Batteries: The Front Runners

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Cover: Three advanced types of storage batteries, ultimately destined for utilities, are in the running for evaluation in a few years at the Battery Energy Storage Test Facility: the zinc chloride, the zinc bromide, and the beta.

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Batteries: Foresight and Perseverance

It has been said that technology development is a matter of foresight and perseverance. This is especially true in the development of batteries for electric utility energy storage. Energy storage is destined to play a major role in future electric utility systems by enabling petroleum and gaseous fuels to be replaced with off-peak electricity produced by coal or nuclear plants and by permitting more effective use of solar energy. The benefits that will accrue from the large-scale implementation of energy storage will extend beyond the conservation of petroleum and gas. Environmental benefits could include reduced air pollution and fewer transmission lines. The costs of electricity could be reduced through lower fuel costs and better utilization of large baseload power plants. In addition, the reliability of the utility system could be increased through the existence of a network of small, dispersed energy storage systems.

The exact nature and magnitude of these benefits will be dictated by the success of current efforts to develop advanced storage technologies. Storage batteries, pumped hydro (conventional or underground), and compressed-air storage are the energy storage alternatives likely to be available to the industry in the near-to-intermediate future, and of these options, batteries are the most versatile. Batteries are modular, which should minimize installation time and costs. Because the modules are small, emit no pollutants, and operate quietly, they are expected to have the least environmental impact. This allows them to be installed close to the user, reducing the need for transmission lines and enhancing system reliability and flexibility. Batteries also offer operational characteristics that can greatly enhance the flexibility and reliability of the utility system. There is, therefore, no question that the successful development of batteries for utility use will yield large benefits. It is this foresight that has led to the strong interest in battery development.

However, while pumped hydro and compressed-air storage have been developed and are available for utility use today, batteries will require another 5–10 years before the essential steps of development, evaluation, and verification can be completed. And although each of the candidate battery concepts is confronted by its own set of technical issues, the technical questions do not represent the greatest obstacle to battery commercialization. A more important question is whether the utility industry, the developers, and the government will persevere in the development of battery energy storage or relegate this technology to nonutility applications.

This question may be answered at the Battery Energy Storage Test (BEST) Facility within the next few years. The BEST Facility is sponsored by DOE, EPRI, and Public Service Electric and Gas Co. as a national center for the evaluation of battery energy storage systems. As candidate batteries approach maturity, they will be evaluated at BEST to determine compatibility with the utility grid, ability to be operated and maintained by utility personnel, acceptability of performance, and general system adequacy. The existence of a halfway house such as BEST allows a battery developer to obtain a real-world evaluation of its system before the commercial design is final. Further, it provides the ultimate users—the utilities—with the confidence needed to incorporate battery storage in their generation planning.

At this time at least four battery technologies (advanced lead-acid, zinc chloride, zinc bromide, and sodium-sulfur) are candidates for evaluation at BEST within the next five or six years. Thus, the next few years will be exciting for batteries. However, many questions still remain: Will DOE, under the new administration, continue its support of the BEST Facility? Will the utility industry continue its pursuit of battery storage under present financial pressures? Will the developers continue their interest in the utility storage market and the intermediate objective of evaluation in the BEST Facility? The answers are only a matter of foresight and perseverance.

Arnold Fickett, Director
Advanced Conversion and Storage
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Authors and Articles

Daily peaks in electricity demand are routinely satisfied by burning expensive fuels in peak-load generators. The storage of electricity generated at night by baseload units would make the electricity available when it is needed without the financial burden of peak period generation.

The New Batteries (page 6) will offer several advantages not found in other means of energy storage. The article reviews these R&D incentives and the major electrochemical schemes now in competition for utility load-leveling batteries. Jenny Hopkinson, *Journal* feature writer, is the author, with technical guidance from James Birk, manager of the Energy Storage Program in EPRI's Energy Management and Utilization Division.

Birk initiated EPRI's battery R&D effort when he came to the Institute in December 1973. During six previous years with the energy systems group of Rockwell International Corp., his work included development of a high-temperature battery and liaison with Argonne National Laboratory. Birk has a BS in chemistry from Iowa State University and a PhD in analytic chemistry from Purdue University.

■

Earthquakes produce complex combinations of amplitudes, frequencies, and durations of ground motion, all of which are modulated by soil conditions and by the designs of the structures that are shaken. **Seismic Testing** (page 14) deals with R&D efforts to quantify these interactions so that earthquake design margins will represent intentional conservatism rather than unintentional excess. Suzanne Knott, science writer, worked closely with EPRI's Hui-Tsung Tang to develop the article.

A project engineer for risk assessment in the Nuclear Power Division, Tang came to EPRI in April 1978 after more than five years with the Nuclear Energy Division of General Electric Co. His engineering work there concerned fuel and structural mechanics. Tang came to this country from Taiwan after completing undergraduate study in engineering and graduate study in engineering mechanics. He has an MS and a PhD in applied mechanics from the University of California at San Diego.

■

Dielectric liquids containing polychlorinated biphenyl compounds have been in widespread use for many years, and removing these PCB liquids from utility apparatus will take time and money. **Managing PCBs** (page 20), by Nadine Lihach, *Journal* feature writer, describes the R&D that will help utilities do the job most effectively and economically. Five staff members from three EPRI divisions assisted Lihach with background for this article.

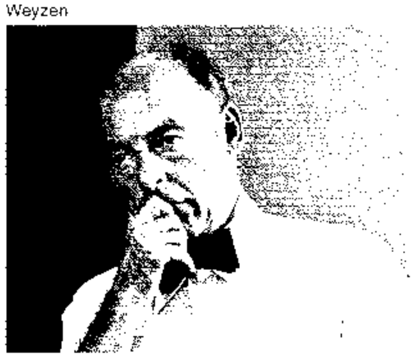
Narain Hingorani, manager of the Transmission Substations Program in the Electrical Systems Division, coordinates the Institute's PCB research efforts. Hingorani, whose special interest is HVDC transmission, came to EPRI in October 1974 after six years with Bonneville Power Administration. Gilbert Addis, a project manager in Hingorani's program since September 1978, was an R&D chemist and chemical technology manager for 28 years. He became familiar with electric power technologies during the development of sodium-conductor cable with Union Carbide Corp., and he was later the engineering manager for two manufacturers of connectors.

John Maulbetsch, manager of the Water Quality Control and Heat Rejection Program in the Coal Combustion Systems Division since August 1975, was previously an R&D consultant and a member of the MIT mechanical engineering faculty. He and Ralph Komai, a project engineer in this program, are concerned with assessment and cleanup of PCB spills. Komai, with degrees in mathematics and chemistry, worked in environmental quality for Southern California Edison Co. for more than five years before he joined EPRI in May 1979.

Walter Weyzen is a project manager in the Environmental and Occupational Health Program in the Energy Analysis and Environment Division. He came to EPRI in October 1979 after 10 years with DOE and its predecessor agencies in studies of nuclear technologies and human health. Weyzen holds MD and PhD degrees from the University of Leyden, The Netherlands.

Hingorani

Weyzen



Addis

Tang

Maulbetsch

Komai

Birk


•ZINC•
BROMIDE
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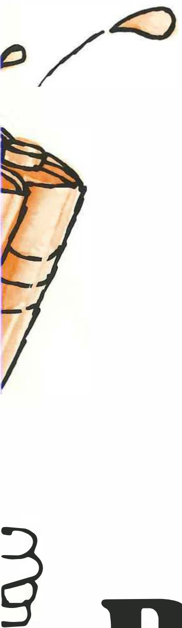
BETA



THE NEW BATTERIES

Charging ahead toward commercialization, advanced batteries still have a long way to go. Continuing research will decide which of the new systems will eventually provide utilities with economic and efficient storage of baseload electricity to feed peak demand.

Energy storage technologies, including conventional pumped hydro, underground pumped hydro, compressed-air storage, and batteries, can all fulfill several distinct utility applications that endeavor to reduce oil use and increase utility system reliability.

But only batteries have the advantage of being modular, a factor that promises a relatively short lead time from order to installation, the capability for adding sections as they are needed, and a wider choice of sites. Another advantage is that batteries can be operated over widely varying loads, and when used at part load, they are more efficient than they are at full load—a unique feature for power delivery systems.

Because of battery energy storage systems' simple, compact design and quiet, nonpolluting operation, delays in their licensing should be few, which would result in lower installation costs. Because of their modular design, battery energy storage plants should be very reliable, and maintenance crews are likely to be unnecessary during normal operation.

Applications

The value of using batteries on a utility system was proven long ago, comments William Shafer, an engineer at Commonwealth Edison Co. and a member of EPRI's Utility Battery Operations and Applications Team. "Fifty or 60 years ago Commonwealth Edison had lead-acid batteries in downtown Chicago locations to level the load put on its dc system by elevators and lighting in large buildings. But with the advent of ac, the old batteries were retired."

However, Shafer points out, utilities may once again need batteries. Fuel-efficient baseload units in a power station are the least expensive to operate. It makes sense, therefore, to keep them running at full tilt during the nighttime hours of lowest demand and to use batteries or other energy storage systems for storing this energy and leveling the load for five or more peak hours during the day. Battery energy storage is particularly cost-effective for peak-shaving applications of three to five hours' daytime duration.

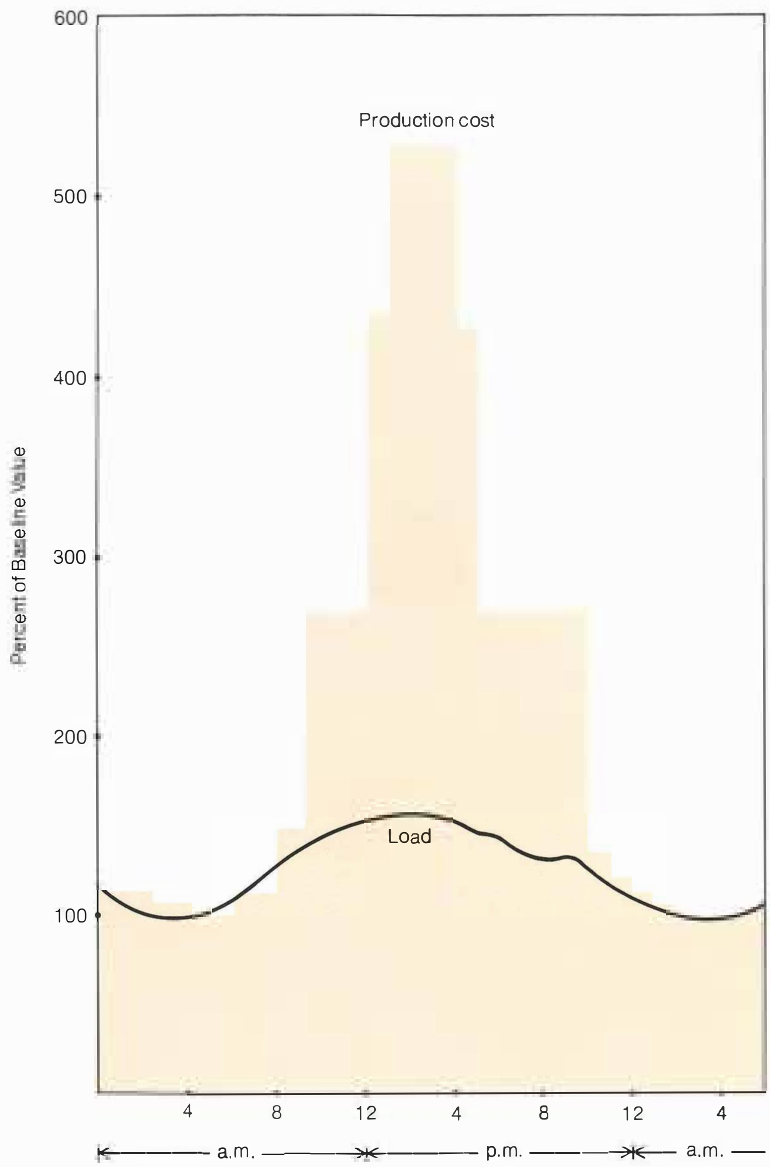
In addition to storing energy for load leveling and peak shaving, batteries can provide spinning reserve—instantaneous emergency power in the event of a sudden power plant outage. Batteries' unique capability to respond to momentary fluctuations in load demand is important, particularly in system regulation. A European utility, Berliner Kraft und Licht, Ag, in West Berlin, is planning to install a 10-MW battery system solely for this purpose.

With power conditioning equipment, batteries can also be used to maintain the proper current-voltage phase relationship on the utility grid; this is called volt-ampere-reactive (VAR) power control, or power factor correction.

Several studies at EPRI and DOE have found that future competitive storage systems could penetrate the utility market to about 15% of peak load demand nationwide and supply about 5% of the total electric energy. In a study for EPRI, Decision Focus, Inc., determined that load-leveling batteries might well penetrate the market first in smaller municipal and rural utilities, helping to reduce charges for peak power (demand charges) bought from larger utilities. In a study for DOE, Battelle, Columbus Laboratories concluded that utilities' industrial customers facing high demand charges could benefit from installing batteries. For battery manufacturers, this could mean an early market for smaller battery systems, with lower financial risk.

The technical readiness of new battery types for utility service is being accelerated by parallel research in the electric vehicle field. Advanced batteries are attractive for EV applications because they store energy in smaller volume and with less weight than the conventional automobile lead-acid battery. The simultaneous development of battery systems for utility and EV application is not just technically synergistic. With more efficient use of pilot production equip-

The summer peak demand pattern at a typical electric utility illustrates the incentive to store electricity generated cheaply at night in order to feed such peak daytime demand. In this particular case, although the load increases from the baseline value by only 56% during the peak, the electricity production cost rises by over 400%. The baseline values are the utility's minimum load and minimum production cost.



ment in two kinds of demonstration, costs can be lowered more quickly by providing systems for several markets.

EPRI's program

The renewed utility interest in using batteries to store energy led EPRI, along with DOE and New Jersey's Public Service Electric and Gas Co., to establish the Battery Energy Storage Test (BEST) Facility—the first in the world able to handle megawatt-scale electric storage batteries.

Operators of the BEST Facility—which is electrically tied to a substation of the PSE&G grid—will control charge and discharge operations and monitor battery conditions by a sophisticated computer system. Key data collected by this system are preserved as a permanent record and are made available for analysis by BEST Facility staff, the equipment developers, and the funding agencies. The data are sent electronically to a second computer, the heart of a system called SCOPE (store, characterize, organize, present, evaluate), which can be accessed by BEST consultants, EPRI, and DOE via interactive computer terminals in any location from coast to coast. This communication link allows participants to cooperate in prompt and effective use of test results.

This year the testing equipment itself is being tested: ac-dc converters and power conditioning equipment, computer systems, and the conventional lead-acid battery that will be replaced in subsequent years by the advanced batteries to be evaluated.

It will be 1983 before any advanced battery is ready for installation at BEST. Meanwhile, in the laboratory, cells are being scaled up and integrated into batteries.

Commenting on the facility, Leonard Rogers, of DOE's Electric Energy Systems Division, Office of Energy Systems Research, says, "The BEST Facility responds to the first requirement of a utility chief executive officer. He wants to make sure he'll put a technology on his system that's compatible with what now exists. The state-of-the-art lead-acid battery now in place at BEST for station checkout will investigate the battery's ability to level load as an integrated component of the utility system. The advanced batteries, when installed, will show their ability to better satisfy that need."

The advanced battery types being sponsored by EPRI are zinc chloride, zinc bromide, and beta (sodium-sulfur). (The name *beta* has been officially adopted by the world's battery developers; it is derived from beta alumina, the battery's electrolyte material.)

Of the three EPRI projects, the zinc chloride battery has the greatest opportunity to reach the BEST Facility first. Currently, 50-kWh battery modules are being operated under laboratory conditions by Energy Development Associates (EDA), a subsidiary of Gulf+Western Industries, Inc. John Rowan, president of EDA, says that the company plans to fabricate and test at least 10 modules (connected in series) by 1982. The next step will be the evaluation of a prototype battery at the BEST Facility in 1983.

A zinc bromide battery may be available for installation at BEST in 1983–1984, probably in a 500-kWh size. Gould Laboratories is working on this battery with support from EPRI and DOE, while Exxon Corp. has a separate contract with DOE.

EPRI is funding and participating in the management of the beta battery project with General Electric Co. and Chloride Silent Power, Ltd. (CSP) in England. The beta battery also is being developed elsewhere in the world by several other major organizations, most notably Brown Boveri Corp. (Federal Republic of Germany), British Rail (England), Ford Aerospace and Communications Corp. and Dow Chemical Co. (United States), Yuasa (Japan), and Compagnie Générale d'Electricité (France). About 350 people at these organizations are working to develop the beta system, making it the most popular of the advanced batteries. Ford and the General Electric–CSP team could deliver experimental batteries of beta cells to the BEST Facility by 1985.

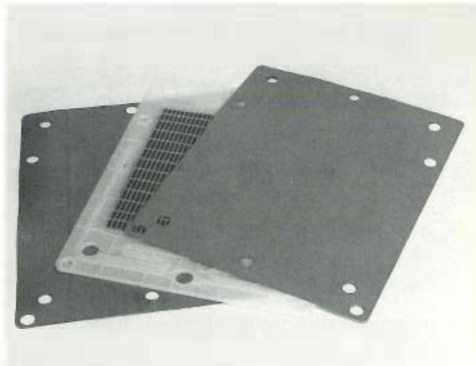
Battery technology

The zinc chloride battery uses materials (zinc and chlorine) that are low-cost, lightweight, and readily available. During both charge and discharge, the aqueous electrolyte (zinc chloride) circulates continuously through the chlorine electrode compartment. As dc is fed into the cell during charge, zinc metal is electrodeposited on the negative electrode plates, while chlorine is generated at the positive plates. The gas is immediately dissolved in chilled water to form an ice-like solid, chlorine hydrate, which is stored until the battery is discharged. During discharge, as dc is withdrawn from the cell, the chlorine hydrate is melted and the evolving chlorine dissolved in the circulating electrolyte. As it returns to the cell, chlorine is reduced at the positive electrode plates; the zinc plated on the negatives is oxidized to zinc chloride.

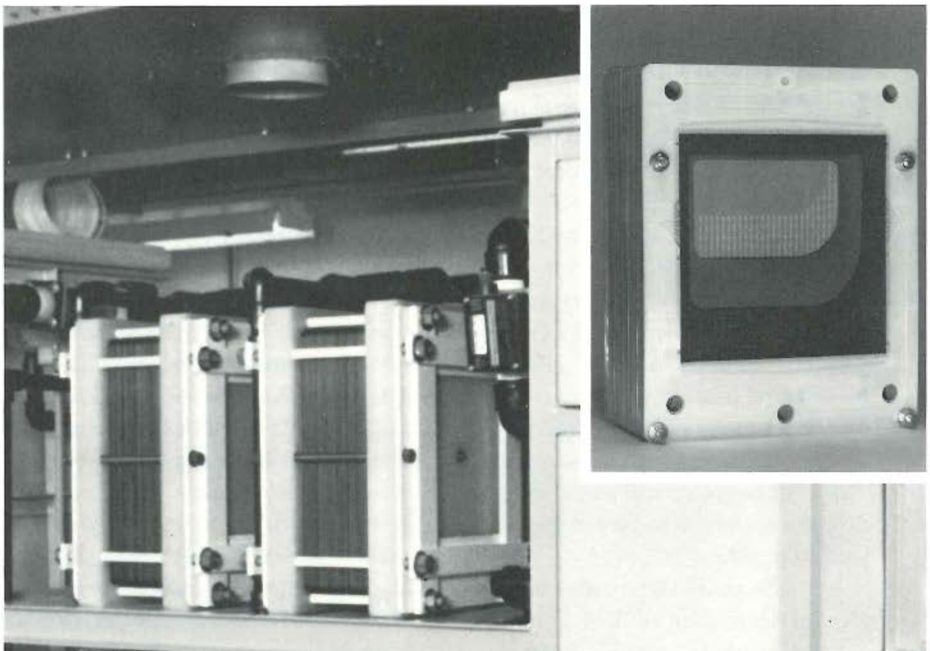
EDA, the major developer of the zinc chloride battery, has scaled the technology from small laboratory cells to 50-kWh engineering modules. Recently, EDA succeeded in producing a 50-kWh zinc chloride module capable of unattended operation through several charge and discharge cycles.

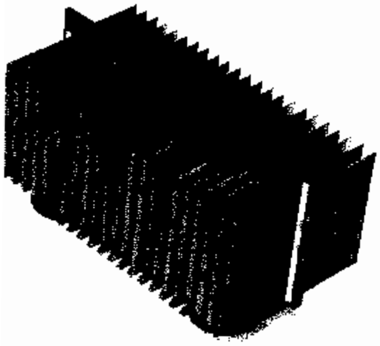
A number of challenges still remain, however. One involves the measurement and control of the chemical inventory, particularly the inert gases that can accumulate in the interior space of the cell because of its operation below atmospheric pressure and because of the slow oxidation of graphite, the substrate material of the chlorine electrode plates. Another challenge results from the properties of the graphite itself, which is porous and must be manufactured in such a way as to produce a uniform distribution of pore sizes to allow suitable operating efficiency.

The zinc bromide battery, with separator (top) and 1-ft^2 (0.09-m^2) carbon-plastic bipolar electrode contained within a plastic frame. The upper surface of the electrode is the zinc (negative) side, while the lower surface is the bromide (positive) side. The 8-kWh submodule has a series stack of 25 of the bipolar electrodes. An 80-kWh battery, standing about 6 ft (1.8 m) high and built by Gould Laboratories, contains 10 submodules. The battery also has two storage tanks that supply electrolyte to each side of the carbon electrode. The battery has operated successfully since early summer.

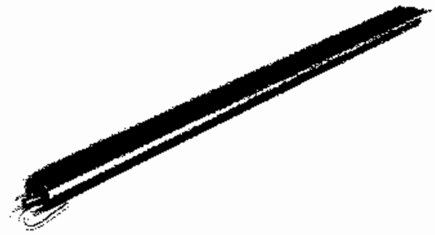


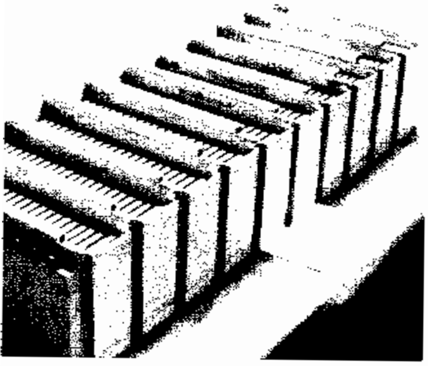
Components of a 1-kWh zinc chloride cell. A graphite bus separates the zinc electrode plates (right) and the chlorine electrodes (left), which measure 2 in by 4 in (51 by 102 mm). Ten cells in series compose a 3-ft-long (0.9-m), 10-kWh submodule. A 60-kWh battery module, standing about 5 ft (1.5 m) high, contains six submodules in parallel, as well as electrolyte, gas pumps, and chlorine store. This module was fabricated by Energy Development Associates; several have been tested in the last two years.

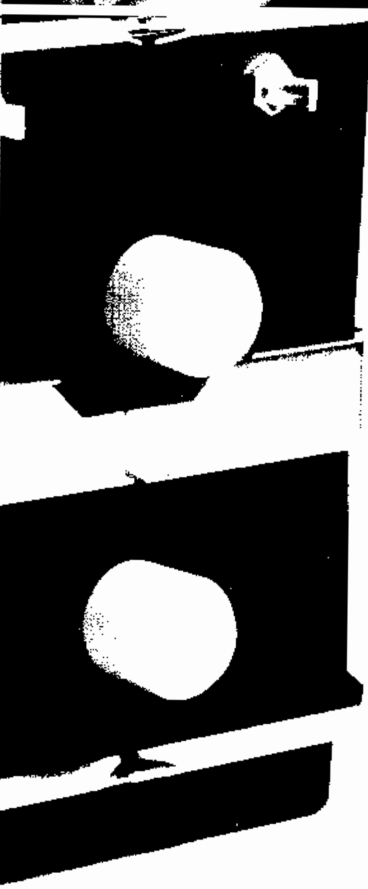


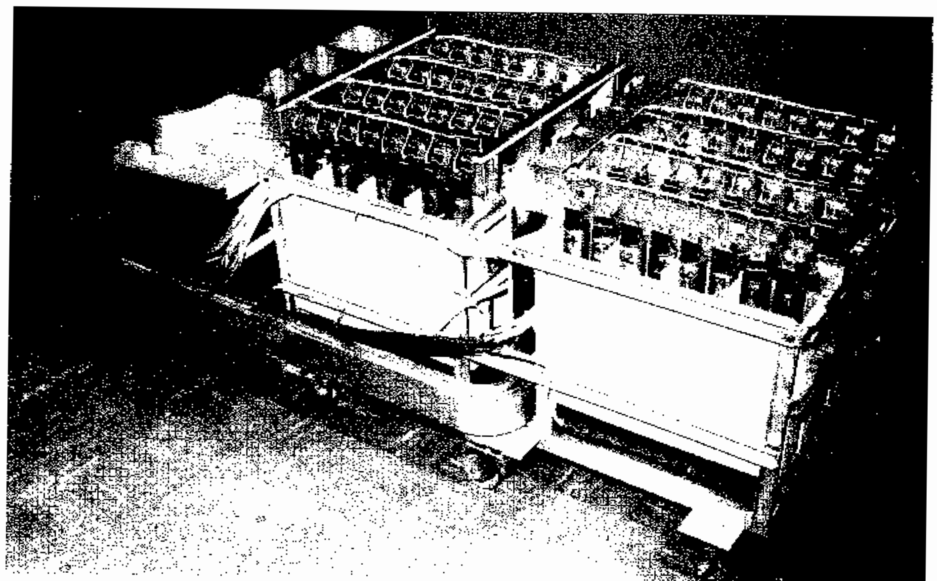


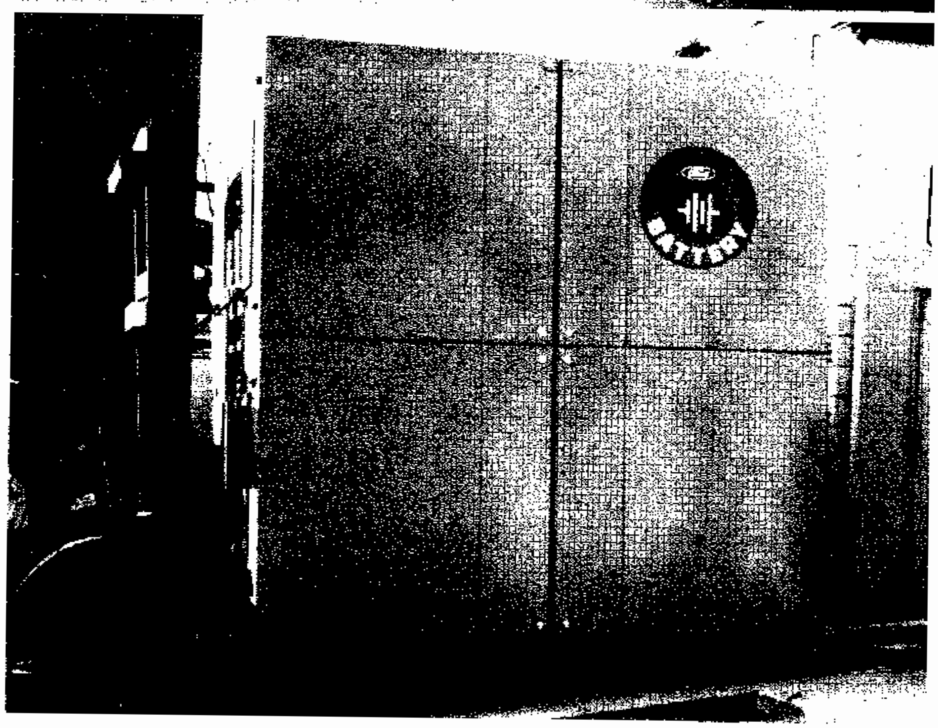
A 300-Wh beta cell constructed by Chloride Silent Power Limited. Inside the 2.5-ft-long (0.8-m) cell, the white beta-alumina electrolyte tube separates the sodium electrode from the sulfur electrode. In this version, the sulfur electrode lies within the electrolyte tube. The 25-kWh battery, fabricated by Ford Aerospace and Communications Corp., has two submodules, electrically in series, each containing sixty-four 200-Wh cells in parallel. The 100-kWh FACC battery, with eight submodules in series, is now being tested—the largest high-temperature operating battery ever built.











