conduct experimental and analytic work in parallel. To avoid the uncertainties associated with small-scale modeling of detailed structural response and leakage rates, the EPRI experimental program features tests of large- and full-scale segments of concrete containments. Work at the Construction Technology Laboratory of the Portland Cement Association has begun with simple tests on structural elements to define material behavior and is progressing systematically to more prototypical tests of containment segments with penetrations and structural discontinuities to provide data on leakage from realistic liner failure mechanisms (RP2172-2).

The first phase of testing, carried out in a preexisting NRC facility, included eight uniaxial and biaxial tension tests of concrete slabs 5 ft square by 2 ft thick (1.5 m by 0.6 m) and four biaxial tension tests of liner plate specimens 4 ft square (1.2 m). With loads applied to reinforcing bars, the tests on both reinforced and prestressed concrete designs provided extensive data on elongation, strains, and crack opening as a function of loading well into the inelastic region (Figure 1). The liner plate tests showed that even with butt welds or pipe penetrations, the plates can withstand up to 6% elongation, or more, without rupturing.

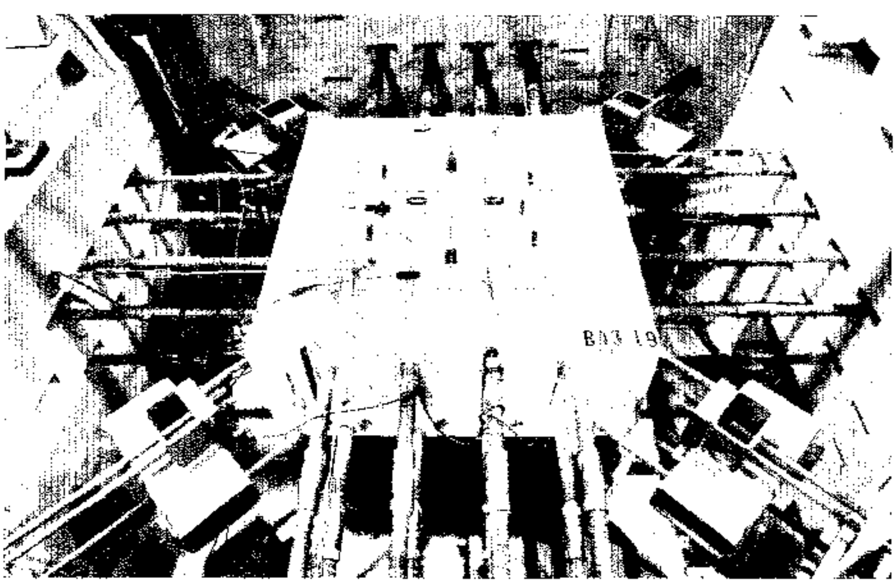


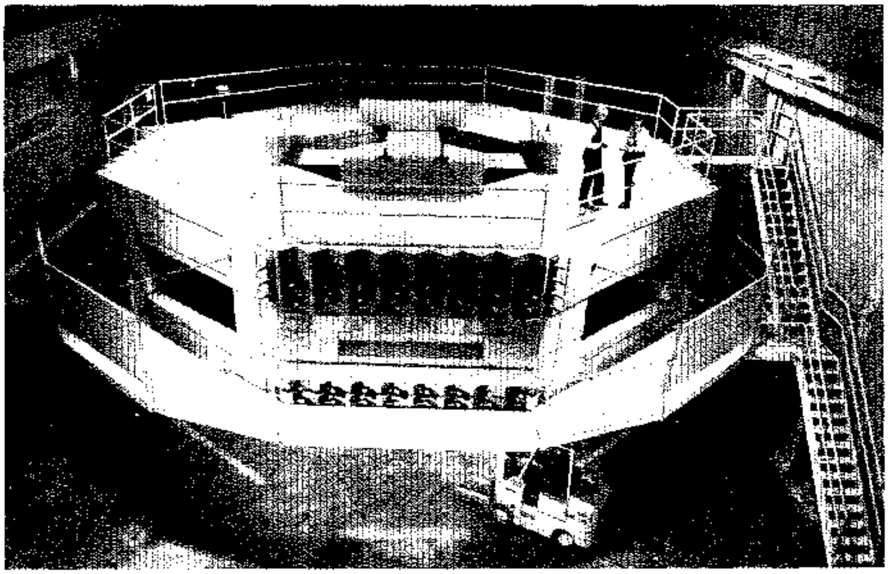
Figure 1 A reinforced concrete slab, representing a segment of a reactor containment wall, is loaded in biaxial tension to simulate the stresses that would be applied during overpressurization in a postulated degraded-core accident. Gages are installed to measure deformations and crack opening.