THE LEAD-ACID BATTERY

State of the art of large secondary batteries is represented by the lead-acid system. Until now, the rugged and reliable lead-acid battery has been the favored technology for automobiles, mine and tunnel locomotives, and industrial forklifts, as well as backup power for diesel-driven submarines. It also provides standby power in nuclear plants and in circuit breakers, communications, switching, and lighting.

But despite its reliability, it is heavy, bulky, and relatively expensive because of its lead content. Further, lead is a material with limited availability and wide price fluctuations in the current market.

For these reasons, the lead-acid battery does not suit the utility or utility customer market overall, but it can be used in hundreds of specific situations. For example, any utility that today can put batteries to a multiplicity of uses (spinning reserve, system regulation, and VAR control) and is able to defer underground cable installation by siting the battery at carefully selected urban distribution substations, would probably find a lead-acid battery cost-effective. The same applies to small utilities and large industrial customers that have short peaks of five hours or less and high demand charges of $7–$8/kW per month for the electricity they buy. □

Overall, the basic design and operation of a zinc bromide battery are similar to those of the zinc chloride battery. The reactions in a zinc bromide battery take place on opposite sides of a bipolar electrode plate, a thin nonporous carbon sheet. The negative electrode reaction during charge is the deposition of zinc onto one side of the sheet. The positive electrode reaction during charge is the oxidation of bromide ions to bromine, which dissolves in the aqueous electrolyte.

In cell assemblies, a microporous separator between the electrodes reduces the transport rate of bromine from the positive electrode to the negative, where it would otherwise react with the zinc in such a way as to reduce the operating efficiency of the battery. Two separate reservoirs supply electrolyte to each side of the carbon sheet.

In a submodule test, Gould demonstrated the zinc bromide cell's efficiency and reliability in unattended operation. A six-cell 2-kWh submodule has cycled automatically and continuously for 11 months and 700 cycles with energy efficiencies between 55 and 60% and only occasional maintenance. A much larger battery module (10-kW–80-kWh) was successfully tested this summer, demonstrating the ability to scale this battery system to larger sizes.

In the beta battery, energy is stored in the form of molten sodium and sulfur, the electrochemically active negative and positive materials, respectively. During discharge, these materials combine electrochemically to produce sodium polysulfide. To maintain these materials in the molten state and to keep the beta alumina electrolyte sufficiently conductive, the operating temperature of the battery must be kept between 300 and 350°C. Key to the functioning of the beta battery is beta alumina, a solid ceramic material capable of conducting sodium ions, which acts as electrolyte and separator.

The beta cell is still being perfected. Designed as an electrolyte tube within a metal cylinder in which both the tube and cylinder contain an electrode, the cell has presented numerous technical challenges, mostly related to material requirements at the high temperatures needed to keep the sulfur and sodium molten. In particular, the external seal for bonding the sodium and sulfur electrode containers to an insulator posed problems: glass seals were too fragile; mechanical seals, although tough, were short-lived. Eventually, a new type of metal-to-ceramic seal, made possible by use of an aluminum gasket and simultaneous application of heat and pressure on the seal, was developed by one of EPRI's contractors, the Marcoussis Central Research Laboratory of Compagnie Générale d'Electricité.

This thermocompression seal, along with improvements in corrosion resistance of the metallic cylinders and advances in the manufacture of a ceramic electrolyte with good conductivity and high strength and density, has allowed semiautomated production of commercial-size beta cells.

The present major goal of beta development programs is to achieve adequate reliability. Typical cell life is about 500 cycles, about an order of magnitude below the goal. The major culprit is the beta alumina electrolyte. Over the last few years, a great deal has been learned about the chemical and structural properties of the electrolyte. This knowledge is now starting to pay off. British Rail and General Electric have developed electrolytes that are substantially more resistant to degradation. However, it takes many months of testing to validate that cell-life goals are being achieved.

Although some doubt still exists about the level of cell reliability that can be attained with further development, battery performance on the one hand and development of manufacturing processes on the other have been encouraging. Ford, under contract to DOE, has assembled and tested a 512-cell (100-kWh) beta battery. Also, CSP of England has established a complete pilot manufacturing facility that uses a high degree of automation in the production of cells.

Commercial viability

The goal of EPRI's battery development program is successful use of commercially viable battery energy storage systems by the utility industry. Achieving this goal will require that suppliers be confident enough about both the technology and the market to produce batteries for the utility industry. In addition, utilities must be sufficiently confident in the suppliers and in the reliability of the technology to purchase the battery systems.

One problem, as J. R. Birk, manager of EPRI's Energy Storage Program, points out, is that "costs of the new battery systems will not be attractive until several systems are produced and the learning process is well on its way." The learning process involves the lowering of cost with increasing levels of production made possible with more-automated production modes. The relationship between cumulative production volume (and experience) and production costs is called the learning or experience curve. This learning curve has been quantified for many technologies, and based upon the results, an experience factor of about 0.85 is expected for advanced battery systems—meaning that the price, P, will drop to $0.85P$ for each doubling of cumulative production.

Birk points out that the cost of underwriting this learning process is enormous. "Although EPRI can't underwrite these costs," Birk says, "we can catalyze the use of mechanisms where the parties expecting a future economic gain can proportionately share in the up-front costs." The supplier can also take advantage of those early markets and applications where higher costs can be afforded by the utility or its customer.

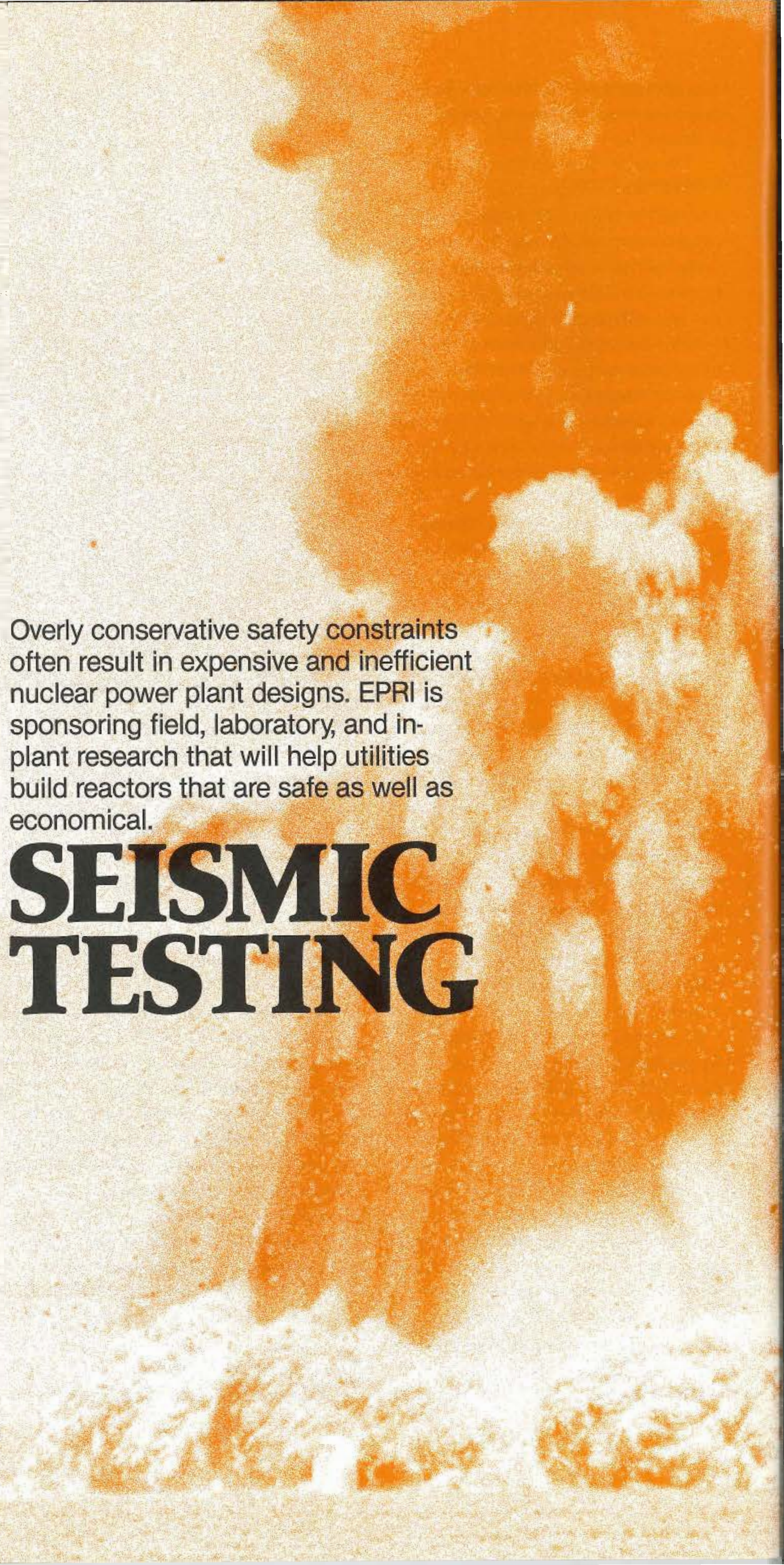
Another major problem is the historic time lag between completion of development and the commercialization of any new technology. In an EPRI commercialization study, Decision Focus quantified this lag as between 8 and 15 years, depending on the type of utility. Largely responsible for this lag is the fact that utilities are not yet confident about key specifications, such as reliability of batteries as a new technology.

Close communication ties and information transfer might be established between the manufacturers, the utility industry, and EPRI to increase the mutual awareness of technical viability, manufacturer capability, market potential, and utility requirements (specifications). As Birk explains, utility requirements are the reason EPRI established the Utility Battery Operations and Applications Team. This group is made up of members from eight utilities that represent about 20% of the nation's generating capacity. The team has begun to evaluate the ways batteries can be used and maintained in a utility system.

In addition to the need for better information dissemination is the need for technology demonstrations. Also important is the need for positive action by utilities and manufacturers to establish acceptable strategies and involvement in the commercialization process.

Using battery storage systems to provide power during peak demand may be one way to reduce oil use for electricity generation. Although present oil stores are up, Birk comments, "The glut of oil we have now shouldn't lull us into inactivity. Unless the utilities, government, and suppliers can develop acceptable commercialization strategies, batteries and other desirable new energy technologies capable of saving oil will never reach the marketplace. If we wait until the oil price justifies conventional private financing in demonstrations, it would take many more years to achieve commercialization and obtain the benefits of new energy storage systems." ■

This article was written by Jenny Hopkinson. Technical background information was provided by J. R. Birk, Energy Management and Utilization Division.



SEISMIC TESTING

Overly conservative safety constraints often result in expensive and inefficient nuclear power plant designs. EPRI is sponsoring field, laboratory, and in-plant research that will help utilities build reactors that are safe as well as economical.

Nuclear power plants are designed and built to withstand major earthquakes. But because there are uncertainties in the limited data on earthquakes and their effect on the interaction between structures and soil, such designs are generally based on overly conservative safety factors. These constraints often result in expensive and inefficient designs.

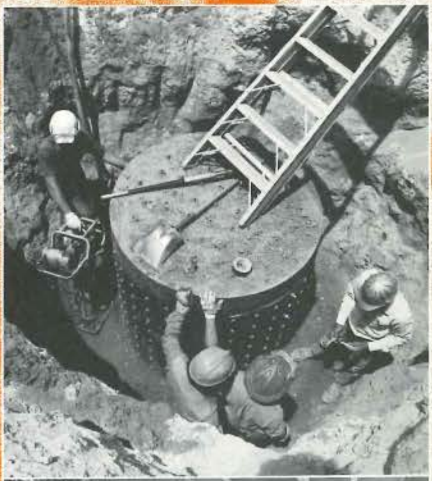
For more realistic and better-qualified earthquake design guidelines, EPRI has undertaken a number of projects that may result in eliminating unnecessary and costly conservatism and help satisfy licensing requirements for new and existing plants. Using controlled explosive tests, shake tables, and pipe vibration studies, EPRI plans to develop a data base and design tools that will help utilities build nuclear power plants that are safe as well as economical.

Simulated earthquake tests

One of the most important aspects of earthquake study is how buildings respond to ground motion. To study this phenomenon, EPRI sponsored a series of explosive tests, which were carried out in the spring of 1977 at the University of New Mexico's McCormick Ranch test site near Albuquerque, New Mexico. These tests, conducted by the university, Civil Systems, Inc., and Anco Engineering, Inc., were designed to measure soil response to ground motion and the interaction between the soil and a structure during strong ground motion. The objective of these tests was to assess the interrelationship of earthquake ground motion, local soil and geologic conditions, and a structure's response.

The test procedure was to construct arrays of explosives in the ground so that detonating them would give the desired amplitude and frequency in ground motion. Model structures of different sizes were constructed and embedded to various depths in different soil types. Investigators monitored the motion produced in the soil at a distance from the model structures and near the structures to

Field simulations of earthquake tremors are being used to study the interrelationship of ground motion, local soil and geologic conditions, and the structural response of nuclear plant containment buildings. Arrays of explosives are employed to create the seismic disturbance, and the containment structures are modeled at scales of 1/8, 1/12, 1/24, and 1/48.



assess the soil-structure interaction.

The first of these experiments consisted of three events: mini-SIMQUAKE, SIMQUAKE IA, and SIMQUAKE IB. Mini-SIMQUAKE was a small-scale experiment: 450 lb (204 kg) of explosives arranged in two arrays were fired to evaluate the use of explosives in sequence to extend the duration of the ground motion. This test, a verification of the procedure before the main test, was fired on March 8, 1977.

The main SIMQUAKE event was a large-scale experiment consisting of two arrays of explosives that totaled 70 t (63.5 Mg). Each array was 200 ft (70 m) long, 75 ft (23 m) deep. The arrays were 100 ft (30 m) apart, and the front one was about 120 ft (37 m) from the closest structures. The front array was to have fired 1.5 seconds after the back but did not because of a firing system malfunction. The back array of 40 t (36.3 Mg) was fired at the scheduled test time on May 17, 1977, and this event is called SIMQUAKE IA. The front array firing—called SIMQUAKE IB—occurred on June 22, 1977. The two firings resulted in complete sets of data on two different levels of ground motion measured with accelerometers and velocity gages at various ranges and depths.

These explosive tests were carried out on five model structures. The largest one, $\frac{1}{12}$ the size of a generic concrete containment vessel, was embedded to 25% of its height in recompacted dry alluvium native to the area. Three of the structures were $\frac{1}{24}$ the size of a containment structure. Of these, one was buried under an amount of soil equal to its height. The other two were embedded to 25% of their height, one in native soil and the other in sand. The fifth model was $\frac{1}{48}$-scale and buried to 25% of its height in the native alluvium.

The explosions created strong ground motion, which caused several of the structures to rock nonlinearly; that is, the models' responses were not directly proportional to the motion in the ground created by the explosions. Cavitation—the formation of cavities or voids in the soil—was one of the major causes of the strong nonlinear response, which resulted when the motion of the structure beat the embedding soil back, breaking the contact between structure and soil. This nonlinear soil-structure interaction reduced the $\frac{1}{12}$-scale model structure's low-amplitude frequency severalfold, from 16 Hz to 5–8 Hz in SIMQUAKE IA, which produced about 1 G of excitation, and to 2–4 Hz in SIMQUAKE IB, which produced about 2.5 G of excitation. These findings are significant for defining reactor components' response to strong earthquake motion.

To find out how the models responded to multiple ground motion cycles and to cycles of extended duration, investigators carried out a second experiment, SIMQUAKE II. The SIMQUAKE II test included a larger model structure ($\frac{1}{8}$-scale) and additional tests to measure movement. A tank of water was placed in one model to measure fluid-structure interaction. A duplicate $\frac{1}{12}$-scale structure was embedded at a different distance from the explosives. In this way investigators could observe the behavior of the same structure at different amplitudes as the motion passed through the soil. And another of the structures was mounted on rubber bearings, which absorbed the energy of the motion. These bearings tested the effect of isolating buildings from ground motion.

The array sizes and explosive amounts were about the same as those used in SIMQUAKE IA and IB. However, special precautions were taken to ensure that both arrays would fire at the required time. For the largest model, the $\frac{1}{8}$-scale, SIMQUAKE II produced 1 G of excitation and reduced the rocking frequency from 12 Hz to about 2 Hz.

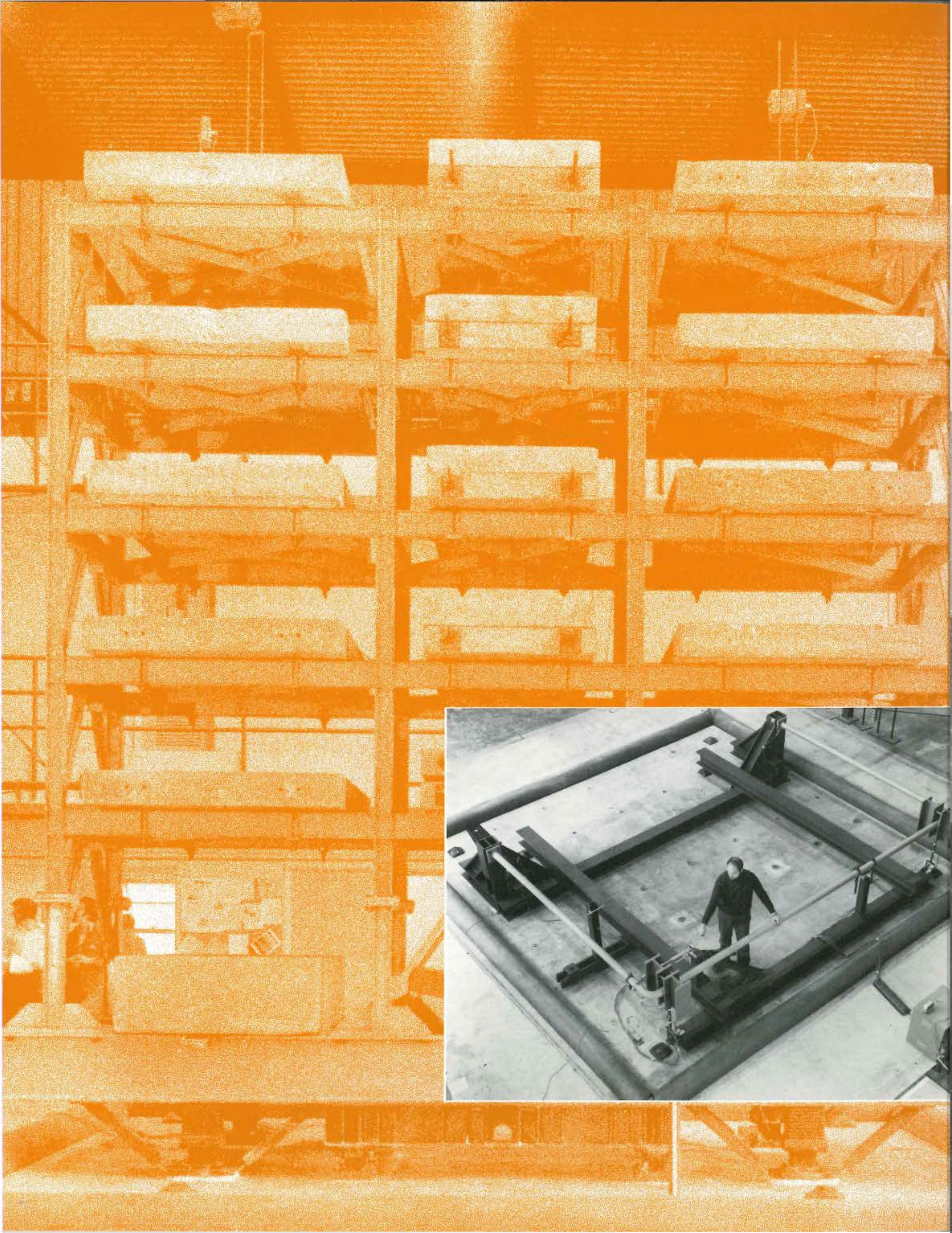
In all the experiments, instruments were placed in the free field (away from the structures) and in the near field (near and in the structures). The free-field measurements were of horizontal, vertical, and transverse ground motion acceleration and velocity. Near-field measurements included these as well as angular displacement and stress on the front, rear, and base faces of the structures. A few soil stress measurements were also taken in the near field. Array detonation, structure motion, and fluid motion were also recorded by high-speed photography.

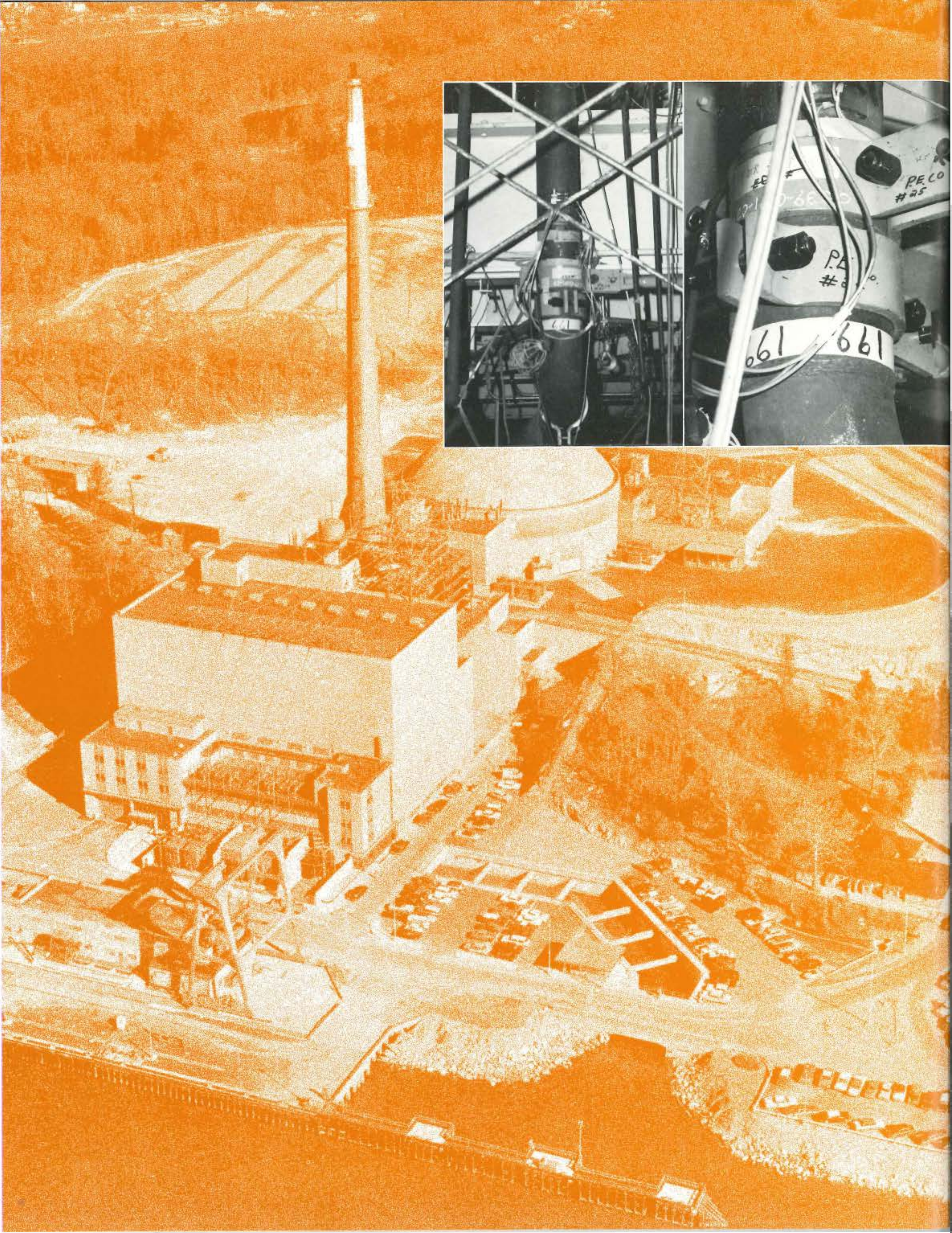
These simulated ground motion experiments have yielded important information by which nonlinear soil-structure interaction behavior and parameters can be identified and better understood. Both $\frac{1}{8}$- and $\frac{1}{12}$-scale data have been used to qualify the STEALTH–SEISMIC code for full-scale nonlinear soil-structure interaction studies of nuclear power plants.

In addition to studying soil-structure interaction, researchers are interested in separating structures from ground motion. At the University of California at Berkeley, a device called a shake table is being used in an attempt to determine ways of isolating individual structure response from ground motion.

The shake table is a large concrete slab mounted on a device that can shake the slab horizontally and vertically, simulating earthquake ground motion. A frame representing a structure is mounted on multilayered rubber bearings, which, in turn, are mounted on the table. When the

In the laboratory, tests are being performed to determine ways of isolating containment structures from earthquake ground motion. A frame representing a structure is mounted on multilayered rubber bearings, which absorb horizontal and vertical vibrations induced mechanically in a concrete shake table.

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The response of reactor piping systems to seismic movement is being studied in actual reactor settings. Forced vibration and snapback tests are being used to obtain data on vibration frequencies, damping effects, and pipe support characteristics.

table is shaken, the multilayered bearings, which can sustain large shear deformation, absorb the energy of the motion and reduce the frame's response to the motion.

In addition to laboratory testing, this device was field-tested at the New Mexico test site during SIMQUAKE II with a model $\frac{1}{48}$ the size of a containment structure. In this test, the "table" was the ground, which was shaken by the explosives.

Other UC laboratory shake table experiments include tests of pipe systems with multiple supports to evaluate the response of the pipes as well as pipe-structure interaction.

Pipe tests

Other pipe tests are being carried out in an actual reactor setting. There are about 23 miles of pipe in a light water reactor, and the cost of designing, installing, and maintaining this labyrinth is 10–15% of the cost of a nuclear power plant. Therefore, understanding such an intricate system's response to vibration and movement is necessary to avoid inefficient and expensive overdesign and retrofit. To this end, several tests were conducted at Consolidated Edison Co.'s Indian Point-1 plant by Consolidated Edison, Philadelphia Electric Co., Anco Engineering, and EDS Nuclear, Inc.

These tests—on the 8-in-diam feedwater pipeline—were carried out in three phases. The pipe was tested in May and June 1979 as it had originally been designed, constructed, and licensed for operation. One method of testing was a snapback test, in which the pipe was pulled and suddenly released. This action creates a transient and allows the investigators to study the damping effects of the pipe as it returns to a steady state.

Forced vibration tests were also conducted. In these tests a vibrator was mounted for continuous input, and the frequency and amount of force applied were measured over time. In addition to measuring damping effects, these tests studied the response of the pipe systems to various pipe frequencies and forcing levels and the characteristics of various supports.

The second phase of the piping tests was similar to the first except that the pipe insulation had been removed. Twenty snapback tests were performed on these noninsulated pipes. The anchors and support systems were the same.

The third test phase was between August and December 1980. Original restraints and supports were replaced by various modern systems, such as mechanical or hydraulic snubbers. The objective of this phase was to better understand how modern restraints contribute to damping and to piping system response. This experiment also included both snapback and forced vibration tests.

Model development

The data obtained from the explosive experiments are being used to test the simulation capabilities of the existing computer codes FLUSH, TRANAL, and the EPRI-funded STEALTH–SEISMIC. The data have yielded significant information on model responses and the limitations of certain linear models in nonlinear simulations.

New codes are being developed to expand simulation capabilities. One such code is ABAQUS–ND, a nonlinear dynamic finite element computer program. Among its capabilities is analysis of pipe whip design to determine the structural response of the pipe under a hypothetical rupture situation. This code is also being used to further analyze seismic design of pipe systems where the number, placement, type, and mechanical property of supports are critical reactor design parameters for determining piping response. The ABAQUS–ND capabilities are being expanded to apply to other components in the nuclear power plant.

Although nuclear power plants are built to withstand a major seismic event, overly conservative safety features often result in inefficient and expensive designs. A greater understanding of design constraints can be made possible by more sophisticated testing and modeling. Improved design methods based on experimental and analytic findings are an important key to providing safe and economical nuclear reactors, which are an essential element in the continued generation of reliable low-cost electricity. ■

Further reading

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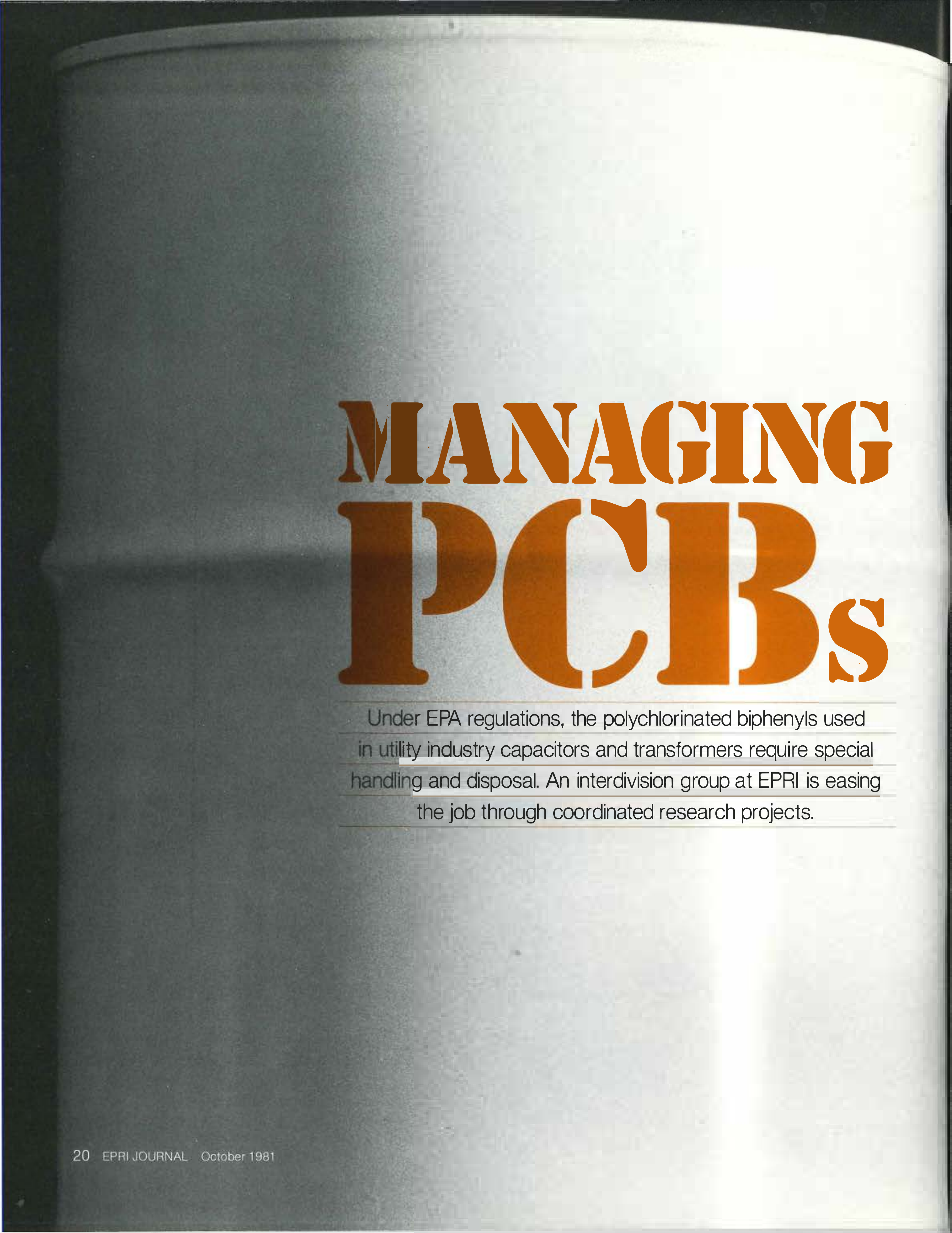
This article was written by Suzanne Knott, science writer. Technical background information was provided by H. T. Tang, Nuclear Power Division.



MANAGING PCBs

Under EPA regulations, the polychlorinated biphenyls used in utility industry capacitors and transformers require special handling and disposal. An interdivision group at EPRI is easing the job through coordinated research projects.

Over a period of 40 years, organic compounds known as polychlorinated biphenyls seemed an ideal choice for insulating electric utility capacitors and transformers. PCBs boasted attractive dielectric properties, fire resistance, and chemical stability. They were used in millions of capacitors and in thousands of transformers. Then, in 1976, the Toxic Substances Control Act was passed; TSCA identified the all-too-durable PCBs as environmental contaminants. Further manufacture of PCBs was subsequently banned, although the continued use of PCBs in a totally enclosed manner, such as in transformers and capacitors, was permitted. Some 750 million pounds of PCBs are still in functioning electrical equipment, most of it in the utility industry. The industry must now comply with EPA regulations that require close management of PCBs, including record keeping, spill cleanup, storage, and disposal.

Cost to the industry

PCB management will take time, effort, and money on the part of the utility industry. What must now be ensured is that these resources are used efficiently. The Edison Electric Institute is currently trying to develop exact cost estimates for PCB management. Although EPRI has not conducted such a study, Narain Hingorani of EPRI's Electrical Systems Division roughly estimates that proper disposal and handling of PCBs in accordance with current EPA regulations could cost the industry approximately $5 billion over the next 10 years. This estimate does not include replacement costs for PCB capacitors and transformers.

EPA regulations divide PCB materials into two distinct categories: PCB equipment and PCB-contaminated equipment. PCB equipment is that which contains PCB concentrations of over 500 parts per million. PCB-contaminated equipment contains 50–500 ppm. Concentrations lower than 50 ppm are not regulated.

As much as half a billion dollars could go to disposal and spill cleanup of PCB capacitors and PCB transformers under current regulations, ventures Hingorani. This equipment contains insulating fluid with PCB levels over 500 ppm, and these higher concentrations are subject to the strictest of EPA regulations. The number of PCB capacitors and transformers now in service is uncertain, and EEI is attempting to inventory this equipment.

A larger part of the PCB management budget—nearly $5 billion, Hingorani estimates—could go toward the identification and reclamation of the estimated 2.5 million PCB-contaminated transformers that may contain 50–500 ppm PCBs in their insulating oil. Although many transformers use ordinary mineral oil as insulating fluid, some may have been contaminated with PCBs during servicing.

A multi-billion-dollar budget for PCB management puts significant demands on utility industry financial resources. The cost will be still greater if EPA revises the maximum allowable limit on PCB concentrations to below the present 50 ppm. Pending any changes in the PCB limits, utilities are complying with existing regulations. It is possible, however, that ongoing EPRI R&D may provide a way to pare down the bill.

To rapidly advance PCB R&D, EPRI has established an interdivision PCB working group with members from three of the Institute's technical divisions: Electrical Systems (ES), Coal Combustion Systems (CCS), and Energy Analysis and Environment (EAE). Organized about one year ago, the group is coordinating a $7 million budget for PCB research over the next five years. The ES Division is concentrating its efforts on detection, removal, and destruction of PCBs in functioning utility equipment; the CCS Division is focusing on PCB spill cleanup and final PCB destruction or disposal; the EAE Division is evaluating the health effects of PCBs. Hingorani is group chairman.

Detection and destruction

Among the most urgent research requirements of the utility industry is a quick, inexpensive way of identifying PCB-contaminated transformers, which, like PCB equipment, are subject to disposal regulations. Hingorani suggests that perhaps 5% (1.5 million) of distribution transformers and about 20% (1 million) of power transformers filled with mineral oil may be contaminated with PCBs in the 50–500 ppm range. But EPA considers all mineral oil transformers to be PCB-contaminated (50–500 ppm) unless tested or otherwise proved to be non-PCB equipment.

Commercial gas chromatography can identify PCB levels in transformer oil, but the process is inconvenient, time-consuming, and expensive. Samples of transformer oil must be drawn in the field, then sent to a laboratory for examination by skilled technicians. It costs $50–$100 to test each sample, and more than one sample may have to be tested to make a positive identification. To test every transformer suspected of PCB contamination might cost the industry as much as $2–$3 billion, estimates Hingorani.

A portable inspection device that could quickly and inexpensively identify PCBs in transformer oil might reduce the cost of detection to as low as $500 million. EPRI's ES Division is now developing such a device. Project Manager Vasu Tahiliani explains that under EPRI contract, General Electric Co. scouted other industries for applicable devices and found that the oil industry uses an X-ray fluorescence instrument from Horiba Instruments, Inc., to measure undesirable sulfur content in oil. Chlorine atoms in PCB respond similarly to X rays, so on General Electric's recommendations and specifications, Horiba modified the device to measure chlorine to the required sensitivity.

General Electric is now using the device to test thousands of samples of PCB-contaminated oil, evaluating how well its chlorine analysis correlates with PCB analysis by standard gas chromatography. The device, which consists of a portable analyzer and a portable data processor, will soon be taken to the Salt River Project's service area for field testing and evaluation.

Because the new device measures chlorine rather than PCBs directly, some transformer oil samples may require retesting in laboratories by conventional gas chromatography. EPRI ultimately plans to develop a more advanced device that measures PCBs explicitly; the ES Division is now exploring possible research in that area.

Once utilities have identified PCB-contaminated transformers, the contaminated oil could certainly be drained and destroyed and the transformers refilled with fresh insulating fluid. But transformer-quality naphthenic oil may not be available in sufficiently large quantities to replace all the contaminated oil at once, according to Project Manager Gilbert Addis. And because stringent requirements apply to the incineration or the landfill disposal of PCB-contaminated oil, large-scale incineration or landfill disposal programs may be impractical. Instead, utilities might reduce the level of PCBs in transformer oil to below the regulated limit. This could be accomplished by either destroying the PCBs in the oil in situ or extracting them from the oil for later destruction. The purified oil might then be reused in transformers, assuming no oil degradation or further contamination takes place.

Commercial methods of reducing PCBs to acceptable concentrations are not readily available, however. PCB compounds are both remarkably stable and similar in physical properties to the transformer oil with which they may be mixed. As a result, they resist both destruction and extraction. Only recently have several processes emerged that are potentially suitable for destruction or extraction. The ES Division has singled out several of the most promising techniques and is assessing them to see if any are appropriate for the utility industry. Addis notes that the largest EPRI contract for PCB destruction and extraction is with General Electric, which is researching two processes for PCB destruction and two for PCB extraction. Based on transportability, operability, downtime requirements, and other considerations, General Electric will select the best of the four processes for scale-up to a demonstration project at a later date.

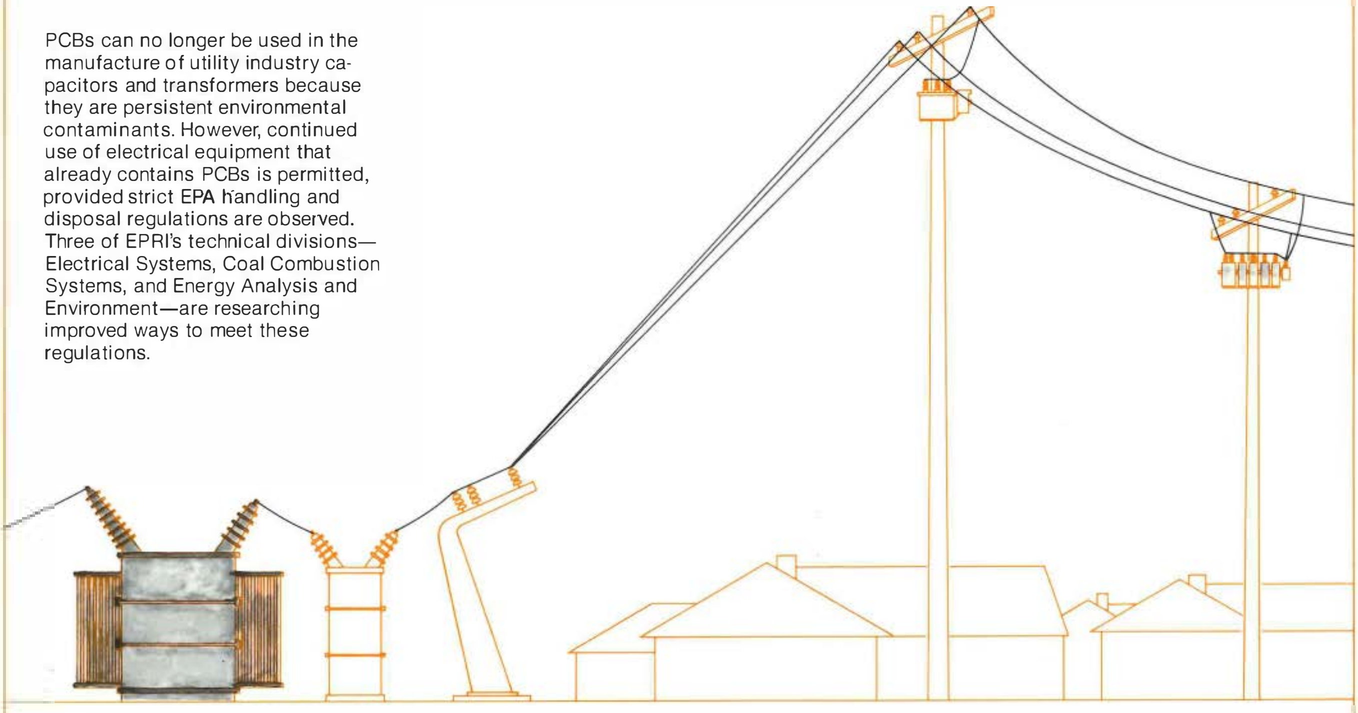
The first PCB destruction process employs electron-beam irradiation to decompose PCBs by breaking off chlorine atoms from the compound. The second process uses a sodium reagent for dechlorination. One extraction process is a liquid-liquid extraction; the other process is a supercritical fluid-liquid extraction. Yet a third extraction process is being researched by Franklin Research Center; in this process, the PCB in the extracting solvent would be destroyed or removed by a second solvent.

Once PCBs are destroyed or extracted from transformer oil, there is no guarantee that the treated oil will be suitable for reuse in a transformer. The sodium destruction process, for example, might leave behind by-products that could lead to transformer failure. Similarly, extraction processes might leave behind harmful traces of extractant or remove chemicals essential to the oil's dielectric qualities. General Electric will study the long-term effects of these processes to be certain that PCB destruction or extraction does not leave the oil unsuitable for return to a transformer.

The four processes that General Electric is studying are all performed while transformers are shut down. But downtime is inconvenient for utilities. RTE Corp. has developed a process that can be used while a transformer is in operation. The process reportedly requires several months to reduce the PCBs in a transformer by a significant amount. Through an ES project, RTE researchers are checking to see if this procedure can be accelerated. The project will also determine the rate at which PCBs concentrated in the transformer core will leach out to recontaminate the cleaned oil.

PCB RESEARCH REQUIREMENTS . . . AND WHAT EPRI IS DOING ABOUT THEM

PCBs can no longer be used in the manufacture of utility industry capacitors and transformers because they are persistent environmental contaminants. However, continued use of electrical equipment that already contains PCBs is permitted, provided strict EPA handling and disposal regulations are observed. Three of EPRI's technical divisions—Electrical Systems, Coal Combustion Systems, and Energy Analysis and Environment—are researching improved ways to meet these regulations.



- EPA assumes that all mineral oil transformers are PCB-contaminated (50–500 ppm) unless proved otherwise, but conventional laboratory tests for PCBs are costly and time-consuming. EPRI is developing a portable device that can quickly test transformers for PCB content.

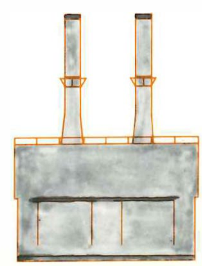
- Draining and destroying PCB-contaminated oil from transformers and refilling the transformers with non-PCB oil may be impractical for a variety of reasons. Instead, utilities may be able to reduce PCB levels with techniques under development by EPRI.

- Without a field instrument to detect soil PCB levels, utilities often resort to laboratory tests to meet cleanup requirements. Research for a device that can detect soil PCB levels in the field is under way at EPRI.

- PCB spill cleanup and disposal can be complicated and costly; a series of EPRI handbooks provides utilities with information about their options.

- EPA regulations require that PCBs at spill sites be reduced to concentrations of less than 50 ppm. EPRI is beginning research on a technique for decomposing spill residues on site.

- Spills from PCB capacitors can be expensive to clean up. EPRI is investigating techniques to identify capacitors with incipient faults and thus avert spills.



- PCB wastes of over 500 ppm must be destroyed in special high-temperature incinerators, but few facilities are licensed for this. EPRI sponsored a test burn at one such facility and is planning further disposal R&D.

A seminar to review detection and destruction techniques for PCBs in utility equipment is being planned by EPRI for this December; Addis is seminar coordinator.

Capacitors are another area of the ES Division's PCB research. Most capacitors manufactured before 1977 are known to contain PCBs over 500 ppm. Researchers are trying to find a way to anticipate failure in PCB-filled capacitors because when these capacitors do fail, they sometimes rupture and spill PCBs over the immediate area. Cleanup costs for a capacitor spill are high and may result in an annual cost to the industry exceeding several million dollars. Yet because capacitor manufacturing capability is limited, as is PCB-capacitor storage and disposal, utilities cannot replace all PCB capacitors overnight with non-PCB capacitors.

As a possible alternative, EPRI and Westinghouse Electric Corp. are investigating the feasibility of several devices that identify capacitors with incipient faults. Field and factory data indicate that weeks to months may go by before a partial electrical discharge results in an internal failure large enough to rupture a capacitor. If a utility had a device that could alert it to partial discharges, units with incipient faults could be replaced prior to rupture, and the number of capacitor spills could be minimized.

One device being considered is an acoustic detector that senses partial discharges. A partial electrical discharge in a capacitor produces gas that in turn can lead to capacitor rupture. Since partial discharges typically emit ultrasonic sound, acoustic detectors for partial discharges could alert utilities to capacitors that are about to fail.

Another device is an infrared scanner equipped with an optical display. Because a capacitor approaching failure would probably be at a higher temperature than its neighboring capacitors, the infrared scanner could pick it out, according to Project Manager Robert Tackaberry.

Once Westinghouse has completed its review of these and other fault-detection devices, the most successful of them will be installed in a van for field-testing on more than 1000 capacitors at a cooperating utility. The van and contents are expected to be ready early next year.

Spill cleanup and disposal

PCB spill cleanup and disposal are other areas where utilities would be greatly aided by additional research. Although EPA regulations generally permit contained PCB or PCB-contaminated equipment to remain in service, sooner or later utilities with such equipment must handle those PCBs. Assuming no spill occurs during operation or maintenance, the equipment eventually wears out and has to be retired and disposed of.

PCB spill cleanup and PCB disposal can be complicated and costly for utilities, according to Program Manager John Maulbetsch. EPA regulations require, for example, that PCBs spilled on earth, concrete, or other surfaces must be reduced to concentrations of less than 50 ppm. PCB liquids and capacitor wastes of over 500 ppm must be burned in EPA-approved high-temperature incinerators.

Because the complete sweep of PCB regulation can be both confusing and costly, EPRI's CCS Division (with support from the EAE Division) has developed a series of handbooks to provide information about cleanup and disposal options. The first handbook, *Disposal of Polychlorinated Biphenyls and PCB-Contaminated Materials* (prepared by Stearns, Conrad, and Schmidt Consulting Engineers, Inc.), gives utility engineers general information on PCB production and use, details on present and proposed regulation, projected requirements for disposal capacity, and an overview of available incineration and landfill technology.

The second and third handbooks provide guidelines on how to develop spill-prevention techniques and countermeasure control plans to ensure that risks associated with PCB activities are minimal. Included are model operation plans that address assembly and servicing of PCB-filled components, proper use and maintenance of these components, and containment procedures for preventing and confining accidental releases. All handbooks are available from Research Reports Center, according to Project Manager Dean Golden.

Besides developing guides to spill cleanup and disposal, the CCS Division has been working on cleanup and disposal techniques. One key project is the development of an instrument capable of measuring soil PCB levels in the field. At this time, according to Project Manager Ralph Komai, no field-usable instruments are available that can do this job. When a spill occurs, soil in the immediate area is removed. Commonly, samples of the remaining soil are taken to a laboratory for analysis to see if the spill has been cleaned to legal limits. Typically much more soil is removed than would be necessary if a field-usable detection method were available.