The next phase of testing in 1984 will be performed on fully prototypical concrete slabs 3.5 ft thick (1.1 m), with liner plates anchored into one side. Because some of the slabs will include a 30-in-diameter (0.8-m) penetration sleeve, the specimens will be as large as 11 ft square (3.4 m). Special apparatus will be needed to measure air leakage, if it occurs; to apply transverse pull-out loads to the penetrations; to apply shear-bending to a specimen representing a corner of a containment; and to simulate accidentlike heat input to the liner plate of some specimens. To accommodate this apparatus and the full-scale structural segments, a new multiaxial test facility has been built for EPRI (Figure 2). The largest of its kind in the world, the two-story, prestressed concrete facility has a capacity of 50×10^6 lb (222 MN).

The containment regions having a potential for liner plate tearing and subsequent leakage are at structural discontinuities. Therefore, the final phase of the experimental program, planned for completion by 1986, will consist of pneumatic pressurization and leak rate tests of large-scale 360° segments that include the wall-roof or wall-basemat intersections in a concrete containment. To coordinate these tests with the NRC program, the EPRI large-scale segments will be scaled-up versions of the containment models to be tested by NRC.

The analytic effort, conducted by Anatech International Corp. (RP2172-1), has centered on the verification and application of the nonlinear finite-element code ABAQUS–EPGEN (developed partially under EPRI sponsorship) for predicting the complex concrete cracking and concrete-steel interaction behavior that could produce local failure of the liner plate. Unlike many other applications of concrete under compression, the behavior of concrete containments is governed primarily by tensile stresses in the concrete-steel composite material. The challenge here is to develop a material model and finite-element idealization that can account for the overall response of the building and the local deformations leading to liner rupture or warping of penetrations. An important aspect of the code development work is the systematic bench-marking of the analyses against experimental program results. The end product will be a test-verified code for making realistic estimates of structural leak areas as a function of containment pressure. *Project Managers: G. E. Sliter, Y. K. Tang, and R. K. Winkleblack*

Figure 2 Construction of EPRI's multiaxial test facility has been completed at the Construction Technology Laboratory of the Portland Cement Association in Skokie, Illinois. This facility, the largest of its kind, will be used in 1984 to measure air leakage through full-scale prototypical containment wall segments, some with cable/pipe penetrations, under loads totaling up to 50 $\times$ 10^6 lb (222 MN).



MEETING THE UTILITIES' SPENT-FUEL STORAGE NEEDS

With the signing of the Nuclear Waste Policy Act in January 1983, the responsibilities of both the government and the utilities for the back end of the fuel cycle were more clearly defined. DOE was made responsible for building waste repositories by 1998 and for the transportation, packaging, and disposal of spent fuel in the repositories. The utilities were made responsible for storing spent fuel until it could be removed from their sites by the government. Utilities are obligated to pay the government's full cost for the transportation and disposal of spent nuclear fuel through a one-time fee of 1 mill/kWh paid to the Nuclear Waste Fund. In addition, utilities must pay for their own on-site storage and transshipment costs up to the time the government begins to execute its responsibilities for transportation and disposal. EPRI is involved in several projects that are structured to assess the technical progress of the government's waste disposal program and to assist utilities in meeting their interim storage requirements to 1998 and beyond. This article discusses the activities to help provide technically sound, licensable, and cost-effective storage alternatives.

Projected storage needs

At the end of 1982, some 9000 t of spent fuel had been discharged from U.S. power reactors, and virtually all of it was stored in water pools. The current storage inventory is now growing at a rate of about 1800 t/yr, which is the rate that fuel is being discharged from reactors. By 1998 the annual fuel discharge rate will have increased to more than 3000 t/yr. Based on DOE surveys of the capabilities of utilities to store fuel in reactor pools, it appears that by 1998 between 10,000 and 15,000 t of spent fuel will have to be accommodated outside the existing reactor pools.

Figure 3 graphically presents the expected storage scenario until the year 2000. It can be seen that the repository will not be a major factor in reducing the requirement for additional storage even if the target startup date of 1998 is achieved. Should the repository be delayed, then the ability of utilities to provide incremental additions to storage capacity becomes increasingly important as more and more of the reactor pools become filled. Newer dry-storage technologies are a particularly attractive way to provide incremental storage capacity. Figure 3 also points out that large-scale use of dry storage is not expected to begin before the mid 1980s, and it will be the early 1990s before substantial quantities of fuel are in storage.

Since 1981 EPRI has been involved in a variety of projects that support the development of spent-fuel storage technology. Table 1 groups these projects under four categories.

Pool storage activities

In this status report two of the current pool-storage-related projects are discussed. The larger of the two is a multiyear agreement with Northeast Utilities that is designed to demonstrate the technology and licensing of maximum density pool storage by using rod consolidation techniques (RP2240-2). This project is also supported by Baltimore Gas & Electric Co. and by Combustion Engineering, Inc., the prime subcontractor for Northeast Utilities.

The project began in late 1982 and is scheduled to be completed in 1985, culminating with a hot demonstration in the Millstone-2 pool. Specific objectives include development of nonproprietary codes to be used in licensing, development and demonstration of consolidation equipment and tooling, and development of equipment to treat and package the bundle scrap hardware that remains after removal of the fuel pins. The advantage of rod consolidation is that the fuel from two assemblies can be stored in the same space normally occupied by one unconsolidated assembly. However, there are important design considerations (e.g., seismic, criticality, and thermal-hydraulic adequacy) that must be addressed before implementing a rod consolidation project.

A second EPRI project that supports advanced pool storage is the application and benchmarking of a three-dimensional, thermal-hydraulic code to analyze spent-fuel storage pools. NUS Corp. has made available (on a nonproprietary basis) the newly developed GFLOW code, which combines the sophistication of a three-dimensional model with a methodology that allows relatively simple modeling and low-cost computer analyses of a storage pool (RP2240-4).

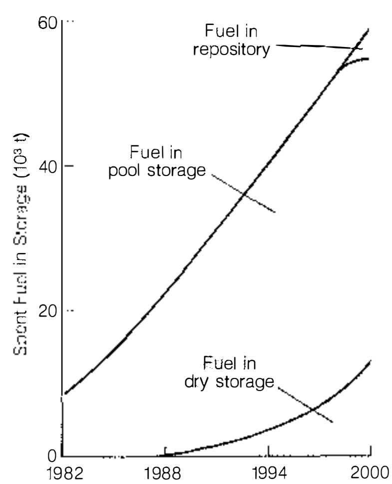


Figure 3 Future spent-fuel storage needs are expected to continue to be met mainly by pool storage, but starting in the mid 1980s, supplemental dry storage will be needed. Some 13,000 t of dry storage is projected by the year 2000.

Table 1
SPENT-FUEL ACTIVITIES

Activity	Project No.	Contractor	Objective
Long-term fuel integrity	RP2062	Hanford Engineering Development Laboratory	UO_2 oxidation
		Stanford University	Modeling of cladding failure
		S. Levy, Inc.	Evaluation of storage risk
		Pacific Northwest Laboratory	Surveillance of pool storage
		Atomic Energy of Canada Limited	Investigation of stress corrosion cracking
Economics and system integration	RP2062	Boeing Engineering & Construction	Analysis of storage cost
	RP2511	Boeing Engineering & Construction	System integration and optimization
	RP2406	Transnuclear	Analysis of cask criterion
Dry-storage system performance	RP2406; RP2566	Pacific Northwest Laboratory	Thermal evaluation of consolidated fuel
		Transnuclear	Cask cleaning
		Pacific Northwest Laboratory	BWR calorimetry at General Electric Co., Morris facility
		Virginia Electric and Power Co. (planned)	Cask demonstration—solicitation for cooperative agreement proposal
		Carolina Power & Light Co. (planned)	Silo demonstration—solicitation for cooperative agreement proposal
Rod consolidation for pool storage	RP2240	Northeast Utilities	Rod consolidation demonstration
		NUS Corp.	Pool thermal hydraulics
		INET Corp.	Safeguards for consolidation

The purpose of the code is to remove the conservatism normally used and permit more accurate predictive modeling of actual pool thermal hydraulics.

To validate the code, pool temperatures and flow velocities were measured at the Maine Yankee reactor in the fall of 1982. At that time the pool was filled with spent fuel, including a full-core discharge that had been placed in storage only days after reactor shutdown. The experimental data matched the predicted pool thermal gradients extremely well and confirmed that actual pool thermal gradients are significantly less than those predicted by previous conservative modeling. The first phase of the work was reported in NP-3097. Follow-on work is expected to be completed shortly and will include further code refinements that will make the code even easier to use. The code and methodology will also be documented in a user's manual.

Dry-storage activities

EPRI is currently involved in several projects in support of developing licensable, cost-effective dry storage. Initial projects consisted of cost studies, technical assessments, and laboratory-scale experiments aimed at building a technical base for safe, long-term dry storage. These included risk analyses studies that have reviewed the potential failure mechanisms of fuel in dry storage and compared the relative risk of various dry-storage techniques with those of wet storage and other fuel cycle risks (RP2062). Another project has evaluated the impact of dry-storage package failures on regulatory release limits to ensure that the safety of these systems is neither a regulatory nor a public acceptance issue.