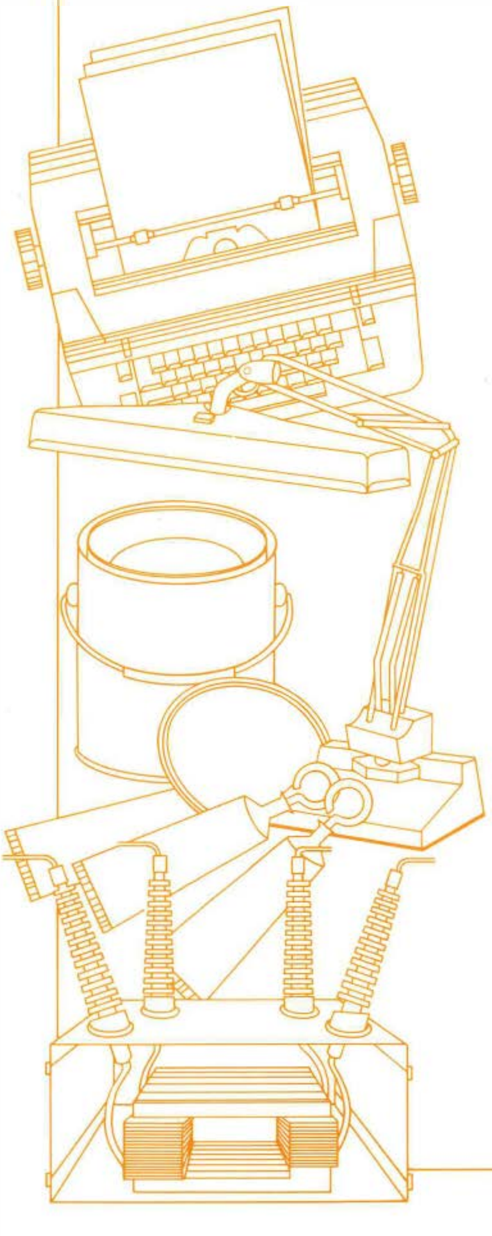
PCB detection costs vary, depending on spill size and extent, but represent a significant annual expenditure to the industry. A portable instrument that could perform inexpensive, on-the-spot analysis would greatly simplify spill cleanup. This type of instrument must be sensitive enough to detect the many regulated PCB compounds, yet not so sensitive that other substances in the soil can obscure the analysis. EPRI is developing such a device with Oak Ridge National Laboratory. One approach is to extract PCBs from soil samples and analyze them on location. The other approach is to vaporize oil from soil samples in a portable chamber, then ionize the vapors with an ultraviolet lamp; the level of ionization indicates the amount of PCB present. The ORNL project is expected to be completed later this year, and the resultant prototype will be made available to interested utilities for field-testing.

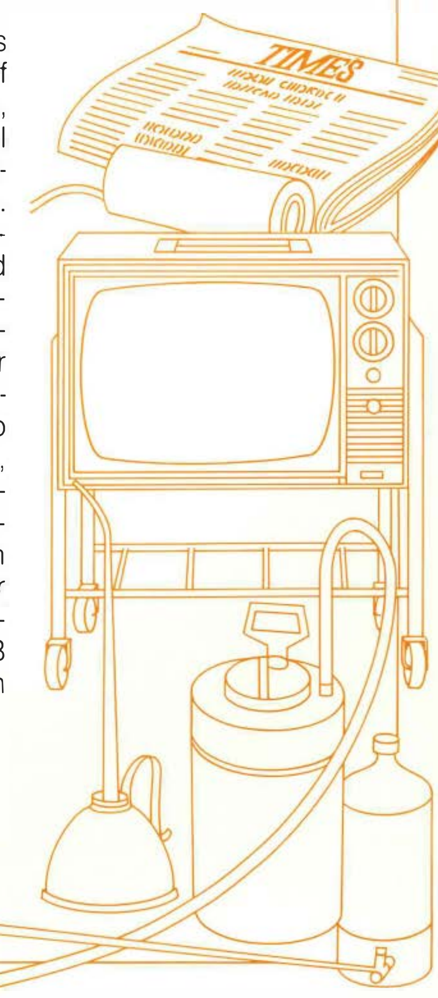
Other important CCS Division work in spill technology is development of a treatment that will quickly decompose or remove PCB spill residues on such surfaces as soil or cement. Such a treatment would eliminate the necessity of having to ex-

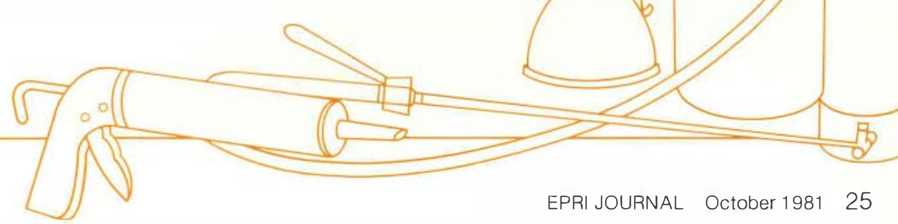
UTILITY ROLE IN PCB MANAGEMENT

From 1929 to 1977, 1.4 billion lb (635,026 Mg) of PCBs were manufactured in the United States and routinely used for applications that included electrical equipment, plastics, adhesives, lubricants, carbonless copying paper, and inks. A small percentage of that amount was eventually destroyed; close to half of it was buried in landfills, escaped into the environment, or exported and is not addressed by EPA regulations. But over half of it—some 750 million lb (340,193 Mg)—is still in service, practically all in sealed electrical equipment. Electric utilities have a large part to play in the management of these PCBs.

According to preliminary estimates made by Narain Hingorani, chairman of EPRI's interdivision PCB working group, perhaps 25% of the PCBs in electrical equipment are in small capacitors in fluorescent lights, motors, and appliances. Somewhat less than 40% are in large capacitors, most of which are in utility and industrial jurisdiction and can be retrieved; about 40% are in PCB transformers, most of which are also in utility or industrial jurisdiction and can be retrieved. And about 0.05% is believed to be in PCB-contaminated transformers, which are essentially filled with transformer oil. Ironically, this 0.05% in contaminated transformers is mixed with billions of pounds of valuable transformer oil; finding and retrieving it may cost utilities far more than the retrieval of the PCB capacitors and transformers that contain higher concentrations of the compound.







cavate contaminated soil or debris and later dispose of it at approved landfills. Through a newly negotiated contract, Battelle, Pacific Northwest Laboratories is evaluating proprietary chemical treatments that promote accelerated photodecomposition of PCBs. The CCS Division is planning to explore other methods as well, including application of a poultice-like substance to PCB-contaminated areas at spill sites. The substance would dissolve PCB residues in a volatile solvent, then adsorb them as the solvent vaporizes. The substance and the entrapped PCBs could then be removed, possibly in the form of a dry powder.

Disposal options are another area on the CCS Division's PCB research list. These options are limited at this time. EPRI sponsored a test burn at the Energy Systems Co. (Ensco) incinerator in El Dorado, Arkansas, to see if this facility could incinerate PCB wastes in accordance with EPA regulations. The burn, which took place in 1979, included liquid PCBs drained from transformers, as well as shredded capacitors. (Because most of the PCBs in capacitors are absorbed into the capacitor's paper insulation, capacitors cannot be easily drained and so are shredded and fed into incinerators.) The test showed incineration at the Ensco facility was highly efficient: samples from the incinerator's stack, scrubber, and ash were analyzed for PCBs. Only in the ash were PCBs confirmed and those were at levels below regulation. The Ensco facility subsequently received EPA approval for PCB incineration, making it the second of two facilities in the nation to be approved for liquid PCB incineration and the only facility to be approved for solids shredding and incineration. The cost of destruction of PCB liquids ranges from $500 to $650 per 55-gal drum.

Meanwhile, the CCS Division is investigating alternative ways to dispose of solid PCB materials, such as capacitors, to expand the range of utility options. Rather than shred and incinerate this equipment, chemical processes that extract the PCBs for later incineration might be developed, and the division is planning to fund research in that area later this year.

Health effects

Beyond PCB detection, destruction, spill cleanup, and disposal, still another area of PCB research is basic to the utility industry: health effects, particularly occupational health effects. The utility personnel who service transformers, clean up capacitor spills, and ultimately retire this equipment from service must be assured that work practices protect them from any potential risks from PCBs. Utilities must also be confident that current practices protect the general public.

However, as with most low-level exposures to contaminants, the PCB risk to humans has not yet been exhaustively investigated. Explains Walter Weyzen, EAE project manager, "The immediate toxic health effects of undiluted PCBs in animals have been well documented. Similar health effects in humans were observed following ingestion of relatively large amounts of PCB-contaminated rice oil in Japan. The results of animal studies indicate that pure PCBs have a low toxicity but some PCB contaminants or reaction products are potent toxicants.

"However, the possible long-term health consequences of PCB exposure have been less well documented. Results of some animal studies appear to suggest that PCBs at high levels of exposure are either carcinogenic or promote the carcinogenicity of other chemicals. The important question for utilities, their employees, and the public is whether low-level exposures pose risks to humans. Epidemiologic studies of humans, accidentally or occupationally exposed, have not demonstrated PCB-associated cancer, but many more years of observation are desirable to confirm such findings," concludes Weyzen.

Epidemiologic studies require detailed information on well-defined and statistically significant population samples over long periods of time. But retrospective studies are difficult to accomplish because exposure and health records of adequate quality may not exist. If a small risk from very low levels of PCB exposure exists, it will take records on a very large number of potentially exposed persons to conclusively demonstrate the presence or absence of health risks.

EPRI's EAE Division, with the cooperation of six utilities, is now attempting to see if a study of PCB-exposed utility employees is feasible. If the study reveals that sufficient information is available, a study of workers exposed in the past might be undertaken by EPRI, according to Weyzen.

Meanwhile, the EAE Division is planning a PCB workshop for utility health and safety personnel. The workshop, tentatively scheduled for this fall, would present the latest information on the potential health risks of occupational PCB exposure. Industrial hygiene, work practices, and legal and regulatory issues will also be discussed. Workshop attendees can use this information in their own utility information programs. Weyzen is workshop coordinator.

The utility industry must make sure that PCB substitutes are environmentally acceptable. The EAE Division is planning a two-year project that will provide basic health and environmental information on PCB substitutes used in utility equipment. This study is expected to begin in 1982.

Without a doubt, the utility industry's continued management of PCBs will require time, effort, and money. But through coordinated research, those inevitable expenditures can be significantly reduced. The trilateral effort of EPRI's three divisions on the PCB problem should yield results that will make the industry's effort easier.

This article was written by Nadine Lihach. Technical background information was provided by Narain Hingorani and Gilbert Addis, Electrical Systems Division; John Maulbetsch and Ralph Komai, Coal Combustion Systems Division; and Walter Weyzen, Energy Analysis and Environment Division.

Federal Energy Advisory Committees

Composed of nongovernment volunteers, federal advisory committees make the knowledge of outside experts available to government decision makers. In terms of energy policy, advisory councils have already played a strong role.

Bargains are not often found in federal spending, but the use of advisory committees provides the government with expert advice at moderate expense. Federal advisory committees are composed of nongovernment experts and public representatives who volunteer their time to investigate a specific issue or provide broad policy advice. This advice can take the form of commentary during committee meetings or extensive reports, such as the Kemeny commission report on Three Mile Island.

A number of EPRI executives have contributed their expertise to government advisory committees. EPRI President Floyd Culler was deputy chairman of the panel on supply and delivery for the Committee on Nuclear and Alternative Energy Sources of the National Academy of Sciences; Richard Balzhiser, vice president for R&D, has served on the Department of Commerce's Technical Advisory Board; and Vice Chairman Chauncey Starr is a member of the Office of Technology Assessment's Energy Advisory Committee.

In order to provide for greater public participation in the deliberation of advisory committees, Congress passed legislation in 1972 outlining committee requirements. The Federal Advisory Committee Act (Public Law 92-463) provides for public notice of the meetings of any advisory committee and for public access to committee records. The law also states that interested people may attend meetings and appear before or file statements with any federal advisory committee. The Committee Management Secretariat, now part of the General Services Administration, was established to oversee the operations of all the advisory groups. Also, the president is required to make an annual report to Congress on the groups' activities.

The latest annual report shows that of the 974 councils in existence during 1980, 109 completed their work or were terminated by the end of the year. Most of the remaining 865 are concentrated in a few departments or agencies. The Department of Health and Human Services reported the largest number of advisory committees, 237, and the Department of the Interior ranked second with 131. The Department of Energy reported 16 councils in existence in 1980.

A look at the activities of some past energy advisory councils lends an understanding of their influence on energy policy, and a focus on some current advisory committees shows their impact on the energy decisions of the present administration.

Ad Hoc Committees

Federal energy advisory councils can be authorized by law, established by an agency request, or created by presidential directive. Ad hoc committees perform a specific task or look at a specific issue and then disband, usually releasing a report that states their conclusions and recommendations. A few of these reports have become classics of energy literature.

The Committee on Nuclear and Alternative Energy Sources (CONAES) was formed in 1975 under an agreement between the Energy Research and Development Administration (ERDA) and the National Research Council, the operating arm of the National Academies of Sciences and Engineering. The administrator of ERDA, Robert Seamans, wrote to the academies in 1975 requesting "a detailed and objective analysis of risks and benefits associated with alternative conventional and breeder reactors as sources of power." The Governing Board of the National Research Council decided that it would be more appropriate to look at the role of nuclear power, including breeder reactors, in the context of alternative energy systems; this expanded topic proved acceptable to ERDA.

When CONAES was formed, it consisted of 16 volunteer members selected by the National Research Council. Because of the private status of the National Research Council, its study committees are not subject to the dictates of the Federal Advisory Committee Act as are committees of federal agencies. The original 16 members were responsible for the study's conclusions, but by the time the report was released to DOE in December 1979, four major panels supported by 22 resource groups had been created. In all, nearly 300 people contributed to the CONAES study.

The final report, *Energy in Transition: 1985–2010*, was the product of four years of research and $4.1 million. The report analyzed the state of the art of alternative energy technologies and compared their associated risks and impacts. It concluded that the only choice open to the nation to meet near-term electricity demands is to burn coal and build nuclear plants, but it also emphasized that energy efficiency must be a high priority. Harvey Brooks, chairman of the committee and former dean of engineering at Harvard, stated in the report's cover letter that the most vital of the study's observations "is the importance of energy demand considerations in planning future energy supplies." The CONAES report, released to the public in March 1980, is probably the most detailed energy analysis published by the U.S. government to date.

Another energy advisory group supported by the U.S. government and administered by the National Research Council was the Committee on the Biological Effects of Ionizing Radiation (the BEIR committee). This committee was formed to prepare a study requested by the Environmental Protection Agency's Office of Radiation Programs to update an earlier study. When commissioning the new study in the fall of 1976, EPA instructed the committee to obtain current information relevant to an evaluation of the effects of human exposure to low levels of ionizing radiation. The BEIR committee saw the study not only as a summary of knowledge about the effects of ionizing radiation on human populations but also as a scientific basis for the development of suitable radiation protection standards.

The committee's final report was released to EPA in May 1979. As sometimes happens in advisory committees, there was disagreement among the members over the final report. Although there was agreement about genetic effects, 5 of the 16 members of the subcommittee on somatic effects did not agree with the study methodology for estimating the health risks of low-level exposures. Therefore, when the report was released, it included a dissenting view. This view stated that cancer risk estimates derived from data on high radiation doses should not be extrapolated, using a linear nonthreshold hypothesis, to low dose rates for which no epidemiological evidence exists. The minority statement was prepared because two members felt that "because of these failings, the BEIR report will contribute to excessive, and potentially detrimental, apprehension over radiation hazards."

In 1980 the section on estimating cancer risks was updated by seven members of the committee serving on a special panel. Their revised report, although essentially the same as the 1979 report, does not select a single set of numbers but rather presents a range of risk estimates that reflects the uncertainties in interpreting the inconclusive data on cancer and low-level radiation. The revised report was released to the public in July 1980.

Probably the best known ad hoc energy advisory committee was the President's Commission on the Accident at Three Mile Island, commonly known as the Kemeny commission. Established on April 11, 1979, by President Carter, the commission was composed of 12 members of the public with very different backgrounds, including a nuclear physicist, a professor of journalism, a resident of the TMI area, and the governor of Arizona. The chairman was John Kemeny, a mathematician and computer specialist and, at that time, the president of Dartmouth College.

The commission was given six months to probe the circumstances of the accident. It conducted its study through meetings, consultations, and interviews with many people involved in nuclear power development, regulation, and operation. In addition to the services of specialized consultants, the commission was provided with 85 full-time staff members, divided into three groups: technical, legal, and public information.

Issued on October 30, 1979, the final report of the Kemeny commission made 44 recommendations in seven major areas: the Nuclear Regulatory Commission, the utility and its suppliers, training of operating personnel, technical assessment, worker and public health and safety, emergency planning and response, and the public's right to information. These recommendations included restructuring NRC as an executive agency under the leadership of a single administrator; improving the procedures for the regulation of commercial nuclear power; developing enhanced standards for the safe design, operation, and construction of nuclear plants; and maintaining a comprehensive training, examination, and evaluation program for nuclear operators and supervisors.

After his review of the commission's report, President Carter stated, "We cannot shut the door on nuclear energy. . . . We must take every possible step to increase the safety of nuclear power production. I agree fully with the spirit and intent of the Kemeny commission's recommendations, some of which are within my power to implement, others of which rely on the Nuclear Regulatory Commission or the utility industry itself."

The Kemeny commission report is a good example of an advisory committee study that actually produced an impact on government policies. The president asked the relevant federal agencies, particularly NRC, to implement virtually all of the commission's recommendations. NRC initiated programs in evacuation and emergency planning, risk assessment, and operator qualification and licensing. The Federal Emergency Management Agency was directed to fund state planners to develop and test emergency response plans, to create materials describing how to obtain emergency public information, and to develop low-cost, low-range dosimeters. DOE was directed to fund, along with NRC and EPRI, the acquisition and evaluation of data from TMI-2.

One result of the Kemeny commission's review was the creation of the Nuclear Safety Oversight Committee (NSOC) to monitor the progress of NRC, other federal agencies, the states, and the utility industry in improving the safety of nuclear reactors and implementing the Kemeny commission recommendations. NSOC, with a $1.5 million budget, held open hearings on nuclear safety and also produced reports on various aspects of nuclear safety regulation and research. The committee's mandate expired on September 30, 1981, and at that time its responsibilities were assumed by President Reagan's science adviser, George Keyworth. NSOC was headed by Governor Bruce Babbitt of Arizona, who was also a member of the Kemeny commission.

In the current congressional session, one federal energy advisory council has had a major impact on the review of energy legislation. The National Commission on Air Quality (NCAQ), which was established as part of the 1977 amendments to the Clean Air Act, produced a substantial report that is the basis for congressional reauthorization of the act. When Congress authorized the commission, it directed it to evaluate the act and examine alternative means to achieve its goals of protecting public health and welfare. NCAQ was to present its findings in a final report at the end of three years.

NCAQ consisted of four members of Congress and nine presidentially appointed public representatives. The congressional commissioners included the chairman of the Senate Environment and Public Works Committee, Robert Stafford; the chairman of the House Energy and Commerce Committee, John Dingell; and the ranking member of the House committee, James Broyhill. Senator Gary Hart served as chairman.

NCAQ spent two and a half years investigating the federal and state air pollution control efforts conducted under the Clean Air Act. Its report, *To Breathe Clean Air,* was released in March 1981. In it the commission made 109 recommendations on air pollution control and alternative strategies for achieving clean air goals. It also reaffirmed provisions in the act calling for the setting of national air quality standards solely on public health grounds, without regard to costs. The commission did not feel that the Clean Air Act had imposed unreasonable costs or hindered energy development, stating that "even without any changes, the Clean Air Act would allow substantial increases in domestic energy production."

When presenting the report to Congress, Chairman Hart explained that "the work of a commission is especially likely to be helpful on this subject because of the complexity of air quality issues and the complexity of the air pollution control program itself—the nation's most far-reaching regulatory program. A balanced examination of air quality issues and the air pollution control program could help Congress avoid a struggle similar to the three-year effort that went into the preparation of the 1977 amendments to the Clean Air Act." With the presentation of the report, NCAQ's work was completed and it was disbanded.

Since the beginning of the Reagan administration, DOE has terminated four ad hoc advisory councils because a review indicated they were no longer necessary. These committees dealt with fuel oil and gasoline marketing, the food industry, and local government energy policy.

Although also now disbanded, the Energy Policy Task Force was one of the first energy advisory committees to come into existence under the Reagan administration. The task force was formed in February 1981 to advise the secretary of energy on the formulation of the third National Energy Plan (NEP-III). It consisted of 22 representatives of industry, academia, state and local governments, and public interest groups. The task force held seven regional hearings across the country to gain public viewpoints on NEP-III. The energy plan was submitted to Congress on July 17, just two weeks after the task force's charter expired.

The task force considered the economic health of the country to be more important than "achieving a low level of U.S. oil imports at any cost." Thus its report emphasized increased reliance on the forces of the free market rather than government regulations. The report predicted that once appropriate regulatory relief was provided, coal and nuclear production would increase significantly over the next 20 years to meet the projected electricity demand growth of 3% per year. The task force concluded that the government's main obligation is to manage the Strategic Petroleum Reserve.

Standing Committees

In addition to ad hoc commissions, there are advisory councils with a more permanent role. The volunteer members of these standing councils may change, but the councils maintain a permanent staff and office. These groups have been assigned their permanent status by law.

One of the oldest federally chartered and privately funded advisory committees is the National Petroleum Council (NPC), established by the secretary of the interior in 1946 at the request of President Truman. NPC was created in order to advise, inform, and make recommendations to the secretary on any matter relating to petroleum or the petroleum industry. With the creation of DOE in 1977, the functions of NPC were transferred from Interior to that agency.

NPC is chartered by DOE under the provisions of the Federal Advisory Committee Act. The council is made up of approximately 100 people appointed by the secretary of energy. The members serve without compensation as representatives of their industry or interests, not as representatives of a particular company or organization.

The council provides advice and recommendations to the secretary of energy through reports on a variety of petroleum issues. Most of the studies undertaken are in response to specific requests initiated or approved by the secretary. Since its founding, NPC has prepared over 200 reports dealing with many aspects of oil and gas operations. One recently released report analyzes emergency preparedness procedures for dealing with an interruption of petroleum imports into the United States.

NPC holds open meetings in Washington at least twice a year, and study groups meet as necessary. The council's staff, headed by Executive Director Marshall Nichols, helps coordinate study efforts and provides administrative support for the preparation and distribution of reports. The operations of NPC are privately funded through the voluntary contributions of its members, who approve an annual budget. NPC receives no government funds.

The Advisory Committee on Reactor Safeguards (ACRS), another standing advisory committee, was established in 1957 as a result of the amended Atomic Energy Act. Composed of 15 members, ACRS reviews safety studies and facility licensing applications referred to it by NRC in accordance with the Atomic Energy Act and the Energy Reorganization Act.

The committee must publish a report before construction permits and operating licenses may be issued for major nuclear facilities. These reports become part of the public record. In addition, ACRS provides advice to NRC on the hazards of new or existing nuclear facilities and the adequacy of related safety standards. Because of the large number of projects and topics that must be reviewed, a separate subcommittee is established for each nuclear power reactor project and each major subject area. In 1980 ACRS held 94 subcommittee and working group meetings and made four site visits.

NRC appoints the 15 ACRS members, most of whom come from the scientific and engineering disciplines. Members must be willing to devote approximately 130 days a year to the work of the committee. The current chairman is Carson Mark, formerly a division head at Los Alamos Scientific Laboratory.

ACRS was active in the analysis of the TMI accident. The committee prepared many special reports for NRC, including 8 directly related to the accident; 7 related to inquiries, investigations, and reorganizations generated by TMI; and 16 on generic nuclear safety issues. A recent expansion of ACRS's statutory responsibilities requires the committee to review NRC's Reactor Safety Research Program and submit an annual report to Congress regarding its adequacy. Both the Kemeny commission and the NRC Special Inquiry Group on TMI recommended that ACRS have a strengthened role in the regulatory process, including the identification and preparation of safety-related rules. NRC has already initiated action on this recommendation. In accordance with the Federal Advisory Committee Act, ACRS meetings are open to the public, except when classified or proprietary information is being discussed.

R&D Advice

Formed in 1978 under DOE, the Energy Research Advisory Board (ERAB) is considered to be "continuing in nature." This means that it has a broader purpose than most ad hoc councils, although it is still subject to an annual review of its purpose and functions. ERAB is of particular interest to EPRI because it advises the secretary of energy on R&D programs and provides guidance on long-term scientific policy issues. Under the Carter administration, ERAB reported to the head of the Office of Energy Research. Energy Secretary Edwards reorganized the advisory council last July, and it will now report directly to him and Deputy Director Kenneth Davis.

When announcing the reorganization of ERAB, Edwards stressed that it will have an increasingly important function. "As the administration increases its support of complex and high-risk energy research and development projects, the advice and recommendations of the Energy Research Advisory Board become even more important to the department. I expect to take full advantage of the resources of the board and to participate in its activities."

Under the reorganization, a new chairman was appointed, Louis H. Roddis, a consulting engineer and the former president of Consolidated Edison Co. of New York, Inc. The dean and provost of the Medical Center of New York University, Ivan Bennett, is the new vice chairman. Both men were serving on the board at the time of their appointments. The other 20 board members have a broad range of scientific and technical backgrounds and come from universities, public interest groups, state governments, and industry. The budget for ERAB in 1981 is estimated at $950,000.

Bennett Roddis

In the first meeting with the new chairman and new members, the board discussed what the government's R&D priorities should be. Should it be concerned with a project's technological potential only or with the technology development costs as well? To gain insight into this issue, the board considered the formation of new study panels to assess the national laboratories and DOE's R&D on nuclear waste disposal, inertial-confinement fusion, and ocean-thermal energy conversion. It also decided to continue existing panels on conservation, geothermal energy, magnetic fusion, biomass, and solar photovoltaic energy. The board also heard reports by the new DOE assistant secretaries on the projects in their program areas.

President Reagan stated in the 1980 annual review of federal advisory councils that all these groups would be coming under stricter scrutiny during his administration. Yet the recent positive reevaluation of ERAB by the new energy secretary may mean that this is one federal energy advisory committee whose influence is on the upswing. ■

This article was written by Christine Lawrence, Washington Office.

Low-Water-Use Tests Under Way

New wet-dry cooling systems will reduce both power plant water consumption and capital cost.

Experimental work is under way at a new EPRI facility that will test advanced power plant cooling concepts that use at least 75% less water than conventional systems. The Advanced Concepts Test (ACT) project will examine two wet-dry cooling processes that combine cooling by air with evaporative cooling by water. The concepts will be tested over the next three years at Pacific Gas and Electric Co.'s Kern County oil-fired power plant.

Low-water-use systems could help utilities substantially reduce their water requirements for power plant cooling and ease plant siting constraints in many parts of the country where obtaining water rights has become a difficult, costly process.

Both cooling systems under test at the Bakersfield, California, demonstration site use a closed ammonia loop as the primary heat-rejection medium. Air drawn through the cooling tower with fans condenses the ammonia vapor in the loop, and at ambient temperatures above 55°F (13°C), additional heat is carried away with water evaporated by the system. During operation, a computer with input from 150 sensors will monitor every aspect of the system and the ambient environment to examine performance under a host of operating conditions.