Other projects under RP2062 are currently evaluating cladding integrity, particularly stress corrosion cracking. One project at Stanford University is developing a model to predict potential cladding failure rates in long-term storage as a function of dry-storage conditions. Another study is under way to assess the impact of cladding defect size on the oxidation of the contained UO_2 fuel. This effort, jointly funded by TVA, is expected to yield significant benefits by defining the temperature and fuel conditions under which spent fuel may be stored in an air environment.

The next phase of EPRI involvement in dry-storage technology is in the area of full-scale system development and testing. These projects will demonstrate the technical performance of dry-storage systems, provide data to confirm the ability to model the storage systems, provide data at bounding operating conditions, and provide lead test assembly data on fuel integrity under prototypic and bounding conditions.

These demonstrations will be part of cooperative DOE-utility-EPRI programs that were called out in the Nuclear Waste Policy Act. Virginia Electric and Power Co. will be the lead utility in demonstrating metal cask storage technology, and Carolina Power & Light Co., in demonstrating horizontal concrete silo technology. EPRI will play a major role in the R&D portion of these efforts.

Other activities

Project activity is also addressing economics, evaluation of storage alternatives, and system optimization. Boeing Engineering & Construction has recently completed a cost comparison of storage options (RP2062-8). The object of this study was to provide a set of consistent and normalized-cost data for a variety of storage strategies, and the data include all system costs over the life of the storage scenario. When combined with a computerized alternative analysis methodology developed by TVA, utilities will be able to evaluate a wide range of storage options by using probabilistic techniques and economic assumptions customized to represent an individual utility.

Other EPRI efforts are being devoted to bringing about a better integration of utility fuel storage activities and DOE programs for ultimate fuel disposal. Although there are many barriers that make overall system optimization difficult, the economic and operational incentives to the utilities are large.

It is clear that utilities will be spending over $1 billion by the end of the century to provide additional spent-fuel storage capacity. EPRI is committed to helping them meet their storage needs by performing the R&D necessary to ensure that licensable, cost-effective technology will be available in a timely fashion. *Program Manager: R. F. Williams; Project Manager: R. W. Lambert*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP778-2	Exxon Donor Solvent Coal Liquefaction Process	5 months	800.0	Exxon Research and Engineering Co. *H. Lebowitz*
RP1345-4	Measurement of Pressurized-Combustor Particulates	3 months	88.1	TRW, Inc. *A. Cohn*
RP1654-19	CRIP Product Gas Sampling and Analysis	6 months	52.5	Widco *J. McDaniel*
RP2102-3	Optical Pyrometry System to Measure Gas Turbine Blade Metal Temperatures	35 months	271.6	Solar Turbines, Inc. *C. Dohner*
RP2383-1	Use of Petroleum-Derived Heavy Solvents in Direct Coal Liquefaction	11 months	52.5	University of Wyoming *C. Kulik*
RP2383-2	Cooxidative Depolymerization of Coal	10 months	50.0	Western Kentucky University *C. Kulik*
RP2383-3	Coal Liquefaction by Electron Transfer	10 months	50.0	Purdue Research Foundation *C. Kulik*
RP2528-1	State of the Art: Gas Turbine Furnace and Heat Exchanger	10 months	69.2	A. C. Kirkwood & Associates, Inc. *H. Schreiber*
RP2528-2	State of the Art: Diesel Bottoming Cycles	10 months	64.7	A. C. Kirkwood & Associates, Inc. *H. Schreiber*
Coal Combustion Systems				
RP910-3	Field Test: Trace Element Removal by Iron Hydroxide Adsorption/Coprecipitation	27 months	363.9	Brown & Caldwell *W. Chow*
RP1872-4	Guidelines: FGD Maintenance	16 months	120.4	Stone & Webster Engineering Corp. *T. Morasky*
RP1885-3	Failure Analysis of Superheater Tubes Following Chromate Treatment	6 months	25.0	Battelle Memorial Institute *J. Dimmer*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP2154-4	Preliminary Assessment: NO_x and SO_2 Retrofit Controls for Coal-Fired Utility Boilers	4 months	104.1	KVB, Inc. *M. Miller*
RP2301-1	Groundwater Manual for the Electric Utility Industry	11 months	231.4	Southern Company Services *D. Golden*
RP2459-1	Sulfur Meter for Blending Coal	9 months	150.0	Detroit Edison Co. *R. Row*
Electrical Systems				
RP1499-5	Study of Arc Products in Transformer Systems Containing C_2Cl_4	6 months	73.3	Westinghouse Electric Corp. *G. Addis*
RP2201-1	Advanced Distribution Substation Design	18 months	92.5	Ebasco Services, Inc. *T. Kendrew*
RP2202-1	Integration of Load Management Into Power System Control During Normal System Operations	28 months	409.0	Energy & Control Consultants *C. Frank*
RP2308-4	Winding Models for Large AC Motors	2 months	26.0	University of Arizona *D. Sharma*
RP2436-1	Effects of DC Tests on Extruded Dielectric Cables	3 years	519.4	Detroit Edison Co. *B. Bernstein*
Energy Analysis and Environment				
RP1616-28	Plume Model Development and Evaluation	4 years	1598.1	A.R.A.P., Inc. *G. Hilst*
RP1729-7	Robustness of the ANOVA Model in Environmental Monitoring Applications	4 months	29.6	Tetra Tech, Inc. *J. Mattice*
RP1983-2	Coal Unit Train Fuel Consumption	8 months	50.6	Manalytics, Inc. *E. Altouney*
RP2372-1	Integration of Utility Fuel and Investment Decision	8 months	134.1	Dames & Moore *J. Platt*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP2485-6	Unsaturated Ground-water Transport	51 months	648.5	University of California at Riverside *I. Murarka*