The superior heat-transfer characteristics of ammonia allow the new cooling systems to be significantly smaller than conventional dry-cooling systems; thus they will save significant amounts of water while costing only 50–65% as much as conventional wet-dry cooling concepts now commercially available.

The ACT facility is an outgrowth of research sponsored by both EPRI and DOE. The tests now under way are being directed by Battelle, Pacific Northwest Laboratories, with active participation from Union Carbide Corp., developer of the specially enhanced condenser-reboiler that is the heart of the primary heat-exchange system. If the new cooling systems perform as expected, one or both could be available for incorporation into new power plant designs by the middle of this decade. ■

EPRI to Manage New Acid Rain Study

EPRI has been asked to manage a major new effort to monitor acid precipitation in the midwestern and eastern United States. The work is being set up through a newly formed ad hoc committee of electric utilities known as the Utility Acid Precipitation Study Program (UAPSP). The committee now has the support of nearly 40 electric utilities.

UAPSP is funding the monitoring program with special contributions from participating companies. The initial four-year study, begun October 1, will cost about $3 million. This expenditure is in addition to the $14.5 million already being spent under EPRI contracts to study acid rain.

Rockwell International Corp. has been selected as the main contractor for the UAPSP effort, which will monitor daily precipitation chemistry at 19 locations ranging eastward from South Dakota and Texas. The methods used in the project will be compatible with those of other acid rain research programs to enable incorporation of the data into national acid rain data bases. Special reports on project results will be published annually.

According to Project Manager Charles Hakkarinen, the data will provide important information on spatial and seasonal trends in precipitation acidity and the chemicals that contribute to the acidity. Such information could be useful in testing models of acid rain formation and deposition and in identifying regions affected by acid rain for ecological study. ■

Automated Communications Systems

The results of a five-year, $20 million research effort to examine alternative two-way communications systems for distribution-automation and load management uses were recently presented at two EPRI-sponsored seminars. Held in June at sites in Atlanta and Denver, the sessions drew 400 participants, including representatives of some 100 electric utilities. Utility managers and distribution engineers received firsthand information about the performance of 10 experimental systems tested in separate projects throughout the nation. It is believed that such two-way communication systems will vastly improve the efficiency and reliability of utility distribution systems by remote sensing of power requirements and problem areas.

The test projects discussed at the seminars were funded through EPRI, DOE, independent manufacturers, and the host utilities. In all, the systems successfully completed more than two million communications loops while under test. William Blair, EPRI project manager, said he expects systems developed as an outgrowth of the recent research effort to be commercially available within five years if they can be shown to be cost-effective. Results of the test programs are detailed in reports available through EPRI and DOE. ■

Rossin to Head Nuclear Safety Research Group

A. David Rossin, director of research for Commonwealth Edison Co., has been named director of the Nuclear Safety Analysis Center (NSAC), operated by EPRI for the nation's electric utility industry. Rossin's appointment was approved by the EPRI Board of Directors at its August 1981 meeting. He succeeds E. L. Zebroski, who left NSAC in September to become vice president for engineering and analysis at the Institute of Nuclear Power Operations in Atlanta.

Widely known for his work in nuclear power safety, Rossin joined Commonwealth Edison in 1972 after 17 years at Argonne National Laboratory. In his most recent position at Edison, he coordinated the company's research projects in the energy production, engineering, commercial, and environmental areas. He was also general manager of Commonwealth Research Corp., an Edison subsidiary that administers joint projects with the federal government.

Besides reactor safety, Rossin has worked on nuclear plant siting, occupational radiation exposure, materials problems, and nuclear fuel cycle issues.

Rossin holds a bachelor's degree in engineering physics from Cornell University, an MS in nuclear engineering from the Massachusetts Institute of Technology, an MBA from Northwestern University, and a PhD in metallurgy from Case Western Reserve University. ■

Technology Exchange Discussed

Pierre Dersin, science and technology adviser to the Belgian Embassy, visited EPRI in August to promote technology exchanges between the United States and Belgium and to discuss how information could be profitably traded. Dersin (center) met with representatives of several EPRI divisions, including John Cummings (left), director of the Renewable Resource Systems Department in the Advanced Power Systems Division, and Richard Rhodes (right), applications analyst in the Policy Planning Division.

Information and Planning Functions Reorganized

Richard L. Rudman, formerly director of the Policy Planning Division, has been named director of the newly formed EPRI Information Services Group under a reorganization effective October 1. The new group (parallel to the existing Research and Development Group and the Finance and Operations Group) consolidates all the Institute's information and external relations functions under Rudman, who will report to President Culler. The group includes the Communications and Technical Information divisions, the Washington Office, the Regulatory Relations Department, and the Member and International Relations Department.

Also part of the reorganization was the creation of a Planning and Evaluation Division, which integrates all EPRI's planning activities under the vice president for research and development. Heading the new division will be Richard W. Zeren, who has handled much of the planning function for the vice president's staff. The new division is responsible for developing EPRI's strategic plan, recommending allocation of the Institute's R&D budget, reviewing and integrating the R&D plan, and evaluating technologies and projects of interest to EPRI.

Prior to joining the Institute in 1973 as assistant to the president, Rudman worked for International Business Machines Corp. as a consultant on large computer systems. The author of numerous publications and articles, Rudman is a graduate of the University of California at Los Angeles, where he earned BS and MS degrees in engineering.

Zeren first served EPRI as assistant to the director of the former Fossil Fuel and Advanced Systems Division. He later became manager of R&D Program Integration and Evaluation in the division before leaving the Institute in 1979 to work as a senior associate at Booz, Allen & Hamilton, Inc. He returned to EPRI this year to head the planning and evaluation group within the R&D vice president's staff. Before he joined EPRI in 1974, Zeren was on the faculties of both Michigan State University and Stanford University. He holds a BS in mechanical engineering from Duke University, as well as MS and PhD degrees from Stanford in the same field. ■

CALENDAR

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

NOVEMBER

2–4
Workshop: Applied Coal Geoscience and the Electric Utilities
Austin, Texas
Contact: Jeremy Platt (415) 855-2628

3–4
1981 Progress in NDE
Charlotte, North Carolina
Contact: Gary Dau (415) 855-2051

4–5
Seminar: Prevention of Condenser Failures—The State of the Art
Arlington, Virginia
Contact: B. C. Syrett (415) 855-2956

18–20
Seminar: FGD Systems Data Book and Sludge Disposal Manual
Denver, Colorado
Contact: Charles Dene (415) 855-2425

DECEMBER

1–3
Seminar: PCBs
Dallas, Texas
Contact: Gilbert Addis (415) 855-2286

9–11
Cable Fire Materials Detection and Extinguishment
Norwood, Massachusetts
Contact: Roy Swanson (415) 855-2024

JANUARY

11–14
Seminar: Reliability Design of Single-Pole Transmission Structures
Fort Collins, Colorado
Contact: Phillip Landers (415) 855-2307

26–26
Seminar: Environmental Issues in the Siting of Electric Transmission Lines
Dallas, Texas
Contact: Robert Kavet (415) 855-2590

FEBRUARY

8–11
Seminar: Reliability Design of Single-Pole Transmission Structures
Palo Alto, California
Contact: Phillip Landers (415) 855-2307

MARCH

15–18
Seminar: Reliability Design of Single-Pole Transmission Structures
Blacksburg, Virginia
Contact: Phillip Landers (415) 855-2307

CORRECTION

The July/August issue of the *Journal* contained an error in the story "Synfuels and the Energy Transition." In the lower graph on page 25, the second bar should be labeled *methanol* instead of *methane*.

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

ALTERNATIVE FUEL COMBUSTION RESEARCH

Alternative fuel combustion research is part of the Power Generation Program of EPRI's Advanced Fossil Power Systems Department. One of this program's primary objectives is to develop simple and combined-cycle power plant systems that can fire alternative fuels with acceptable reliability, cost-effectiveness, and environmental compatibility. To achieve this objective and to amass a comprehensive data base of alternative fuel operating experience, work is being done with a range of currently used combustion hardware, as well as equipment slated for near-future use in utility boilers, combustion turbines, and diesels.

Liquid, solid, and gaseous fuels derived from coal and oil shale are currently under development as alternatives to natural gas and petroleum-based fuels used in utility combustion systems. A number of alternative fuel processes, including solvent-refined coal (SRC-I and SRC-II), Exxon Donor Solvent (EDS), and H-Coal, have reached a state of development where sufficient quantities of fuel are available for limited field testing.

Alternative fuels derived from coal and oil shale sources have properties characteristically different from natural gas and petroleum-based fuels that can affect their use and performance as utility fuels. For example, although coal-derived liquids are typically low in sulfur, they generally have higher nitrogen content and carbon-to-hydrogen (C–H) ratios. Higher fuel-bound nitrogen results in formation of so-called fuel-NO_x during combustion and higher emissions. Higher C–H ratios also result in formation of higher smoke and particulate emissions. Although these emissions can theoretically be reduced to acceptable levels by known combustion strategies, work must be done to quantify, optimize, and reduce those strategies to practice.

Alternative fuel applications

Alternative fuels derived from coal and oil shale sources can be categorized into three major groups—liquid, solid, and gaseous. The ways in which electric utilities choose to use those types of alternative fuels will vary considerably as a function of region, existing capacity mix, and duty requirements.

Methanol is one of the promising coal-derived clean liquid fuels for near-future use. Methanol can be produced indirectly from coal by gasifying the coal and catalytically converting the desulfurized gas to methanol. Its properties make methanol an excellent fuel for peaking gas turbines and for retrofitting gas-fired boilers.

Other coal-derived liquids can also be produced by using direct coal conversion processes. The range of products made from these direct coal liquefaction processes is similar to the range of materials that can be recovered from petroleum crude oils. Turbine fuels produced from light distillate and/or hydrotreated fractions of coal- and shale-derived liquids are attractive alternatives for replacing petroleum-based fuels in stationary combustion turbines and combined-cycle units. Likewise, boiler fuels produced from heavier distillate fractions of these synthetic crudes are potential alternative fuels for retrofitted gas- and oil-fired boilers.

Low-sulfur solid boiler fuels can be derived from the SRC-I process. These types of low-sulfur solid fuels offer special economic and environmental pay-offs as substitute fuels for existing and newly designed intermediate and baseload power plants currently firing pulverized coal.

The most probable initial application of coal-derived gaseous fuels will be in the area of retrofitting and repowering a fraction of the currently existing 225 GW of oil and gas-fired capacity. This can be accomplished by production of "over-the-fence" medium-Btu gas (having a gross heating value from 250 Btu/ft^3 to 350 Btu/ft^3). Later potential applications of coal gasification technology will involve the construction of integrated grass-roots gasification–combined-cycle plants for baseload power generation. Such systems have the potential to be more efficient, more environmentally acceptable, and less costly than conventional coal-fired steam plants.

Alternative fuel testing

The utility industry requires comprehensive, large-scale tests of long duration in utility equipment before accepting any new fuels. EPRI's Advanced Power Systems Division has set up an alternative fuel combustion test program aimed at developing the data base necessary to evaluate the performance of the various alternative-fuel applications discussed above. The research is designed to obtain specific test data on equipment performance, emissions, fuel handling requirements, and operating experience.

Alternative fuel testing in utility boiler systems follows a step-by-step sequence. New boiler fuels are first screened in small-scale furnaces of 1–5 $\times 10^6$ Btu/h capacity. This testing is followed by others in intermediate-scale boilers of about 50 $\times 10^6$ Btu/h capacity. Data from these small-scale experiments are used in developing the actual test plans for utility field tests.

Turbine fuel testing is handled in a similar way. In the past, three sizes of single-can combustions have been used in EPRI's combustion test programs: miniscale, subscale, and full-scale. Figure 1 shows the relative dimensions of two test combustors. As in the case of boiler fuels, data obtained during rig tests with these single-can combustors are used to characterize the fuel's burning properties and to develop the test plan for the eventual field test of a candidate alternative fuel in an actual utility combustion turbine.

Boiler combustion research

Although there are differences in the composition of coal- and oil shale–derived fuel, their nitrogen contents are consistently high across the entire boiling range, much higher than those of petroleum fuels. This fuel-bound nitrogen presents a significant problem for direct substitution because under conventional fuel-lean combustion conditions, the fuel nitrogen converts to NO_x and becomes the major source of unacceptably high NO_x emissions.

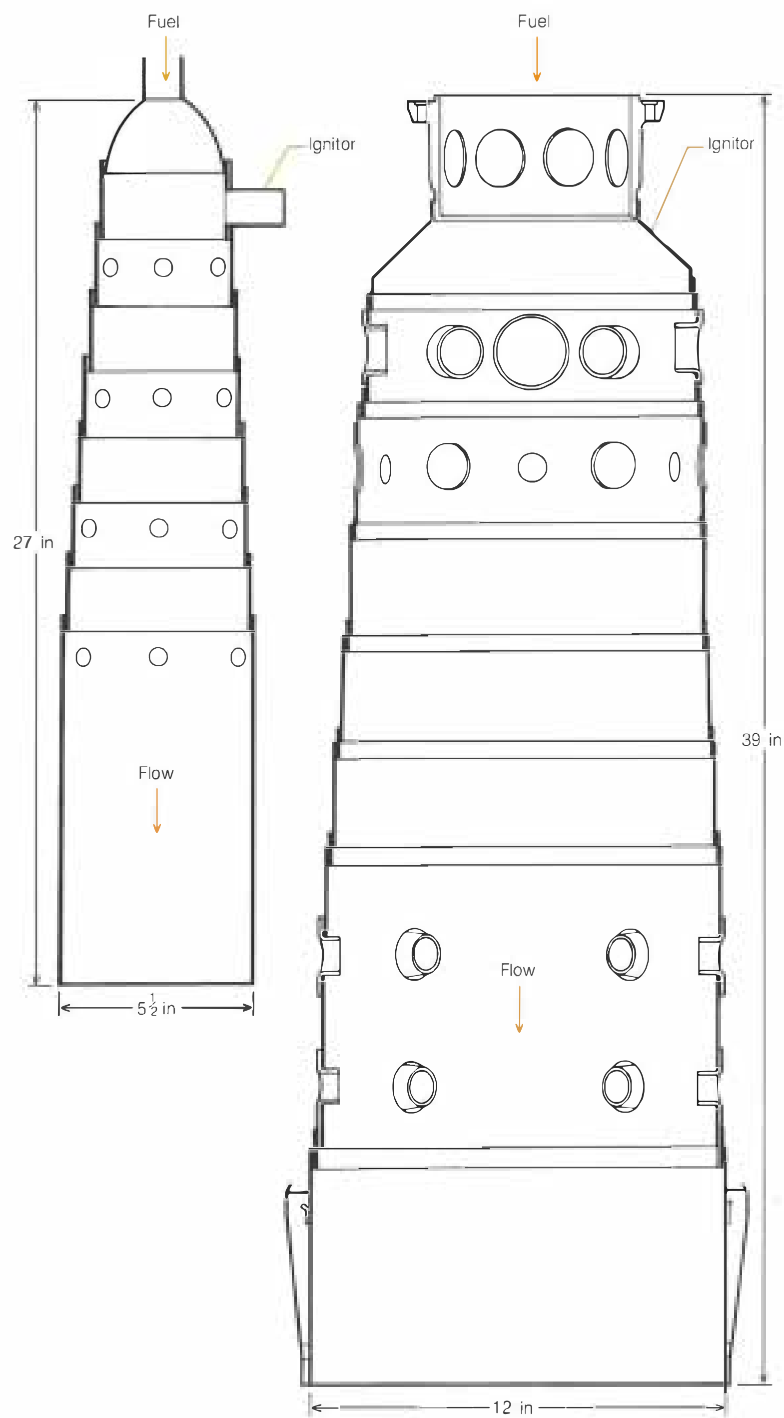
Two small-scale experimental studies are currently being conducted to investigate the amenability of coal-derived liquids to combustion process modification by staged combustion to control NO_x and particulate emissions in utility boilers. MIT is carrying out the first of these studies in its 10×10^6 Btu/h test facility (RP1412-6). The second study is being conducted by KVB, Inc., using a 3×10^6 Btu/h boiler that has been modified to simulate a large utility boiler (RP1412-5).

The research objectives of the MIT study are to identify and quantitatively describe the critical steps involved in the processes of fuel nitrogen evolution and conversion in order to develop a design strategy for minimizing NO_x and particulate emissions. Two fuels are being investigated in this study: an SRC-II heavy distillate fuel oil containing 1.1% fuel nitrogen and a blended SRC-II distillate fuel oil containing 0.9% fuel nitrogen. Both unstaged and staged combustion conditions are being investigated. The unstaged experiments were designed to provide baseline data on NO_x and particulate emissions from the two SRC-II fuel types.

Results thus far indicate that staged combustion can effectively reduce NO_x emissions without excessive emission of carbonaceous particulates. Under unstaged conditions, NO_x emissions ranged from 250 to 500 ppm; under staged conditions NO_x emissions of less than 100 ppm could be achieved. In either case, particulate emissions were below existing EPA standards. Although probably not achievable in actual utility equipment, the value establishes a lower limit for NO_x emissions.

In the second study, the combustion performance of several coal-derived liquids was compared with the combustion performance of No. 2 and No. 6 fuel oils. The purpose of this study was to establish a laboratory-scale test that could reliably predict combustion and emissions trends consistent with current field experience. The results indicated that the emission characteristics (NO_x, particulate loadings, and particulate morphology) obtained in this laboratory-scale apparatus were similar to those obtained with full-scale hardware (the SRC-II test burn at the Consolidated Edison Co. of New York, documented in EPRI FP-1029). Thus combustion tests at this scale can be used as a screening tool to uncover problems that may be experienced at full-scale operation. The results indicate that no fundamental differences in combustion or emissions behavior would be expected for SRC-II fuels in the entire distillate boiling range. The project report (AF-1878) was published in June 1981.

Figure 1 Comparison of combustor sizes used for evaluation of alternative fuels in utility combustion turbines. Subscale combustors (left) are used to perform initial fuel-screening evaluation tests. These initial evaluations are then followed by further testing in full-scale combustors (right) to verify emission and performance results.



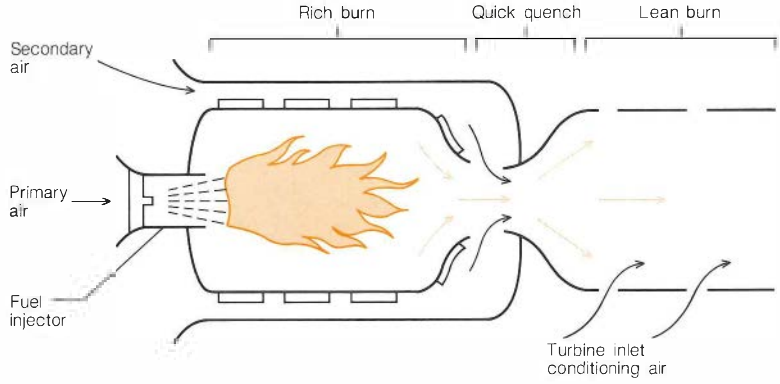
Combustion turbine research

In a related project several coal-derived turbine fuels were characterized in an advanced, rich-lean design, stationary gas turbine combustor (RP1898). The purpose of this project was to determine by combustor rig test and data analysis the effects of alternative fuel property variations on the exhaust emissions, performance, and durability characteristics of this type of advanced stationary gas turbine combustion system. As illustrated in Figure 2, the rich-lean combustor concept is similar to the fuel staging technique used in boiler combustion systems for controlling NO_x emissions from fuels containing high fuel nitrogen. Briefly, a small amount of primary air is mixed with the fuel in the head end of a rich-lean combustor. This creates a fuel-rich combustion zone to release nitrogen from fuels containing nitrogen compounds and to maximize the early formation of molecular nitrogen. The rich-burn step is followed by the rapid introduction of secondary air. This quick-quench step is necessary to achieve complete combustion of unburned hydrocarbons and carbon monoxide under fuel-lean conditions to minimize thermal NO_x formation. The combustion is optimized in the rich stage to reduce the formation of NO_x and molecules such as NO_3 and HCN, which would convert readily to NO_x in the lean stage.

In this research five fuels—No. 2 fuel oil, EDS, SRC-II, H-Coal, and a shale oil residual—were tested in a subscale 5-in-diam, rich-lean staged combustor at conditions representative of a 30-MW utility gas turbine. A minimum NO_x emission level corrected to 15% oxygen of approximately 35 ppm was attained for all the fuels despite fuel nitrogen levels of up to 0.8 wt%. The combustor smoke emissions at baseload conditions were found to depend strongly on fuel properties and ranged between SAE smoke numbers of 20 and 45. (The threshold of visible smoke is SAE 20.) The final project report will be published in late 1981.

As part of a continuing project to develop a dry, low-NO_x, utility gas turbine combustor capable of burning medium-Btu gas (300 Btu/ft^3), two full-scale prototype combustors were designed, fabricated, and tested with actual coal gas produced by the Texaco coal gasifier in Montebello, California. The goal of the project was to achieve emissions of only 15 ppm NO_x at a combustor inlet pressure of 1.27 atm (129 kPa) without water injection or combustor performance degradation (RP985-3). This NO_x goal corresponds to approximately 55 ppm at an engine pressure ratio of 16.5 and a maximum combustor exit temperature of 2150°F (1117°C) and falls within current EPA limits of 75 ppm.

Figure 2 The rich-lean combustor design minimizes the formation of NO_x emissions by consecutive zones of rich burning (to suppress the formation of fuel-NO_x emissions by virtue of a low flame temperature and low concentration of oxygen) and rapid dilution to lean burning (to complete combustion and suppress the formation of thermal-NO_x emissions).



The design of the combustors evaluated in this project was based on the lean premix concept. By mixing fuel and air in lean proportions before combustion, flame temperature and the thermal NO_x formation are reduced. One of the combustors designed in the study also employed fuel staging to improve the operating range of the combustor to include the entire engine operating range.

The improved range of the staged combustor design was achieved by staging the fuel to seven individual venturi premix tubes as shown in Figure 3. Three venturi tubes

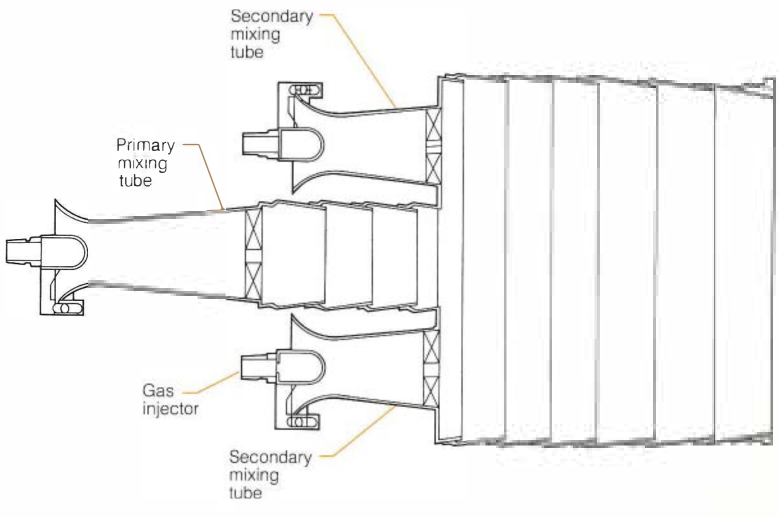


Figure 3 Cross section of the 300-Btu coal gas combustor (configuration V). This lean, premixed combustor design features fuel staging to obtain low-NO_x emission performance over the entire engine operation range of a utility gas turbine engine.

were used as a primary fuel stage for operation at lower power levels; four tubes (two above and two below the three primary venturi tubes) were used as a secondary fuel stage and were fired in addition to the primary stage at intermediate and higher power levels. The results of this study showed that a staged combustor could produce NO_x emissions comparable to those achieved by the best combustor in Phase 1. Further, the staged combustor was operable over the entire range of combustion turbine operating conditions. The final project report on this work is due in late 1981.

Table 1
EPRI EMISSIONS TESTING

	Distillate Oil	Blended Residual Oil	Refined Shale Oil	Methanol
Test Conditions				
Combustion turbine	FT-4C 1DF	W-501 Pace	FT-4A 9DF	FT-4C 1DF
Water-fuel ratio	0.6	0.5	1.0	0.2
Emissions				
NO_x (ppm 15% O_2)				
H_2O-injected	55	95	113	18
Not H_2O-injected	207	200	275	50
Particulates (lb/10^6 Btu)	0.008	0.09	0.01	0.005
CO (ppm 15% O_2)				
H_2O-injected	60	98	439	116
Not H_2O-injected	50	30	75	43
Smoke	none	none	none	none

Field test results

Table 1 summarizes the emissions results of a series of recently completed combustion turbine field tests. The data in the first and last columns were obtained in a field test at Southern California Edison Co.'s Elliswood station. In this field test petroleum distillate oil was fired in one engine of a United Technologies Corp. twin-pack FT-4C gas turbine generator set, and methanol was fired in the other one (RP988). The data in the second column were obtained in a field test program to compare the operation and maintenance costs of firing residual fuel oil with those of firing distillate fuel (RP1079). This test was performed in two identical Westinghouse 501 combustion turbines at Florida Power & Light Co.'s Putnam station. The third set of data presented in the table was obtained during a field test on a UTC simple-cycle FT-4A engine at Long Island Lighting Co.'s Barrett station (RP1691). The fuel evaluated in this field test was a hydrotreated heavy distillate shale oil.

Although the absolute level of emissions measured in each field test is related to actual engine type used, an order-of-magnitude comparison can be made of the characteristics of the gaseous, smoke, and particulate emissions of each of the fuels evaluated. The data shown in Table 1 include emissions data taken with and without water injection for control and reduction of NO_x emissions. As can be seen, NO_x and particulate emissions are significantly reduced by using methanol fuel, and NO_x emissions can be further reduced by injecting water into the combustion chamber. However, the high costs and limited availability of methanol make it an impractical utility fuel at the present time.

The data in Table 1 further indicate that the gaseous, smoke, and particulate emissions from the shale oil residual and petroleum distillate fuels are substantially the same except for NO_x emissions, which are higher from the shale oil residual because of its high fuel-bound nitrogen content (0.5 wt%). As is shown, the use of water injection could reduce the NO_x emissions produced by the shale oil residual to below the Environmental Protection Agency (EPA) NO_x limit of 125 ppm for fuel containing 0.25% nitrogen or greater. However, the excessively high water injection rate (water-to-fuel-mixture ratio of 1:1) required significantly reduced combustion efficiency, as evidenced by the high CO emission rate (439 ppm).

Acceptable NO_x emissions and combustion efficiencies could be achieved with water injection while firing blended petroleum residual oil containing 0.2% nitrogen. The EPA NO_x emission limit for this fuel is approximately 122 ppm. The EPA NO_x limit for petroleum distillate is 75 ppm; this limit could also be met with water injection.

Future testing

Until recently, sufficient quantities of coal- and oil shale–derived fuels have not been available to permit many full-scale tests in utility boilers, combustion turbines, and diesels. This has prevented the identification of potential problems associated with the handling of these fuels and their combustion in full-scale utility equipment. Starting in mid-1981, the Power Generation Program of Advanced Power Systems Division will initiate a number of field tests. The plan for the next five years calls for conducting one or more such field tests each year. A variety of distillate and residual coal-derived fuels, as well as shale oil and methanol, will be evaluated in various utility combustion systems as they become available.

The first of these field tests (RP2049) will be conducted in late 1981 to evaluate the suitability of a fraction (boiling between 400°F and 700°F; 204°C and 371°C) of EDS coal liquid as a utility diesel generator fuel (RP2049). The purpose of this project is to identify the system changes that may be required in diesel plants to accommodate alternative fuels and to determine the effect of their burning on the engines, existing systems, and the environment. The test results are expected to provide the industry (particularly small electric utility plants) with the means of evaluating domestic coal-derived liquids as a substitute for natural gas or oil as a utility diesel fuel.

Three additional field tests are planned for mid-1982. Two field tests will involve utility boilers; the third will involve a utility combination turbine. Two utilities with boilers in the range of 40–70 MW will be selected. The three field tests will fire distillate products produced from the H-Coal and EDS processes to demonstrate the feasibility of these fuels for utility application. *Project Manager: Leonard Angello*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

PRESSURIZED FLUIDIZED-BED COMBUSTION

Future coal-fired electric generating systems could be based on several alternative technologies, each with unique characteristics that permit utilities to best meet their specific fuel, environmental, cost, and operational requirements. These include advanced pulverized-coal-fired boilers with scrubbers, fluidized-bed combustion (both atmospheric and pressurized), coal-derived liquids, and integrated gasification–combined-cycle plants. Pressurized fluidized-bed combustion (PFBC) power plants are expected to be strong market contenders because of two distinct advantages: high power cycle thermal efficiency and, in comparison with other high-efficiency options, simple process flowsheets. In these plants gas turbines would be turned by the coal combustion products from a pressurized fluidized-bed combustor operating at pressures below 16 atm (1.62 MPa) and temperatures up to 1700°F (927°C). The formidable technical barriers to PFBC are gradually being overcome by experimental work at various test rigs and pilot plants in the United States and abroad. The emphasis at EPRI over the past year has been on defining the optimal thermal power cycle configuration for full-scale commercial plants in order to specify the required characteristics of a PFBC test plant.

A gas turbine capable of expanding coal combustion products has been a goal of researchers for more than 40 years. Past experiments all burned pulverized coal, and each was eventually terminated because of rapid erosion or pluggage of the turbine blades. PFBC technology developments in the last decade, and the last two years in particular, have greatly increased the probability of overcoming the barriers that blocked those pioneering efforts. In short, coal-fired gas turbines with commercially acceptable lifetimes appear to be achievable under the following conditions.

- The coal is burned in a pressurized fluidized-bed combustor.

- The gas stream is more thoroughly and reliably cleaned than in past experiments.

- On-line instrumentation is used to continuously monitor the particulate loading of the gas stream to the turbine.

- The turbines are hardened to be able both to ingest higher particulate loadings than are normal for engines burning natural gas or distillate oil and to resist hot corrosion induced by the high alkali vapor content of the coal combustion products.

By matching such PFBC systems to Rankine reheat-steam cycles, direct-coal-fired combined-cycle power plants can be realized. These plants will have the advantages of in situ control of SO_x and NO_x emissions to levels below projected standards without the use of add-on scrubbers; reduced water use; reduced coal pile–to–busbar energy cost; and the simplest process scheme of any of the advanced high-efficiency coal-based options.

Several variations of the basic PFBC thermal cycle are possible, depending on the arrangement of the process components (pressurized fluidized-bed combustor, gas cleanup train, heat transfer surfaces, and gas turbine) and the operating conditions (working fluid type, pressure, and temperature). In large part, EPRI's recent PFBC efforts have been directed toward defining the optimal cycle from the standpoints of thermodynamic performance and mechanical design. This information is needed before a utility-scale test plant—that is, a plant at least 20 MW (e) in capacity—can be built to resolve the remaining hot gas cleanup and turbine reliability issues.

A joint research project was begun in the summer of 1980 with Brown Boveri & Co., Ltd. (BBC), and Babcock & Wilcox Co. to provide answers to questions about the optimal cycle arrangement (RP1645-3). Thirty candidate cycles were screened by BBC. Of these, the following five were selected for a detailed investigation based on the use of a BBC Model 11 gas turbine as the common element.

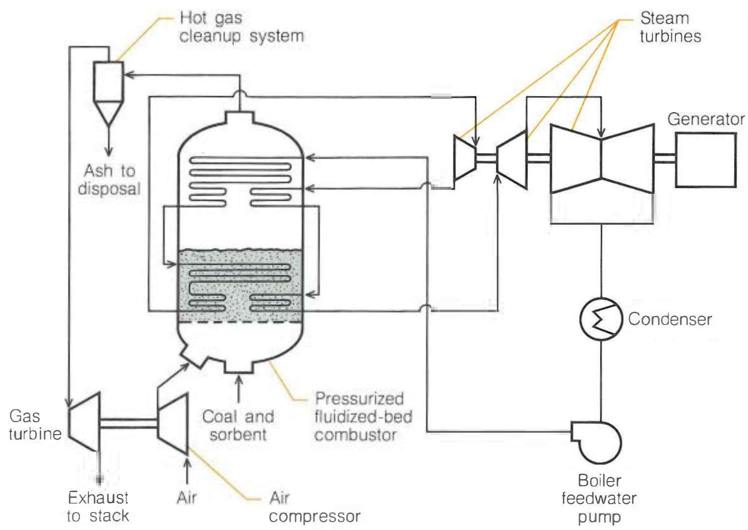
- Cycle A is a "conventional" PFBC cycle, with 20% of the total plant power coming from the gas turbine. The steam is generated at 2400 psig (16.55 MPa) in the combustor and in a heat recovery steam generator; the throttle and reheat temperatures are both 1000°F (538°C).

- Cycle B is a low-pressure, turboexpander cycle, operating either in a low-temperature, self-sustaining condition (no net power out of the turboexpander) or in a high-temperature condition in which the turboexpander generates 13% of the total cycle power. Steam conditions in both cases are 2400 psig (16.55 MPa) and 1000°F/1000°F (538°C/538°C).

- Cycle C is an air-tube cycle, in which two-thirds of the air from the compressor is indirectly heated to 1590°F (866°C) in tubes immersed in the combustor bed and the other one-third is supplied to the combustor as combustion air. The combustion products and hot air recombine for expansion through the gas turbine, which produces 58% of the total plant power. All steam for the Rankine cycle is generated in the heat recovery steam generator.

- Cycle D features an adiabatic pressurized fluidized-bed combustor. Combustion air, supplied at extremely high excess air levels (~300% in this case), is the sole means of removing heat from the combustor. The gas turbine accounts for 69% of the total plant power output. All steam is generated in the heat recovery steam generator.

Figure 1 PFBC system with turbocharged combustor. The gas turbine operates on combustion products at 770°F (410°C) and 8.7 atm (0.9 MPa).



▫ Cycle E features a turbocharged pressurized fluidized-bed combustor (Figure 1). All electric power is generated by the steam turbines; there is no net power out of the gas turbine to the grid. Steam is generated entirely in the combustor at 2400 psig (16.55 MPa) and 1000°F/1000°F (538°C/538°C).

The analysis of these cycles showed that cycle A, the conventional PFBC cycle, has the highest gross thermal efficiency (40%); cycle E, which uses the turbocharged combustor, is next at 38%. The preliminary results indicate, however, that the busbar cost of electricity from cycle E will be about equal to that of cycle A. This is because cycle E has lower capital costs as a result of its lower combustion product gas temperature: 770°F (410°C), compared with 1560°F (849°C) in cycle A. This lower gas temperature and the concomitant difference in gas density (cycle E gas is 1.6 times more dense than cycle A gas) considerably reduce the requirements for both the type and amount of high-alloy steel for the hot gas cleanup train and the hot gas ducting.

Cycle E is an attractive possibility for the ultimate commercial plant configuration; in addition, its inherent conservatism (i.e., the low gas turbine firing temperature) will make it especially suitable for a first-generation PFBC plant application. Plants in subsequent generations would be able to incrementally increase the turbine operating temperature to achieve full combined-cycle efficiency benefits.

BBC has also been preparing a conceptual design of an adiabatic pilot plant that will be capable of operating the test turbine at both 970°F (521°C) and 1560°F (849°C). This one plant, therefore, will have adequate flexibility to test the operating conditions of both the self-sustaining and full combined-cycle PFBC plant concepts. The combustor is adiabatic in order to reduce both plant complexity and cost. This project has recently been included in EPRI's five-year plan and is scheduled to begin combustion in 1984. *Project Manager: Steven Drenker*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

OVERHEAD TRANSMISSION

Galloping conductors

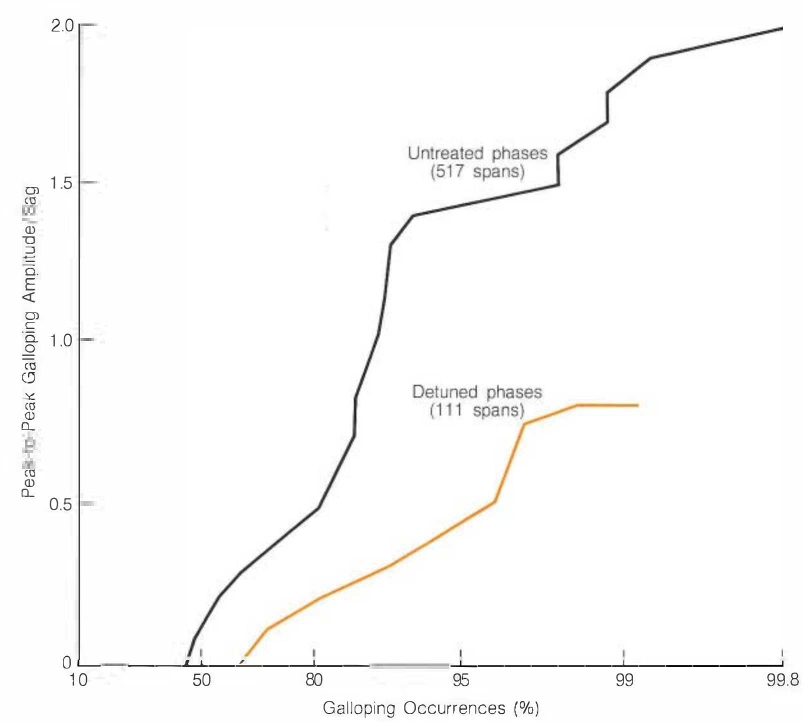
Galloping conductors have been a dilemma as long as transmission and distribution lines have been in the air. Although EPRI's research on galloping control by detuning (RP1095) is only in its fourth year, significant progress in solving this problem has been made. After evaluating the observations made by the utility observer teams thus far, there is no doubt that the detuning pendulums (Figure 1) reduce the occurrence and amplitude of galloping. Yet to be determined are the span lengths and conductor sizes and tensions for which the pendulums work best. With the enthusiastic support demonstrated by the observer teams on this project, verification of the detuning pendulum is expected to be completed by 1985.

Ontario Hydro, the initiator of this study, has long recognized the worldwide nature of the problem and has been instrumental in securing international cooperation in seeking a solution. Six countries in Europe are now assisting in the evaluation of the detuning pendulum, as well as investigating other mitigating devices.

The problems with galloping became so severe in Europe that an international organization, Corech, was formed. EPRI has now actively joined this multinational effort in the quest for a near-term solution.

The success of this joint observation and the realization that no known control device will be a universal cure-all for galloping led participating utilities to request EPRI to expand the research, which now includes the observation of other devices that promise to reduce galloping. Another galloping season will shortly be upon us, and our continued progress is directly tied to the enthusiastic support of each of the galloping observer teams. We again are requesting observer team support in pursuing an early solution to this elusive and worrisome problem. *Project Manager: Phillip Landers*

Figure 1 These plots compare incidences of galloping on lines with and without detuning pendulums.



DISTRIBUTION

Advanced cable plow

Utilities and utility contractors install millions of feet of power, telephone, and television cables annually. Cable plowing appears to have certain technical as well as economic advantages over trenching.

Although in the late 1970s there were 18 cable plow manufacturers, no one plow had a full range of capabilities. Problems existed with ground disturbance; cable feed and tension; and expensive, time-consuming mobilization and cleanup. In spite of these problems, very little new technology has been developed in the cable plow industry since the 1960s. Research that would solve the technical problems and take full advantage of advanced 1980s technology was needed.

The objective of a project with Oretek Laboratory, Inc., was to develop a lightweight, highly maneuverable, and powerful cable plow capable of a continuous plowing operation up to 42 in (1.07 m) deep in a variety of soil and terrain conditions (RP1518). A vibratory plow blade that would cause minimum ground disturbance and a cable feed shoe that could install various cables either separately or in a random lay were design goals. The ultimate goal of the research was to increase the reliability and efficiency of cable plowing operations. Such an achievement would significantly reduce the cost of underground cable installation.

The research produced a prime mover that is revolutionary in design and technical innovations in the plow blade and cable feed shoes (Figure 2). The entire system, called the Scorpion, is small, self-contained, and versatile. The prime mover is a diesel engine with a hydraulic drive unit that powers the tracked undercarriage. The boom, on a swing frame, is mounted outside of and above the engine housing tube by heavy steel rings. These rings are powered hydraulically and rotate the entire boom system vertically around the engine housing tube. The boom is also capable of vertical movement at its point of interface with the swing frame and can also rotate 320° horizontally. At the end of the boom is a swivel mechanism, capable of vertical and horizontal movement, to which the plow blade or other auxiliaries may be attached.

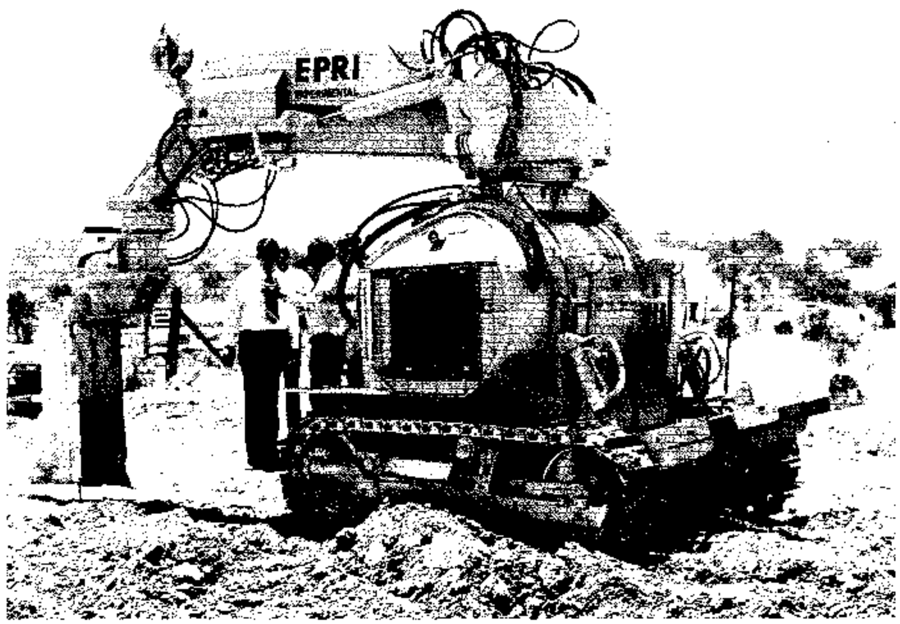
At the front of the Scorpion are extendable arms that can carry a large cable reel or a dozer blade. The Scorpion is capable of a wide variety of functions with the proper attachments, such as a backhoe, a boring and pipe-pushing tool, an earth auger, a pole-setter, a winch, and a dozer blade (Figure 3).

The plow blade is unique in two ways. Conventional vibratory plows have the vibration mechanism attached above the blade, and much of the vibratory energy is lost in the blade mount, rather than being transferred through the plow blade into the ground. On the Scorpion's plow blade, the vibration mechanism is in the blade, transferring much more of the energy into the ground, thereby increasing efficiency and reducing wear on the equipment.

The other unique aspect of the blade is the water-jet system. On the leading edge of the plow blade are high-powered, strategically placed water-jet nozzles. These form 10,000-psi (68.9-MPa) low-volume water jets that help to cut away, soften, and lubricate the earth as the plow blade advances.

Two cable feed shoes have been designed for the blade. Each can be attached to the back of the plow blade. One feed shoe is

Figure 2 The Scorpion. Its compact design concentrates the power of the hydraulic drive units on the plow, tracked undercarriage, and boom. Plow blade and cable feed shoes at rear incorporate technical innovations.



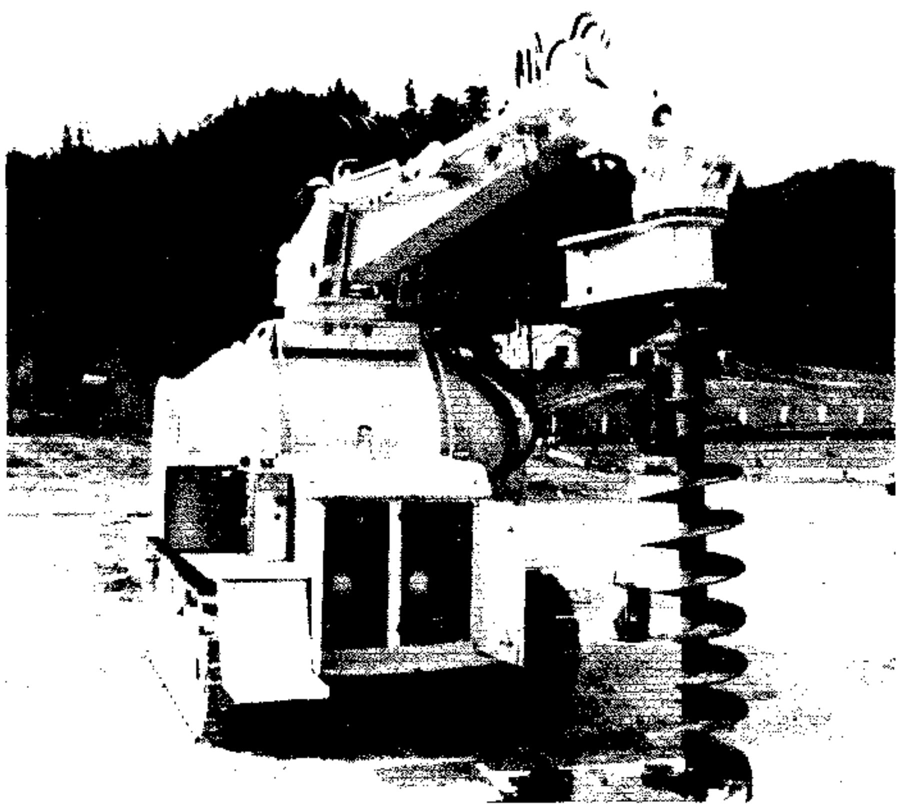


Figure 3 Attachments for the Scorpion could include a backhoe, a boring and pipe-pushing tool, an earth auger (shown here), a winch, and a dozer blade.

used with a single cable, and the other is used when simultaneously installing multiple cables. This feed shoe allows a loop to be pulled in one cable, while leaving the plow blade, feed shoe, and other cable undisturbed in the ground.

The design innovations in the cable feed shoes, plow blade, and engine constitute improvements over conventional cable plows. The feed shoes are intended to use the vibration from the plow blade to achieve proper cable tension. The loop-pulling capabilities allow work to proceed without interruption, which reduces man-hours and cleanup problems.

On the plow blade, the vibrator and water-jet assists act to reduce drawbar pull, and when used together the drawbar pull is up to 75% less than that required by an unassisted plow blade. Stall tests, performed at 40-in (1.02-m) plow depth in dark-brown clay silt (western Oregon red clay) have been dramatic. In no case during any of these tests could the blade be stalled when the vibratory and water-jet assists were being used. Without the assists, the plow blade was easily stalled in the hard, dry ground, and full tractive effort of 43,000 pounds (19.5 Mg) was unable to move it forward. When the assists were turned on, the blade was able to move ahead at 30–40 ft/min (9.14–12.2 m/min).

Because the power requirement for drawing the blade through the ground is low, the small engine is quite adequate. It is easy to manipulate, and the wide horizontal rotation of the boom allows the unit to push or pull the blade or to draw it along on one side if cable is being installed next to a house or fence. The vertical rotation of the boom around the engine tube enables the blade to enter and exit the ground without prior trenching or backhoe excavation. Ground disturbance and the resultant cleanup are minimal.

The Scorpion has great potential as a multipurpose machine. Additional items that will extend its usefulness include a trailer for handling the Scorpion and its attachments, street pads for the tracks, an eight-function dozer blade for minor cleanup, and a winch for moving equipment into place or large obstructions away from the plowing path. Later, a backhoe and a boring and pipe-pushing tool for installing a cable under roads could be added. These tools will make this cable plow system entirely self-sufficient, and the operation would require only one machine and a minimum crew. Plans further in the future conceive the Scorpion as a pole-setting and anchor-placing machine. Attachments for that purpose would include a few of those listed above and an earth auger and a pole hugger. A pole hugger, attached to the end of the boom, could pick up a pole from the trailer, move it into position, turn it upright, and set it into the hole prepared by the earth auger. A nonexclusive licensing agreement has been reached with Gerlinger Industries Corp. of Salem, Oregon, for sale and distribution of the plow. *Project Manager: T. J. Kendrew*

ROTATING ELECTRICAL MACHINERY

Shaft torsional monitor

Severe electrical disturbances on utility transmission networks often ripple through the turbine generators connected to the network, causing mechanical damage. For example, couplings may slip, coupling bolts may be galled, and vibration may increase. When shaft damage is severe, the unit must be shut down, resulting in a costly, unplanned outage for extensive repairs. A disturbing number of such incidents have been reported in the United States and abroad.

EPRI funded an initial three-year research project with General Electric Co. in 1980 to develop a shaft-monitoring system that would both warn utilities when damage had occurred and assess the extent of the damage (RP1746). The instrumentation developed measures both electrical and mechanical perturbations associated with severe electrical disturbances. The electrical data are indispensable in determining the nature, severity, and frequency of disturbances; the mechanical data show the degree of shaft motion at both ends during a disturbance.

When combined and analyzed, the electrical and mechanical data permit a utility to calculate stress all along a shaft, loss of shaft life, and the turbine generator's response to a given disturbance. The first two items are determined by applying the data to two custom model representations of the specific shaft involved. This analysis is printed out at the power plant's terminal within 30 min of the disturbance (Figure 4).

Archival storage of the original (raw) data and the results of the analysis will be securely maintained in the remote computer and available to and accessible only by that

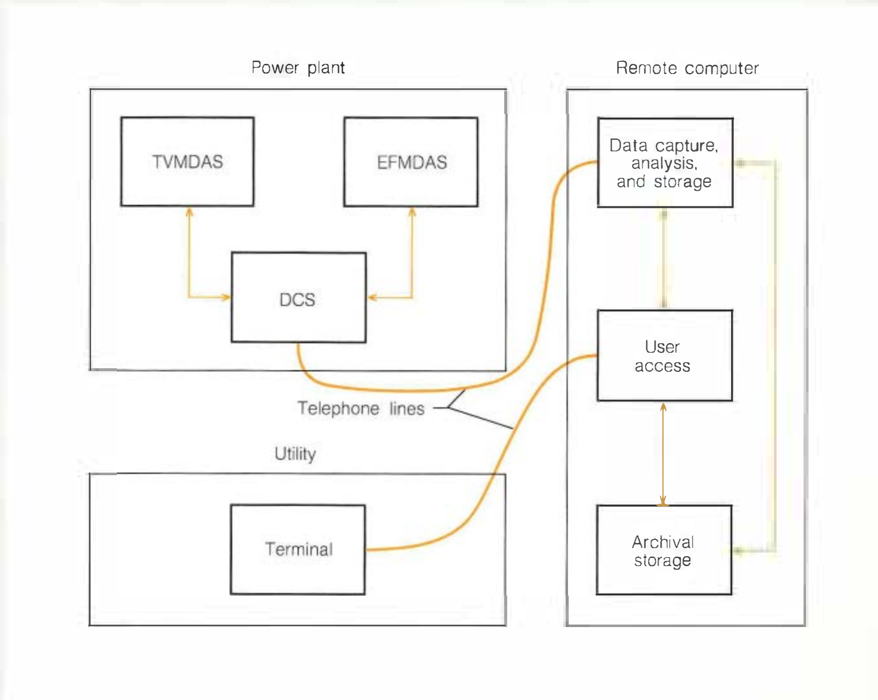


Figure 4 When an electrical disturbance produces significant torsional oscillations on the turbine generator shaft system, mechanical and electrical prefault data and fault data are temporarily stored by the torsional vibration monitor data acquisition system (TVMDAS) and the electrical fault monitor data acquisition system (EFMDAS). These data are communicated to the remote computer by the data communication system (DCS). Analysis of the data is sent back to the originating power plant and to any other terminal that has been established by the utility.

utility. Having the original data permits the reassessment of all recorded faults in the event the industry develops a better and more highly refined representation of shaft torsional fatigue characteristics.