Energy Management and Utilization

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1084-7	System Planning Studies: Storage Technologies	7 months	82.3	Energy Management Associates, Inc. *D. Rigney*
RP2036-13	Current Trends in Commercial Cool Storage	6 months	30.0	Argonne National Laboratory *V. Rabl*
RP2036-14	Market Constraints for Residential Ice Storage	7 months	28.2	QLA, Inc. *V. Rabl*
RP2237-1	Solar Domestic Water Heating Consolidation Assessment and Manual	9 months	118.2	Burt Hill Kosar Rittelmann Associates *G. Purcell*
RP2416-10	Electric Melting R&D	7 months	50.0	Oregon Graduate Center *R. Mauro*
RP2478-1	R&D Application Center for Metals Fabrication	3 years	1600.0	Battelle, Columbus Laboratories *I. Harry*

Nuclear Power

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP819-4	LaSalle Radiation Assessment	22 months	29.3	Commonwealth Research Corp. *C. Wood*
RP1250-8	Heat and Mass Transfer for Boiling in Porous Deposits	1 year	32.5	University of Illinois *A. Machiels*
RP1393-8	Reliability Analysis of Refueling Outages	9 months	138.1	Westinghouse Electric Corp. *T. Law*
RP1580-7	Response to NRC–PCI Licensing Issues	4 months	31.6	Combustion Engineering, Inc. *J. Santucci*
RP1845-8	Test: EPRI–NRC Transient Prototypical Generator (MB-2)	27 months	735.4	Westinghouse Electric Corp. *S. Kalra*
RP1930-9	Demonstration: BWR Hydrogen Water Chemistry	68 months	3318.4	Commonwealth Research Corp. *A. Roberts*
RP1935-6	Cobalt Replacement and Radiation Field Measurements in CANDU Reactors	23 months	70.4	Ontario Hydro *H. Ocken*
RP2009-2	Manual: Self-Assessment of Nuclear Power	10 months	167.9	Wyle Laboratories *J. O'Brien*
RP2167-3	Enhancing Plant Effectiveness by Improving Organizational Communications	21 months	211.6	Essex Corp. *H. Parris*
RP2177-5	Flow and Temperature Distributions in the PWR Upper Internals in Postulated Degraded-Core Accidents	11 months	273.2	Westinghouse Electric Corp. *B. Sehgal*
RP2177-6	Analysis of PWR Upper Plenum Flows in Degraded-Core Accidents With Commix Code	3 months	60.3	Argonne National Laboratory *B. Sehgal*
RP2231-1	Erosion/Corrosion of Turbine Piping	8 months	129.0	Gilbert Associates, Inc. *N. Hirota*
RP2292-1	Validation and Integration of Critical PWR Signals	30 months	640.4	Babcock & Wilcox Co. *A. Long*
RP2296-6	Electropolishing Corrosion Validation	5 months	106.3	General Electric Co. *C. Wood*
RP2338-1	On-Line Monitoring and Diagnostics for Submerged Vertical Shaft Pumps	2 years	513.1	Shaker Research Corp. *G. Shugars*
RP2348-4	Assessment of Past System Interaction Identification Studies	4 months	59.9	Envirospace Co. *B. Chu*
RP2352-2	Validation of Gamma-Ray Analysis Capacity	8 months	129.9	Brookhaven National Laboratory *O. Ozer*
RP2356-6	Seismic Wave Attenuation in Central and Southern New England	5 months	63.1	Woodward-Clyde Consultants *J. Stepp*
RP2393-1	Flow Regimes in Large Pipes: Diameter Entrance Effects Evaluation	4 months	61.5	Creare R&D, Inc. *M. Divakaruni*
RP2393-2	Flow Regime Experiments	4 months	50.0	Science Applications, Inc. *M. Divakaruni*
RP2430-16	Large-Scale Prototype Breeder: Design of a Uranium-Fueled Core and Operability of a Distributed Digital Processing System	8 months	171.5	General Electric Co. *D. Gibbs*
RP2430-18	Large-Scale Prototype Breeder Reactor Plant: Methods for Handling Large Components	6 months	40.0	Bechtel Group, Inc. *D. Gibbs*
RP2430-20	LMFBR: Seismic Isolation	5 months	62.2	Burns and Roe, Inc. *D. Gibbs*

Planning and Evaluation

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1348-18	State of the Art: Sun-Convective Solar Ponds for Power Generation	5 months	65.6	Massachusetts Institute of Technology *S. Feher*

New Technical Reports

Each issue of the *Journal* includes information on 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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ADVANCED POWER SYSTEMS

Texaco Environmental Tests on a 165-t/d Texaco Gasifier
AP-3204 Final Report (RP1799-8); $11.50
Contractor: Texaco, Inc.
EPRI Project Manager: John McDaniel

Evaluation of Exxon Donor Solvent Coal-Derived Liquid as Utility Diesel Fuel
AP-3224 Final Report (RP2049); $22.00
Contractors: Easton Utilities Commission; Cooper Energy Services, Inc.; Battelle, Columbus Laboratories; Control Data Health Care Services; Southwest Research Institute
EPRI Project Manager: Henry Schreiber

Conceptual Design of a Moving-Ring Fusion Reactor
AP-3229 Final Report (RP922); $32.50
Contractors: Pacific Gas and Electric Co.; Cornell University; General Atomic Co.; Lawrence Livermore National Laboratory; University of Michigan
EPRI Project Manager: F. R. Scott

Cool Water Coal Gasification Program: Second Annual Progress Report
AP-3232 Interim Report (RP1459); $11.50
Contractor: Cool Water Coal Gasification Program
EPRI Project Manager: T. P. O'Shea

Methods for Wind Turbine Dynamic Analysis
AP-3259 Final Report (RP1977-1); $22.00
Contractor: Systems Control, Inc.
EPRI Project Manager: F. R. Goodman, Jr.

Protective Cladding and Coatings for Utility Gas Turbines
AP-3267 Final Report (RP1460-1); $20.50
Contractor: General Electric Co.
EPRI Project Manager: John Stringer

Proceedings: Seventh Annual Geothermal Conference and Workshop
AP-3271 Proceedings (RP1195-9); $26.50
Contractor: Altas Corp.
EPRI Project Manager: V. W. Roberts

Cost Estimates for Large Wind Turbines
AP-3276 Final Report (RP1989-1); $28.00
Contractor: Bechtel Group, Inc.
EPRI Project Manager: S. M. Kohan

Potential Economic and Financial Impact on Utility Systems of Not Burning Liquid Fuels
AP-3279 Final Report (RP832-8); $14.50
Contractor: Zaininger Engineering Co.
EPRI Project Manager: B. M. Louks

Assessment of Technical Risks and R&D Requirements for a Magnetic Confinement Fusion Fuel System
AP-3283 Final Report (RP1969); $28.00
Contractor: McDonnell Douglas Astronautics Co.
EPRI Project Manager: F. R. Scott

COAL COMBUSTION SYSTEMS

Mechanical Properties of a Titanium Blading Alloy
CS-2933 Final Report (RP1266-1); $13.00
Contractors: Technische Universität Hamburg-Harburg; Ruhr Universität Bochum
EPRI Project Manager: R. I. Jaffee

Calculation of the Water Flow Rate Evaporated in a Wet Cooling Tower
CS-3144-SR Special Report; $10.00
EPRI Project Manager: J. A. Bartz

EPRI Condenser-Related Research Projects
CS-3196-SR Special Report; $13.00
EPRI Project Manager: I. A. Diaz-Tous

Diethylenetriamine Solutions for Stack Gas Desulfurization by Absorption/Stripping
CS-3228 Final Report (RP982-20); $13.00
Contractor: University of Texas at Austin
EPRI Project Manager: D. A. Stewart

Design of a Cubic Nozzle for Use in Metering Steam Turbine Condensate Flow
CS-3241 Final Report (RP1878-2); $11.50
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: T. H. McCloskey

Impurity-Induced Embrittlement of Rotor Steels
CS-3248 Final Report (RP559); Vol. 1, $17.50; Vol. 2, $8.50
Contractor: University of Pennsylvania
EPRI Project Manager: R. Viswanathan