An anonymous analysis of data collected from all utility monitors will be published in the final report. The conclusions from this analysis will provide the industry a new dimension in the specification and application of turbine generating equipment, turbine generator maintenance, and systems operation planning as it affects system performance and the capability of electric generation equipment.

During operation, the original data are placed in a memory bank for further comparative analysis. Data received during this EPRI project will be stored in an anonymous memory bank. The final project goal is the statistical analysis of the data from all participating utilities.

This shaft torsional monitoring system is now available to utilities for permanent installation on turbine generating units. The monitor and the supporting analysis will provide users with a continuous record of loss of shaft fatigue life and a record of interactions between the turbine generator and the power system. In addition, the monitor can help reduce maintenance expense by identifying problems well in advance and by predicting difficulties to be expected in disassembly, such as seized or distorted couplings and coupling bolts.

A large number of shaft torsional monitoring systems need to be installed in participating utilities across the United States if EPRI is to develop a satisfactory electrical fault and shaft response data base. In return, participating utilities will be given a detailed analytic and statistical assessment of their own data. The anonymous analysis of data collected from all other utility-owned monitors will be published in the final report. This information will provide the industry with a far better base from which to review and modify operating practices, as well as aid them in specifying new equipment. Interested utilities should contact the EPRI project manager. *Project Manager: James Edmonds*

POWER SYSTEM PLANNING AND OPERATIONS

Hierarchical control and data management

As digital computer costs have plummeted in recent years, utilities are finding wider use for computers in day-to-day operations. In power system operations, computers are applied from the multicompany power pool supervisory level, through control area functions, down to generation and transmission remote substations. The availability of computers at these levels has caused an information explosion. Two research projects were initiated to identify a means of getting the right information to the system operator at the right time.

In a three-year project, Computer Sciences Corp. has developed a digital computer program for analyzing the performance and cost of a multilevel computer environment (RP1047-1). This multilevel environment in electric utilities is a result of the installation of digital computers at data acquisition remote terminal units, area control centers, company control centers, and power pool control centers.

The program developed by Computer Sciences is intended for use by those utilities planning to install new computer equipment or planning to upgrade equipment already installed. The computer program is designed to analyze trade-offs of various computer equipment, application programs, and geographic distributions of communication equipment.

In the first level of the analysis, the user can explore variations on hardware and software locations and the effect on computer and communication equipment use and performance. Once several prospective variations meet the performance requirements, the user can analyze the costs associated with each of these variations.

The final report describing the tools developed during this project will be available by May 1982. The computer program will also be available from the Electric Power Software Center at that time.

In a second three-year project, Case Western Reserve University has developed a method for recognizing the characteristics and trends of the large amounts of data available from data acquisition remote terminals (RP1047-2). Whereas the Computer Sciences project addressed the data management problem from the top down, this research concentrated on the wealth of data available from remote substations.

The technique that Case Western has developed uses pattern recognition with the aid of associative memories. Several analytic breakthroughs during this project have considerably improved the practical use of associative memories. The first development extended the number range of the patterns from Boolean values (0 and 1 only) to the full number range. The second advance was the organization of the stored patterns into a multilevel framework when the technique was applied to a static security problem at The Cleveland Electric Illuminating Co. This natural, hierarchical clustering of the power system data greatly improved the associative memory pattern recognition time.

The application of the associative memory technique to Cleveland Electric's static security problem demonstrated the feasibility of this method for practical application in the electric utility industry. In addition to the specific application studied, the associative memory technique has potential for application in power plant equipment status monitoring, preventative maintenance scheduling, and system stability assessment. The final report on this project is available from the EPRI Research Reports Center. *Project Manager: Charles Frank*

Economic operation of power systems

Continual changes in electric utility operating conditions require a periodic reevaluation of the methods used to improve economic operation. A major incentive for the recent reevaluation has been the continued rise in fuel prices.

The objective of the research described here was to reduce the cost of power system operations (while retaining acceptable system stability, security, and reliability) by improving system control performance, generation dispatch techniques, and fuel scheduling coordination.

Key factors that affect the performance of member companies of an interconnected power system were to be identified. This control performance analysis is performed by each member of each control area of an interconnection. In evaluating generation dispatching methods, the contractors determined which generating unit parameters have the strongest influence on economic operations. Coordinated long-term (yearly), mid-term (daily), and short-term (real-time) fuel scheduling was developed.

Of the seven contractors that have been conducting research under RP1048, six have completed their work. The final reports on these projects are either published and available from the EPRI Research Reports Center or are in the last stages of the publication process.

The first three projects to be discussed performed research in the system control performance area. In a 33-month project, Control Data Corp. developed methods for analyzing the performance of any control area in an interconnected power system (RP1048-1). Northern States Power Co. assisted Control Data in this project by providing both technical device and power system data. Control Data used two digital computer programs during this project. One was developed in RP1048-4 and will be discussed below. The other program was developed by Control Data during this project and is available from the Electric Power Software Center. This is a capacity allocation program, which can be used to analyze the performance of a control area. The final report on this project is contained in four volumes (EL-1774). These volumes describe the work done on this project and contain the program information for the capacity allocation program.

In a separate two-year project, Philadelphia Electric Co. developed an area control simulator digital computer program (RP1048-4). Philadelphia Electric Co. developed this program for use by Control Data in the RP1048-1 study. The program allows any control area of a larger interconnected network to investigate the impact of its operating strategies on its system control performance. The area control simulator program is available from the Electric Power Software Center. The final report on this project is contained in three volumes (EL-1648). These volumes also describe the work done on this project and contain program information for the area control simulator program.

One of the largest factors in economic performance is the change in the cost of generating at different levels of power output. As an adjunct to the Control Data research, a project with Power Technologies, Inc., was also undertaken (RP1048-2). This was a three-year project to develop analytic models of power plant components. Once these models were developed, Power Technologies used them to investigate the impact on thermal efficiency while a power plant is helping to match system generation to system load. The results of this project show that for the ranges of pressure and temperature excursions experienced by a power plant in regulating duty, only a small change in thermal efficiency results. The final report on this project will be available by the end of the year.

The next two projects performed research in the general dispatch area. In a 30-month project, Philadelphia Electric Co. evaluated the methods now used to determine and update generation unit total and incremental cost representations (RP1048-3). It then began a series of repeated tests of three steam turbine generators and two gas turbines. The purpose of these tests was to determine which generator unit parameters most strongly affect economic operation and how repeatable were the results obtained from the testing. The final report on this project will be available in November.

In a separate seven-month study, Science Applications, Inc., investigated the feasibility of on-line measurement of the thermal content of coal with a measurement error of less than 2%. The final report on this project (RP1086-2) is contained in Volume 5, FP-989.

In the third research area, two contractors examined ways to improve coordinated fuel scheduling. In a 27-month project, Power Technologies examined the daily fuel scheduling of the New York Power Pool (RP1048-5). Power Technologies investigated the use of the mixed-integer linear programming and sparsity techniques for the daily pool fuel-scheduling problem. The final report on this project, EL-1659, is contained in three volumes.

In a five-year project, Boeing Computer Services, Inc., is developing computer programs for long-term (yearly), mid-term (daily), and short-term (real-time) fuel scheduling (RP1048-6). An interim report on this project, EL-1319, was published in January 1980. The work on this project, which is being done in conjunction with Public Service Co. of Colorado, will continue into mid-1982. *Project Manager: Charles Frank*

TRANSMISSION SUBSTATIONS

Light-triggered thyristors

Light-fired thyristors have had an initial successful demonstration in one phase of the Westinghouse static VAR generator at the host utility, Minnesota Power & Light Co. (RP750; *EPRI Journal*, March 1980, p. 47). In another application, a General Electric HVDC valve using light-fired thyristors is planned for installation at the host utility, Los Angeles Dept. of Water and Power (RP1291; *EPRI Journal*, July/August 1981, p. 51). Development by both contractors is continuing to further simplify the VAR generator and HVDC valve, to reduce system cost, and to increase system reliability.

In the fall of 1981, after more than a year of successful operation, Westinghouse will remove the light-fired thyristor phase from the MP&L VAR generator and rebuild it for test of a new generation of thyristors (RP567). These new light-fired thyristors will be resistant to high dv/dt and will have been designed to self-trigger safely in the event of an overvoltage in the absence of a light-triggering pulse. To maintain operation of the VAR generator in the interim, the original electrically triggered thyristor phase will be put back into service. The light-fired unit will be returned to the factory, where the new thyristors will be installed and the unit thoroughly tested prior to return to service at MP&L in mid-1982.

Paralleling the Westinghouse work (RP567), General Electric is developing thyristors for high-current HVDC valves (RP669-2). In this effort, reduction of operating losses by increasing the thyristor working voltage becomes of equal—if not greater—importance than the cost of the semiconductor devices themselves. For any device, the power loss at a given operating current is essentially fixed, based on the junction voltage drop. Therefore the higher the thyristor operating voltage the lower the valve losses because fewer devices are required in series to block the voltage applied to the valve.

In an earlier phase of the project, an integrally light-triggered device with a 2.6-kV breakdown voltage was developed. Then a 5-kV device was developed, but it required a separate light trigger. Now a 5-kV integrally light-triggered thyristor will be available in the immediate future.

Two additional thyristor advances are contemplated. The first addresses the problem of surface leakage and voltage breakdown at the thyristor edge due to high electric field stress. Despite attempts to correct this weakness mechanically by carefully beveling the edge to a controlled angle, followed by passivation, surface breakdown occurs at a lower voltage than breakdown through the bulk of the semiconductor. However, by a technique called junction termination extension, in which suitable doping patterns are used, the surface voltage gradient can be reduced to a level at which it is no longer the weak link, thus attaining the maximum breakdown voltage governed by the bulk semiconductor properties. The second development provides the thyristor with self-protection by initiating controlled safe breakdown at overvoltage and high available current levels. Excellent progress is being made. *Project Manager: G. I. Addis*

Transformer life characteristics

Two EPRI-sponsored projects designed to develop a better understanding of transformer reliability have recently been completed. General Electric (RP-1289-1) and

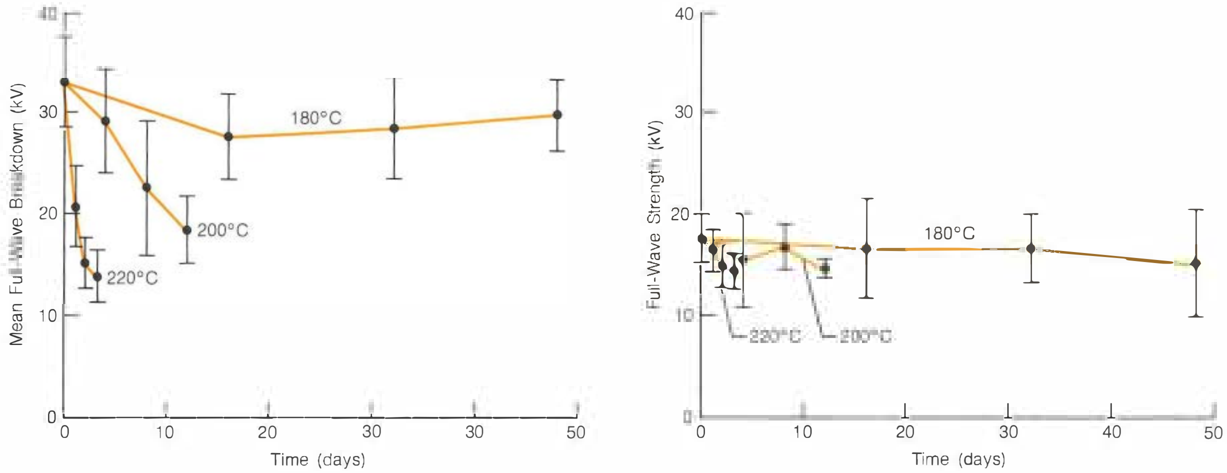


Figure 5 Reduction of dielectric strength with aging is evident for both paper insulation (left) and film insulation (right). Higher temperatures also had a deleterious effect.

Westinghouse (RP-1289-2) both focused two- to-three-year projects on evaluation of short-term and long-term failure modes; the potential short-term failure paths resulting from gas evolution leading to bubbling were reviewed in an earlier *EPRI Journal* article (November 1980, pp. 45–46).

For the past year both contractors have been evaluating the behavior of transformer subassembly models aged in an environment designed to accelerate aging and loss of life. Westinghouse tested a number of models employing both thermally upgraded paper insulation and powder-coated epoxy thin-film insulation at elevated temperatures to simulate hot spots of 180–220°C. Samples survived over 1700 hours at 180°C and 400 hours at 200°C. All models showed reduced 60-Hz and impulse breakdown strength with aging time, and as expected, the breakdown strength dropped more rapidly as the aging temperature increased. The paper-insulated models lost dielectric strength more rapidly than did the film-insulated models, but the latter showed lower initial values (Figure 5 gives impulse breakdown data). Westinghouse has concluded that the tensile strength criteria employed in industry specifications (50% reduction) provide acceptable end-of-life criteria with margin to spare and might be too conservative. Westinghouse is currently attempting to scale these results to full-size transformers.

General Electric life-testing was performed with models equipped with a conservator. Dielectric breakdown strength tests at 60 Hz for about 600 hours (after 180°C aging) support the conclusion that aging results in loss of strength, in this case for modified cellulose and Formvar-enamel film insulations. Model turn-to-turn dissipation factor, water content in oil, oil dissipation factor and breakdown strength, and gases in oil (CO_2, CO) were all measured. General Electric concluded that gas generation appears to be a sensitive indicator of insulation degradation.

The objective of these projects was to examine parameters that influence transformer life to determine the most significant variables, with focus on the core and coil assembly of the transformer; establishment of reliable test methods was another objective. At the beginning of the project, questions existed, for example, on the significance of bubbling, on the merits of tensile strength as aging criteria, and of course, on how to predict loss of life. As is typical of research projects, some questions have been answered, and others have become more pertinent. A substantial number of data were generated and are in the process of being evaluated. However, some overall general conclusions can be noted.

- Gas evolution appears to be small at 140°C, greater at higher temperatures.
- 60-Hz or impulse testing can be employed to follow loss of life.
- Conductor nature (Cu or Al) does not influence loss-of-life behavior.
- Dielectric strength in the presence of the evolved gases (bubbles) does decrease in model coil tests.
- Gas nature (i.e., air and/or cellulose decomposition products) does not appear to influence dielectric strength.
- Gas evolution from hot metallic surfaces does not represent a failure mode.

After these projects were completed, a workshop was held in Washington, D.C., with 35 representatives from the industry (utilities, manufacturers, paper suppliers, and DOE) participating. The workshop focused on the results of this work, on related work elsewhere, and on questions that arose as a result of the projects. The conclusions from the workshop will be useful when planning future work in this area. *Project Manager: Bruce Bernstein*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

DEMAND 80/81

Demand 80/81 presents national forecasts of electricity, liquid hydrocarbons, gaseous hydrocarbons, and coal end-use consumption for the period 1980–2000. The forecasts are based on an econometric model the equations of which represent each end-use sector's consumption of each energy form. Each consumption forecast depends on a forecast of long-run economic growth, together with energy price and conservation policy assumptions.

This study endeavors to reduce some of the uncertainty of long-range national energy needs by projecting the long-range demand for fuels and electricity by economic sector. The projections depend explicitly on assumptions made about the growth and composition of national income and about future relative price trends for fuels and electricity. The projections also depend implicitly on a large number of assumptions made during the construction of each of the sector energy demand models. Other important assumptions were made about the specific way in which these sector models were linked to each other and to the macroeconomic forecast. The Demand 80/81 forecasts should be viewed as ongoing Demand and Conservation Program research and not as an official EPRI electricity and energy forecast.

This research is part of the Demand and Conservation Program's analysis of long-run U.S. energy consumption trends for each economic end-use sector. The major objectives of the forecasts are to provide the following.

- A national perspective to help individual utilities in their forecasting and planning efforts
- A means of testing the performance of energy analysis models developed under EPRI's research programs
- A means of focusing discussion and analyzing the impact of government policies
- An input in the development of EPRI's R&D plan

The Demand 80/81 model covers the major energy-consuming sectors—residential, commercial, industrial, and transportation. Consumption of coal, gas (including coal gasification products), oil (including coal liquefaction products), solar energy, and electricity was forecast for each sector.

Although the data are consistent within each sector, different sectors use different methodological approaches and data. For this reason, fuel use growth by sector is first forecast in percentage growth terms. This figure is then used as a benchmark for the corresponding actual value of the most recent complete year in the U.S. Energy Information Administration's FEDS data base. This makes it possible to forecast energy consumption levels with fully compatible definitions.

Some of the main determinants of future energy consumption trends, such as rates of economic growth, fuel prices, and conservation policy, can be forecast only with considerable uncertainty. Moreover, even if these factors were known with certainty, there would remain many areas of uncertainty about the model itself and the accuracy with which the equations capture the main features of energy consumption behavior.

Modeling many alternative sets of assumptions clarifies the forecast's dependence on exogenous assumptions. In fact, the insights obtained by comparing the relative forecast levels of one scenario with another is a major benefit of the modeling process. Because of the inherent uncertainties in the input assumptions and of the models themselves, the absolute levels of the forecast should be used cautiously. A prudent procedure is to use multiple scenarios and evaluate sensitivities to input assumptions.

Assumptions

Twelve scenarios were developed for Demand 80/81. These scenarios dealt primarily with alternative assumptions about fuel prices, conservation measures, and nonprice influences on future energy consumption. Although the model responds to alternative assumptions about the rate and composition of economic growth, only one macroeconomic scenario was available when the forecasts were run. It should also be noted that there is no account of possible effects of the total energy sector (i.e., producers and consumers) on the general economy.

Three sets of assumptions about future energy prices were developed: baseline, low, and high. Given the inverse relation between energy consumption and prices, these can be thought of as baseline, high, and low consumption scenarios. A fourth class of forecast runs was made with all energy prices in real dollars held constant at their 1976 level. This forms a convenient (but arbitrary) reference line from which comparisons can be made about the amount of price-induced conservation there is in the outputs of the other three price scenarios.

The price assumptions, developed at EPRI, enter the demand equations in two stages. The first stage involves setting the national primary fuel prices. (Table 1 shows the annual percentage growth rate.) Then a series of markups and other transformations are

Table 1
IMPORTANT ECONOMIC ASSUMPTIONS

	Average Annual Growth Rate 1980–2000 (%)		
	Low	Baseline	High
GNP	2.9	2.9	2.9
Oil prices	3.5	4.2	4.9
Gas prices	5.2	6.0	6.6
Coal price	0.3	0.7	0.9
Electricity price	0.5	1.3	2.0

Table 2
FORECASTS OF ELECTRICITY GENERATION, YEAR 2000

	Nonprice Conservation Assumption					
Price Assumption	None		Baseline		Extra	
	10^{12} kWh	%*	10^{12} kWh	%*	10^{12} kWh	%*
Constant 1976	5.2	4.0	4.8	3.6	4.6	3.4
Low	4.9	3.7	4.7	3.5	4.5	3.3
Baseline	4.4	3.2	4.2	3.0	4.1	2.9
High	4.0	2.7	3.8	2.5	3.7	2.4

Note: Does not include cogeneration.

*Annual average percentage change, 1978–2000.

Table 3
FORECASTS OF TOTAL ENERGY CONSUMPTION, YEAR 2000

	Nonprice Conservation Assumption					
Price Assumption	None		Baseline		Extra	
	10^{15} Btu	%*	10^{15} Btu	%*	10^{15} Btu	%*
Constant 1976	146	2.9	138	2.6	123	2.1
Low	118	1.9	112	1.6	99	1.0
Baseline	112	1.6	106	1.4	93	0.8
High	106	1.4	101	1.1	88	0.5

*Annual average percentage change, 1978–2000.

applied to obtain the prices paid by the end users in each sector.

Estimates of nonprice conservation are included in the final forecast results. These measures include incentives, standards, and mandates passed at all levels of government. Many of the steps in making these estimates are judgmental. However, this type of procedure has the advantage of taking explicit account of the nonprice measures. Ignoring the effects amounts to a judgment that nonprice conservation has no impact.

There are three nonprice conservation scenarios: none, which assumes nonenforcement or zero impact of existing nonprice conservation measures; baseline, which attempts to assess the likely impact of current and proposed legislation on energy consumption; and extra, which assesses the potential of nonprice conservation if all levels of government push for significant increases in various nonprice measures. Although these seem more extreme and less likely, they are feasible public choices.

Results

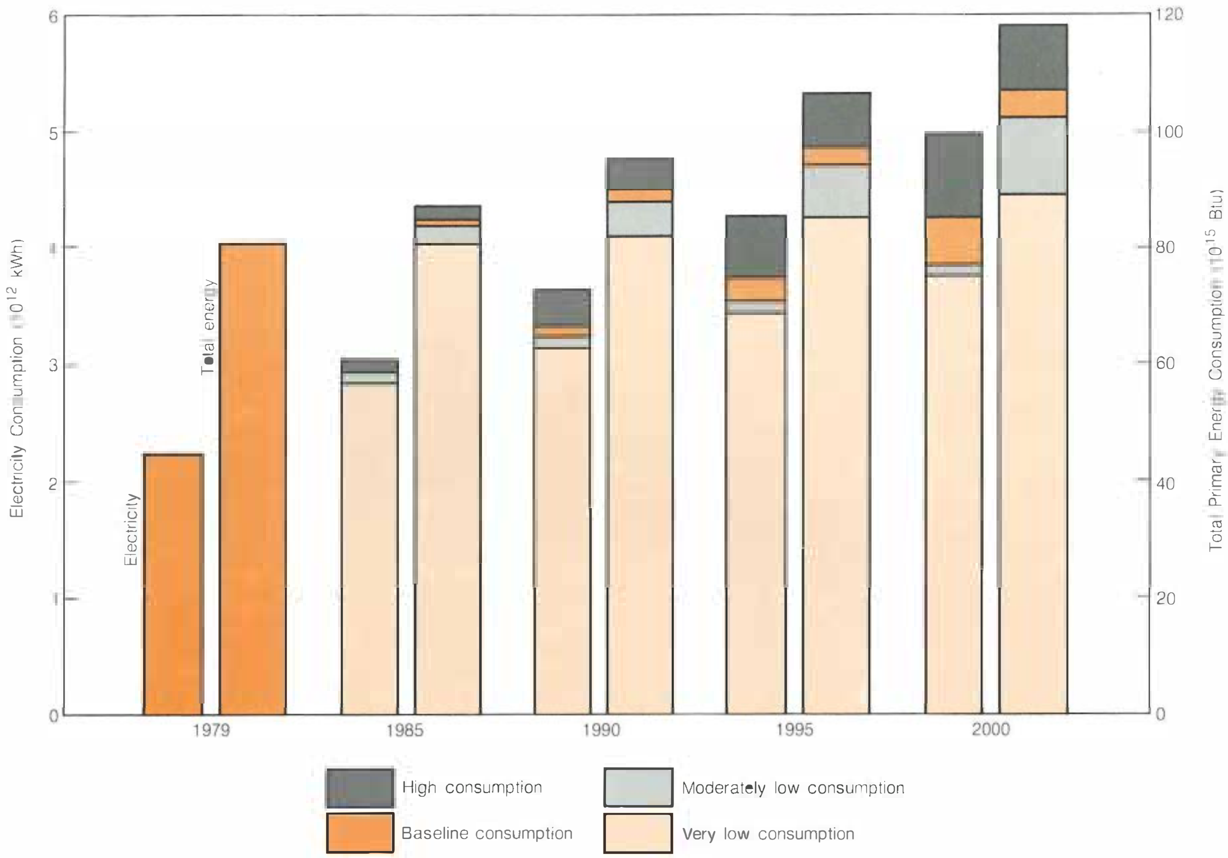
Tables 2 and 3 summarize the forecast results. The four most important cases are:

- Low price, no conservation
- Baseline price, baseline conservation
- High price, baseline conservation
- High price, extra conservation

These represent a high case, a baseline, a low case, and a very low case. Figure 1 shows these four cases. All show that the electricity sector's share of total primary energy increases from about 31% in 1979 to 37–44% in 2000. The highest electrification result is produced in the very low consumption scenario.

The average annual growth rates for electricity range from 2.5% (low consumption) to 3.7% (high consumption) per year. For the same cases, total energy grows between 1.1 and 1.9% per year. (For this discussion we excluded the very low case as improbable.) The baseline price, baseline conservation case shows electricity growing at 3.0% per year and total primary energy at 1.4% per year. For the baseline case, price-induced conservation reduces the year 2000 electricity consumption by 15%. Total primary energy consumption is reduced by 23% in response to price. After the price effects are taken into account, the nonprice effects are much smaller: 5% for electricity and 5% for total primary energy. *Project Manager: L. J. Williams*

Figure 1 Demand 80/81 forecasts: U.S. consumption of electricity and total primary energy.



R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

BEST FACILITY

The Battery Energy Storage Test Facility, a national center for the evaluation of advanced battery systems that are under development for utility application, was dedicated on May 14, 1981. The BEST Facility concept and its implementation are products of cooperation among government, the utility industry, and technology developers; it reflects their mutual desire for the commercialization of cost-effective, oil-saving battery energy storage for utility service. The facility will provide for the testing of 500-kWh to 10-MWh battery systems, permitting the identification of remaining technical and system issues, while minimizing test facility and prototype battery costs. As soon as advanced batteries are verified by the developers at the component and module level, the BEST Facility will be available for evaluation of their performance as a storage system integrated with a utility grid.

The overall objective of the BEST Facility project is to reduce the technical, financial, and safety risks associated with introducing battery energy storage technology into electric utilities. By permitting evaluation of battery technology at the midpoint between large-scale laboratory modules and fully commercial battery configurations and sizes, the BEST Facility will help protect investments in technology development, which are likely to reach several hundred million dollars over the next 5–10 years. It will also expedite the use of batteries in commercial utility service. Batteries and associated equipment will be subjected to treatment similar to that experienced in utility service, for example, interruptions in charging or discharging and long periods of time on standby. Utility personnel will become familiar with the operation of battery systems and will thus be better able to take advantage of their characteristics and assess their maintenance requirements. Important information on the interaction of batteries, power conversion equipment, and the utility system (especially the local substation) will be developed to assist design and planning engineers when full-scale battery installations are being pursued.