Steam Turbine Condensation: Shock Wave Interaction
CS-3251 Final Report (RP1497-1); $16.00
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: T. H. McCloskey

Binary Ammonia Cycle Pilot Plant, Gennevilliers Power Station: Summary of Design and Operating Principles
CS-3254-SR Special Report; $17.50
EPRI Project Manager: J. A. Bartz

Second Conference on Fabric Filter Technology for Coal-Fired Power Plants
CS-3257 Proceedings (WS82-929); $53.50
EPRI Project Manager: David Eskinazi

Noise Reduction in Fossil Fuel Power Plant Draft Fans
CS-3260 Interim Report (RP1649-7); $11.50
Contractor: University of Houston
EPRI Project Manager: A. F. Armor

Use of Additives to Facilitate On-Load Cleaning of Utility Boilers
CS-3270 Final Report (RP1839-2); $11.50
Contractor: Battelle, Columbus Laboratories
EPRI Project Manager: J. P. Dimmer

State-of-the-Art Review: PCDDs and PCDFs in Utility PCB Fluid
CS-3308 Final Report (RP1263-11); $20.50
Contractor: SCS Engineers, Inc.
EPRI Project Manager: R. Y. Komai

ELECTRICAL SYSTEMS

SHORT1–SHORT2 User's Manual
EL-3102-CCM Computer Code Manual (RP1286-2); $11.50
Contractors: Pirelli Cable Corp.; Georgia Power Co.
EPRI Project Manager: H. J. Songster

Formation of Amorphous Metal by Hypervelocity Impact
EL-3238 Final Report (RP2115-6); $11.50
Contractor: University of Texas
EPRI Project Manager: Mario Rabinowitz

Improved Methods for Distribution Loss Evaluation
EL-3261 Final Report (RP1522-1), Vol. 1; $20.50
EL-3261-CCM Computer Code Manual, Vol. 2; $11.50
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: T. J. Kendrew

Remote-Controlled Maintenance Device Feasibility Study
EL-3296 Interim Report (RP1497-1); $11.50
Contractor: Southwest Research Institute
EPRI Project Manager: John Dunlap

Mutual Design of Overhead Transmission Lines and Railroad Communications and Signal Systems
EL-3301 Final Report (RP1902-1); Vol. 1, $29.50; Vol. 2, $25.00
Contractor: IIT Research Institute
EPRI Project Manager: John Dunlap

ENERGY ANALYSIS AND ENVIRONMENT

Catalog of Data for the EPRI Plume Model Validation and Development Data Base: Plains Site
EA-3080 Final Report (RP1616-9); $38.50
Contractor: Systems Applications, Inc.
EPRI Project Manager: G. R. Hilst

External Quality Assurance for the Plume Model Validation and Development Project: Plains Site
EA-3082 Final Report (RP1616-10); $13.00
Contractor: Research Triangle Institute
EPRI Project Manager: G. R. Hilst

Integrated Lake-Watershed Acidification Study
EA-3221 Final Report (RP1109-5), Vol. 1; $19.00
Contractor: Tetra Tech, Inc.
EPRI Project Manager: R. A. Goldstein

Sulfate Formation in Oil-Fired Power Plant Plumes
EA-3231 Final Report (RP1000-1); Vol. 1, $19.00; Vol. 2, $13.00
Contractor: Brookhaven National Laboratory
EPRI Project Manager: Charles Hakkarinen

Model-Based Statistical Sampling for Electric Utility Load Research
EA-3286 Final Report (RP1816-2); $14.50
Contractor: Roger L. Wright and Associates
EPRI Project Manager: Edward Beardsworth

Comparison of Visibility Measurement Techniques: Eastern United States
EA-3292 Final Report (RP862-15); $16.00
Contractor: Aerovironment, Inc.
EPRI Project Manager: G. R. Hilst

ENERGY MANAGEMENT AND UTILIZATION

Site-Specific Assessment: 150-MW Coal Gasification–Fuel Cell Power Plant
EM-3162 Final Report (RP1041-10); $16.00
Contractor: Kinetics Technology International Corp.
EPRI Project Manager: D. M. Rastler

Workshop on Planning for Residential Load Management
EM-3227 Proceedings (RP1833); $23.50
EPRI Project Manager: T. S. Yau

Electric Vehicle Field Test Manual
EM-3242 Interim Report (RP1136-10); $14.50
Contractor: Bevilacqua-Knight, Inc.
EPRI Project Manager: G. H. Mader

Development and Demonstration of a Load-Shape Simulation Model (LOADSIM) for Evaluating Customer Load Management Technologies
EM-3249 Final Report (RP1833); $11.50
Contractor: Systems Control, Inc.
EPRI Project Manager: T. S. Yau

Assessment of a 6500-Btu/kWh Heat Rate Dispersed Generator
EM-3307 Final Report (RP1041-12); $13.00
Contractors: Energy Research Corp.; Fluor Engineers and Constructors, Inc.
EPRI Project Manager: E. A. Gillis

NUCLEAR POWER

SIMQUAKE II: A Multiple-Detonation Explosive Test to Simulate the Effects of Earthquakelike Ground Motions on Nuclear Power Plant Models
NP-2916 Final Report (RP810-1, -6); $16.00
Contractors: University of New Mexico; Anco Engineers, Inc.
EPRI Project Manager: Y. K. Tang

Stress Corrosion of Alloys 600 and 690 in Acidic Sulfate Solutions at Elevated Temperatures
NP-3043 Final Report (RPS191-1); $17.50
Contractor: Central Electricity Research Laboratories (England)
EPRI Project Manager: C. E. Shoemaker

Salt Concentration in Heated Crevices and Simulated Scale
NP-3050 Topical Report (RP1171-3); $10.00
Contractor: Central Electricity Research Laboratories (England)
EPRI Project Manager: C. E. Shoemaker

GO Methodology
NP-3123-CCM Computer Code Manual (RP818; RP1842); Vol 3, $23.50; Vol. 5, $20.50; Vol. 6, $19.00
Contractors: Energy Incorporated; Kaman Sciences Corp.
EPRI Project Manager: B. B. Chu

Radiographic Detection of Intergranular Stress Corrosion Cracking: Analysis, Qualification, and Field Testing
NP-3164-SR Special Report; $8.50
EPRI Project Manager: M. E. Lapides

Report of the Committee on Physics Review of the Adaptive Learning Network Methodology
NP-3216 Interim Report (RP1570-2); $16.00
Contractors: J. A. Jones Applied Research Co.; Ultrasonics International, Inc.
EPRI Project Manager: G. J. Dau

FCODE–BETA Predictions of the Fuel Centerline Temperatures in HBWR Assemblies
NP-3218 Final Report (RP971-1); $13.00
Contractor: Science Applications, Inc.
EPRI Project Manager: David Franklin

Feasibility of Scaling Ferritic Spent-Fuel Storage Shipping Casks
NP-3219 Final Report (RP2240-5); $11.50
Contractor: Fracture Control Corp.
EPRI Project Manager: R. E. Nickell

Effects of Cold Shutdown Chemistry on PWR Radiation Control
NP-3245 Interim Report (RP825-2); $10.00
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: R. A. Shaw

Radwaste Incinerator Experience
NP-3250 Final Report (RP1557-4); $16.00
Contractor: Gilbert Associates, Inc.
EPRI Project Manager: M. D. Naughton

Development of a Production Prototype Pressure Vessel Imaging System
NP-3253 Final Report (RP606-8); $13.00
Contractor: Sigma Research, Inc.
EPRI Project Manager: J. R. Quinn

Airborne Radioactivity in Primary Containments of Nuclear Power Plants
NP-3258 Final Report (TPS79-726); $19.00
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: R. A. Shaw

Early Large-Scale Probabilistic Risk Assessments
NP-3265 Interim Report (RP2171-1); $20.50
Contractor: NUS Corp.
EPRI Project Manager: D. H. Worledge

Evaluation and Optimization of Magnetic Filters on Simulated Boiler Water
NP-3273 Final Report (RPS106-1); $16.00
Contractor: Aquafine Corp.
EPRI Project Manager: R. L. Coit

FREY-01: Fuel Rod Evaluation System
NP-3277-CCM Computer Code Manual (RP1321-4); Vol. 1, $14.50; Vol. 2, $19.00; Vol. 3, $10.00
Contractor: Anatech International Corp.
EPRI Project Manager: A. G. Adamantiades

EPRI Research Related to the Steam Turbine Generator
NP-3288-SR Special Report; $19.00
EPRI Project Manager: Michael Kolar

Segregation of Uncontaminated Dry Active Waste
NP-3299 Final Report (RP1557-9); $10.00
Contractor: National Nuclear Corp.
EPRI Project Manager: M. D. Naughton

PSEUDAX: PWR XY Core Analysis Linked to XYZ Models
NP-3304 Final Report (RP1709); $11.50
Contractors: Science Applications, Inc.; GRP Consulting, Inc.; Brookhaven National Laboratory
EPRI Project Manager: W. J. Eich

INFORMATION SERVICES

Progress on Significant R&D Projects
RA-2733-SR Special Report; $20.00
EPRI Project Manager: R. C. Rhodes

Index to 1983 EPRI Journal

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