The facility, which is located in Hillsborough Township, New Jersey, was built by Public Service Electric and Gas Co. under contract to DOE and EPRI. PSE&G also shared construction costs and will operate the facility for DOE and EPRI. Acceptance testing is under way with a 1.8-MWh lead-acid station battery that has been installed in the first of the facility's three test bays. The battery is now charging and discharging successfully on the utility grid. The line-commutated power-conditioning system and the process control computer have been interconnected with the battery and are functioning satisfactorily. Software for automatic control is being developed. Acceptance testing is scheduled to be completed by the end of the year.

The facility's three test bays will eventually enable up to three multimegawatthour advanced battery systems to be evaluated at one time. Zinc chloride, zinc bromide, sodium-sulfur (beta), lithium–metal sulfide, Redox, and advanced lead-acid battery systems are all candidates for the second and third bays. Although there is still some uncertainty about the timing of advanced battery tests, zinc chloride, zinc bromide, and beta batteries are expected to be tested in the 1983–1986 timeframe.

Installation of each advanced energy storage system (or advanced power-conditioning system) at the BEST Facility will require considerable attention to the interfacing and control of all components. Because the system will be operating on the utility grid, supervisory procedures will be critical to the safe and proper conduct of the tests and to the maintenance of equipment integrity.

A set of test program guidelines is now being developed at PSE&G with the cooperation of user groups representing utilities and developers. These guidelines will establish a uniform framework for the test plans to be submitted by battery developers. They will cover objectives, performance capabilities, instrumentation, test schedules, operation, control, maintenance, data dissemination, and reporting. In meetings with battery developers, general requirements for three phases of testing have been identified. These are summarized in Table 1.

Each potential battery application will

Table 1
BEST FACILITY TEST SERVICES

	Phase 1	Phase 2	Phase 3
Objective	Verify system design concepts	Assess performance in utility environment	Extend cycling on utility grid
Hardware	Preprototype (≥500 kWh)	Prototype (1–5 MWh)	Prototype (5–10 MWh)
Instrumentation	Selective monitoring of key parameters	Comprehensive monitoring	Commercial level
Testing	Developer-oriented	Utility-oriented	Utility dispatch

have particular testing requirements. Battery units might be used for utility load leveling or peak shaving, for example, which can be performed on either a daily or a weekly cycle. Batteries might also be useful for system regulation or spinning reserve.

The charge and discharge rates used in testing will be derived from analyses of representative utility load curves. However, the duration of discharge for individual battery units in an actual utility application will depend on the mode of operation and utility dispatching methods. Batteries might be operated at constant power, or they might be used for load following. These modes might be accomplished by maintaining or varying the output of all units simultaneously; by using a stepped, sequential approach, with each unit operating for the same length of time; or by using some combination of these approaches. All reasonable modes within the facility's capabilities will be evaluated. Testing at the BEST Facility will thus help determine the regime under which each battery is most reliable and economical.

The first major use of the facility, which will follow completion of acceptance testing, will be to verify and expand the testing procedures with the station battery. PSE&G will continue to be the prime contractor, operating the facility under the joint sponsorship of DOE and EPRI. A final report on the construction of the facility is in preparation, and the guidelines for use by equipment developers and utility personnel in planning test programs are also nearly ready for publication. *Project Manager: William Spindler*

UNDERGROUND PUMPED HYDRO

Early studies by EPRI suggested technical and commercial feasibility for energy storage concepts involving the underground storage of air (compressed-air energy storage, CAES) or water (underground pumped hydro, UPH). In a recently completed project (RP1081-1), Potomac Electric Power Co. (Pepco) has developed methodologies, cost estimates, cavern configurations, and plant and machinery details for the concept of UPH storage. These studies indicate that compared with the most competitive combustion turbine alternative, 668 MW of UPH for the Pepco system would yield a $1.25 billion savings and an annual oil savings of 16 million barrels.

Energy storage is the process by which electricity is generated off-peak by baseload plants using relatively low-cost fuel, such as coal or nuclear, and then is made available to the utility system during peak load periods. In its generating mode, a pumped-hydro storage plant is operated like a conventional hydroelectric plant. In the charging mode, during off-peak periods, baseload electricity drives pumps that move water from the storage plant's lower-level reservoir to the upper reservoir. This use of off-peak electricity for pumping keeps the baseload plants nearer full load and maximum efficiency, an important component in reducing production costs.

Because energy from pumped storage replaces energy supplied by intermediate and peaking units, the storage plants save oil or gas and lower overall production costs. In addition to providing capacity to meet system load demands, the plants can be dispatched to provide spinning reserve. Rapid load changes can be easily accommodated in the generating mode. The plants can also aid in system regulation of both load and frequency.

The first pumped-hydro storage project constructed in the United States was the 32-MW Rocky River Project of Connecticut Light and Power Co. (now Northeast Utilities), which went on-line in 1929. The first major U.S. plant went into operation at Niagara Falls in 1954. Since then there have been approximately 30 pumped-hydro projects, totaling almost 13 GW. These have all been of the conventional type; that is, both reservoirs have been constructed at ground level, the upper reservoir usually on top of a mountain and the lower reservoir in a nearby valley. Conventional pumped-hydro storage facilities have specific topographical requirements for the siting of both upper and lower reservoirs, involving greater alteration of land and water resources. An appropriate site is usually remote from load centers; thus extended transmission lines and rights-of-way are necessary, increasing the environmental impact.

EPRI studies have concluded that economic and environmental benefits could be obtained through UPH, that is, by locating the lower reservoir in suitable bedrock at levels 3000–5000 ft (900–1500 m) below ground surface level. Numerous areas scattered throughout the contiguous United States have been identified as having hard rock at depths suitable for underground water storage. Deep borings and seismic surveys are required to determine the most favorable depth and placement of access shafts, water tunnels, and reservoir chambers at a potential site.

In order to verify the commercial design, cost, and availability of the technology for this UPH concept, EPRI and DOE solicited proposals from interested utilities for a preliminary design study. Similar studies were initiated to evaluate the concept of CAES in three different mediums: salt domes, porous aquifers, and hydraulically compensated rock caverns. Pepco, because of the availability of nearby hard rock sites, undertook to assess UPH and CAES in rock caverns (RP1081-1).

Utilities use three basic criteria for assessing the acceptability of any proposed power plant: the capacity must be needed to meet projected system load demands; the plant must yield the lowest total system production costs (which include capital construction costs) of all the options; and the technology must have been demonstrated to be practicable. The objective of the EPRI study was to apply these criteria to UPH with Pepco as the illustrative developer. This required a design of sufficient detail to develop firm cost estimates, define planning activities, establish construction schedules, identify licensing procedures, and determine technical risks. The results were to be used as the basis for a decision about including a storage project in the generation planning schedule.

The study comprised five major tasks. First, overall guidelines for the engineering work and bounding assumptions for the UPH facility were developed. Precedent machinery and power plant installations were reviewed, as well as a full expansion planning study, to establish plant size, storage capacity, installation costs and timing, relative economics, and cost sensitivities to selected design concepts and performance characteristics. Second, a site selection methodology was developed, and several potential sites were evaluated. Because suitable rock is a key to UPH, an exploratory drilling program was performed at the selected site, consisting of a series of shallow boreholes (500–600 ft; 150–180 m) and one deep borehole to 2556 ft (780 m).

Third, design approaches were defined by evaluating various engineering alternatives for system and component designs. With the aid of geotechnical and machinery consultants and manufacturers, configurations for plant shafts and caverns were established and construction schedules and cost estimates were drafted. Fourth, environmental studies were performed for the plant layouts produced. Public safety aspects were addressed, and the magnitude and duration of potential environmental impacts were analyzed. Fifth, the preliminary plant design was formulated and documented. Design decisions and cost estimates were finalized, and reliability and cost risks determined.

The power available from UPH is a direct function of the product of head times flow. Because the excavation of the storage caverns involves over 30% of total plant costs, the volume of the caverns—and hence the water flow—must be minimized. This is accomplished for a given power requirement by increasing the head, that is, the depth of the lower reservoir. UPH heads (depths) of 5000 ft (1500 m) are envisioned as practical. For this head, three types of pump-turbines are available.

□ The single-stage reversible pump-turbine (SSRPT) is the conventional machine that has evolved from Francis turbine and centrifugal pump experience. Currently, it can achieve heads of 2000 ft (610 m). By setting two of these machines in tandem cascade, water storage at twice their individual heads could be achieved; this two-step arrangement is designated SSRPT-2.

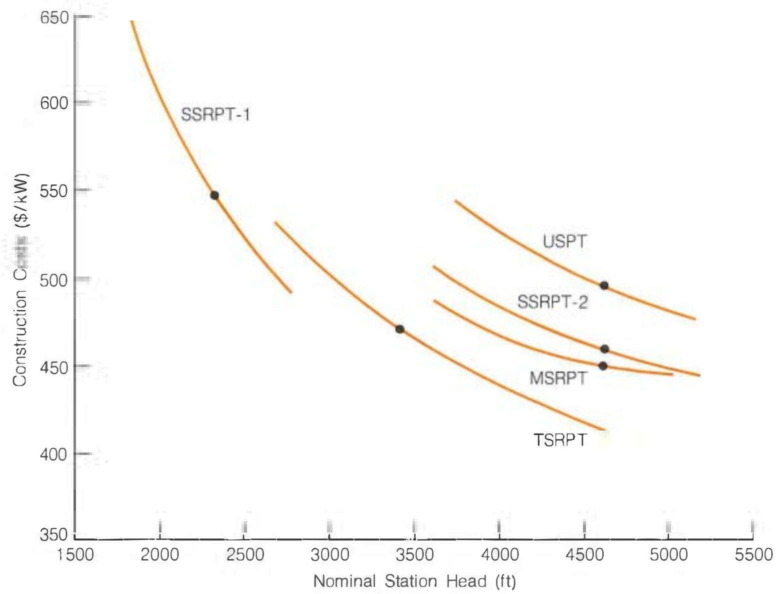
□ The multistage reversible pump-turbine (MSRPT) achieves high heads by combining several impellers in one casing. A major operating disadvantage of these machines is that they do not provide flow control.

□ The unirotational separate pump-turbine (USPT) uses a Pelton impulse turbine and a separate centrifugal pump. These units are conventional state-of-the-art units, but the resulting plant configuration is more expensive because a long shaft is required between the pump and the turbine.

Characteristic cost curves were developed for the head range achievable by each type of pump-turbine (Figure 1). Cost information was also prepared for a two-stage reversible pump-turbine (TSRPT) with flow-regulating capability, which has been proposed by manufacturers for heads in the range presently covered by MSRPTs. However, although such units have been designed, none have been extensively tested, and none are in commercial operation. Thus this economically advantageous concept could not be considered available. The Pepco study selected the SSRPT-2 arrangement, the lowest-cost commercially available machinery meeting the required operating criteria.

The engineering analyses and design efforts resulted in the selection of a two-step arrangement—two power plants in series, with a small intermediate balancing reservoir (Figure 2). A total head of 5000 ft (1500 m), 2500 ft (750 m) for each step, was chosen on the basis of reliable predictions of a realistic advance in SSRPT technology. The design calls for six 333-MW SSRPT units capable of regulating load and operating at 720 rpm, three in the intermediate-level powerhouse and three in the lower powerhouse; each unit would operate in tandem with a unit at the other level.

Figure 1 Sensitivity of UPH plant construction costs to head for various pump-turbine configurations. Costs include direct costs and contingency costs only. The dots represent estimates for actual cases.



Vertical and sloping shafts for access to the powerhouses, for equipment handling, and for housing auxiliary mechanical and electrical equipment were designed, as well as shafts and tunnels for the high-pressure water conduits. An underground arrangement for transformation step-up to 500 kV was adopted. High-speed units with water-cooled rotors and stators were determined to be within acceptable limits of technology.

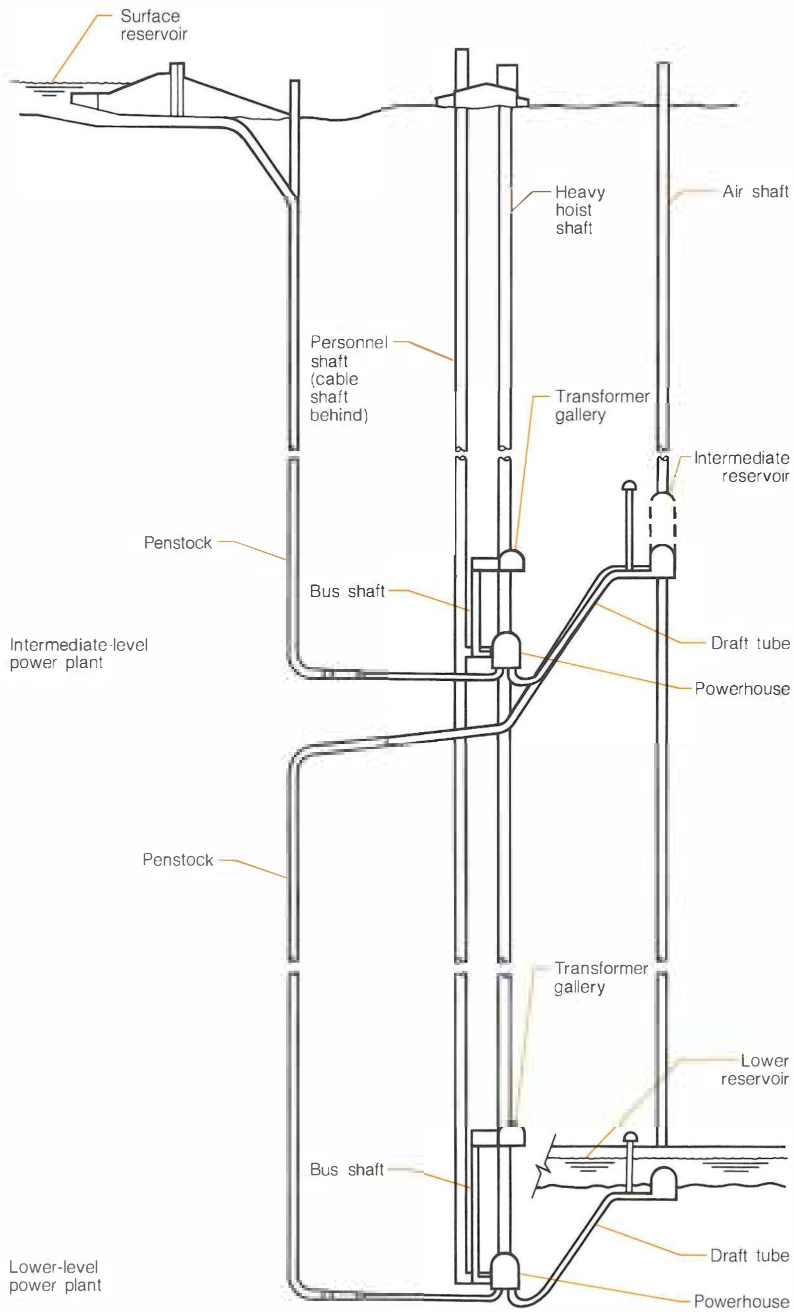
The mid-1979 direct construction costs for the 2000-MW plant were estimated to total $416/kW. When administrative, overhead, engineering and construction management, and contingency costs were added, the estimated project construction costs totaled $603/kW (exclusive of escalation and interest during construction). The breakdown of costs by major components is shown in Table 2.

Because no fuel is directly consumed at the UPH plant site, and because the surface reservoir is small and the surface structures

Table 2
ESTIMATED CONSTRUCTION COSTS FOR 2000-MW (10-HOUR) UPH PLANT

	$ Millions (mid-1979)
Land, site access	6.2
Dams, reservoirs	302.3
Tunnels, shafts	198.1
Powerhouses, civil structures	53.5
Pump-turbines, valves, mechanical equipment	99.1
Motor-generators	80.9
Transformers, electrical and transmission equipment	91.4
Total direct costs	831.5
Administration, overhead, engineering and construction management	249.4
Contingencies	124.7
Total	$1205.6

Figure 2 UPH plant layout. In the generating mode, water is released from the surface and intermediate reservoirs through the penstocks to the hydro turbine generators in each powerhouse cavern. The turbines discharge via the draft tube tunnels into the underground reservoirs. Air vent shafts keep the cavern systems at atmospheric pressure. In the off-peak charging mode, the turbine generators are reversed to operate as motor-pumps. The storage caverns are at a higher elevation than the powerhouses in order to provide positive head on the pumps, thereby minimizing cavitation-erosion on the runners.



limited, the plant's environmental impact is virtually benign. If nuclear- or coal-generated electricity is used for system pumping, peaking with the UPH plant is accomplished without oil. The combination of operating advantages and reasonable construction costs make UPH an attractive generation option from an economic as well as an environmental standpoint. The Pepco system studies found energy storage plants economically attractive for the early to mid-1990s; thus a firm decision to commit to UPH is not needed for several years.

EPRI is sponsoring R&D to make the two-stage regulatable reversible pump-turbine available to the industry within a reasonable time. Use of this machinery would reduce underground plant layout complexity and total plant costs by eliminating the need for an intermediate powerhouse and reservoir and by reducing the size of the lower reservoir. Plant reliability and availability would be increased. Siting flexibility would also be enhanced because competent rock would be needed at only one level. *Project Manager: Antonio Ferreira*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Director

ARRESTING DENTING CORROSION

When nuclear units were changed from phosphate-based chemical water treatment to all-volatile treatment to avoid wastage corrosion, a different form of corrosion resulted. This attack, called denting, occurs when a laminar magnetite (Fe_3O_4) forms in the tube–tube support plate crevices and causes tube constriction. Early work by the Steam Generator Owners Group showed chloride, copper, and oxygen to be the principal chemical aggravators of denting.

Denting control is possible by exercising rigid chemistry control and restricting ingress of these impurities into the steam generator. Some utilities have stopped denting by minimizing condenser leaks and air inleakage, replacing copper-bearing components, and improving feedwater quality. However, denting still occurs in some plants, and work is under way to determine the cause and to find alternative chemical additives that can serve to halt its progression.

The chemical additives must be effective in rapidly halting denting and have sufficient endurance to prevent its reinitiation even during periodic additional system contamination. Alternative chemical treatments have been evaluated in laboratory simulations using periodic soaks under off-line conditions, direct application during on-line conditions, and by a combination of soak and on-line treatment. Laboratory tests using model boilers and heated crevice devices have been made as a preliminary step to applying alternative secondary water chemistry to an operating field unit.

Denting has been successfully reproduced with laboratory model boilers and heated crevice devices with fouled tube–tube support plate simulants in acid chloride media. The morphology of the corrosion produced in the laboratory by using acid chlorides is similar to that found in intersections removed from operating units. Denting has been arrested in laboratory tests by adding alkaline materials, such as calcium hydroxide [$Ca(OH)_2$]. Denting has also been arrested with boric acid, which reacts with the crevice magnetite to form iron-boron compounds that may act to limit the porosity of the crevice region.

Sodium phosphate

Model boiler tests and plant operating experience have shown that on-line phosphate water chemistry inhibits denting at low levels of chloride. However, phosphate water chemistry with high levels of chloride cannot inhibit denting corrosion. Phosphate soaks during off-line periods can halt denting corrosion only if chloride levels are significantly reduced before startup. Arresting denting corrosion with phosphate chemistry control requires on-line additions and careful control of chloride inleakage. Studies of phosphate solutions combined with sludge components show that phosphate-magnetite reactions can occur at steam generator operating temperatures (RP699, S158). As a result of these studies, investigators believe that the reaction products may be sufficiently acid to cause Inconel 600 wastage attack or sufficiently alkaline to cause stress corrosion cracking of Inconel 600. Therefore, phosphate chemistry control to arrest denting is not recommended.

Calcium hydroxide

$Ca(OH)_2$, a strong base with limited solubility at steam generator operating temperatures, has been proposed as a neutralizer for dent-

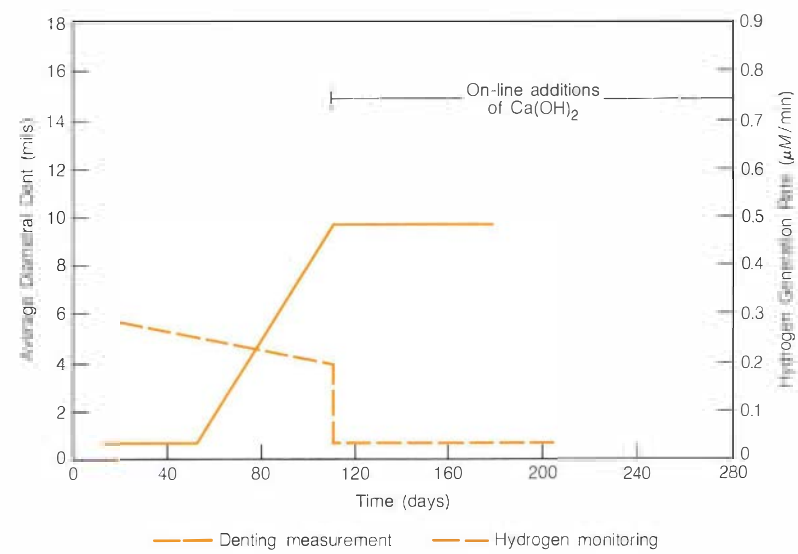


Figure 1 On-line treatment with $Ca(OH)_2$. This process is very effective in arresting denting. Denting initiated with solution concentrations of 0.1 ppm Cl from $CuCl_2$ and 0.2 ppm Cl from seawater. On-line addition was 2.0 ppm Ca as $Ca(OH)_2$.

ing corrosion caused by acid chloride. Its limited solubility makes it an effective neutralizer, while preventing possible caustic cracking, which could result from use of a more soluble alkali. Experimental laboratory work to date that uses calcium hydroxide as a soak with heat flux or in an on-line application has been encouraging (RP623-2, S112).

When used as a soak, $Ca(OH)_2$ alters the rate of denting progression, although denting is not completely arrested. When used as a continuous on-line additive, $Ca(OH)_2$ has been shown to be completely effective. Figure 1 demonstrates this effectiveness by showing data from a laboratory model boiler, which was dented by a chloride solution composed of copper(II) chloride ($CuCl_2$) and seawater. These conditions can produce aggressive denting, which can be measured through tube profilometry (solid line) or corrosion hydrogen evolution (dashed line). With the addition of $Ca(OH)_2$, the measurement of tube diameter and the evolution rate of corrosion hydrogen show that denting has been arrested.

Preliminary studies have also shown that the addition of $Ca(OH)_2$ inhibits the processes by which sodium and chloride concentrate in the crevices (S112). There has been no work to date to examine the effects on the balance of plant or potential scaling on heat transfer surfaces, which could result from the addition of $Ca(OH)_2$ to operating steam generators. This additional testing will be necessary.

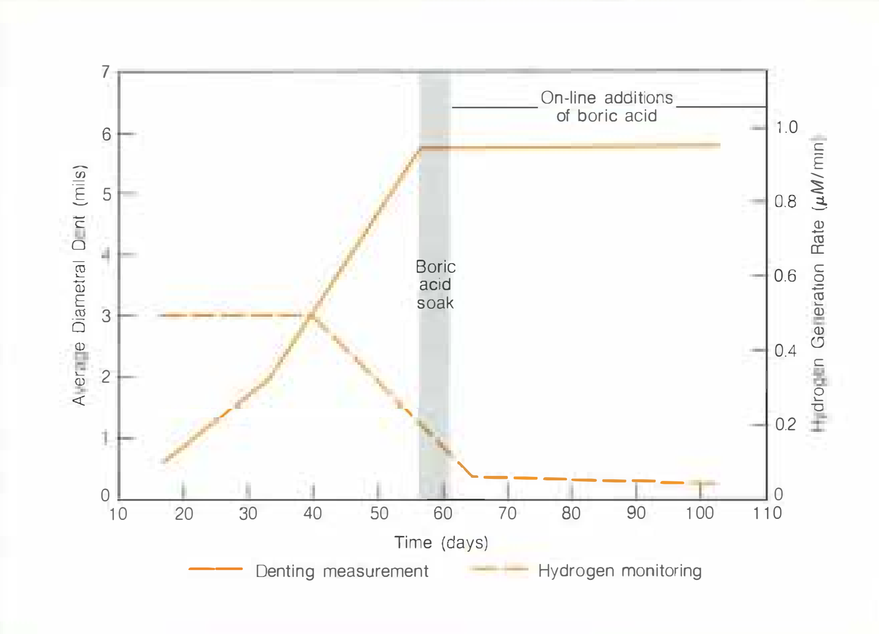
Boric acid

Extensive laboratory tests have shown that boric acid soaks followed by on-line treatment are completely effective in halting denting (RP699, S112). Rather than being a chemical neutralizer of crevice acidity, boric acid is believed to react with the corrosion-generated Fe_3O_4 in the crevice to form iron-boron compounds. These compounds would reduce the crevices' porosity and restrict the diffusion of reactants to the corroding interface. Thus, addition of boric acid stifles the corrosion reaction.

Figure 2 is a plot of denting corrosion and corrosion hydrogen evolution in a laboratory model boiler test of boric acid. Before the boric acid application, denting was progressing at a rate of 4.6 mils per month. The boric acid soak at 50 ppm of boron followed by an on-line level of 10 ppm of boron resulted in a 99% reduction in denting rate as measured by tube profilometry. A corresponding decrease in corrosion hydrogen confirms this reduction.

Boric acid has been effective in many tests, as Figure 3 shows. When boric acid is

Figure 2 Soak followed by on-line treatment with boric acid is very effective in arresting denting. The denting chemistry at all times except during the soak was 0.1 ppm Cl^- from $CuCl_2$ and 0.2 ppm Cl^- from seawater. The boric acid soak chemistry was 50 ppm boric acid; on-line concentration was 10 ppm.



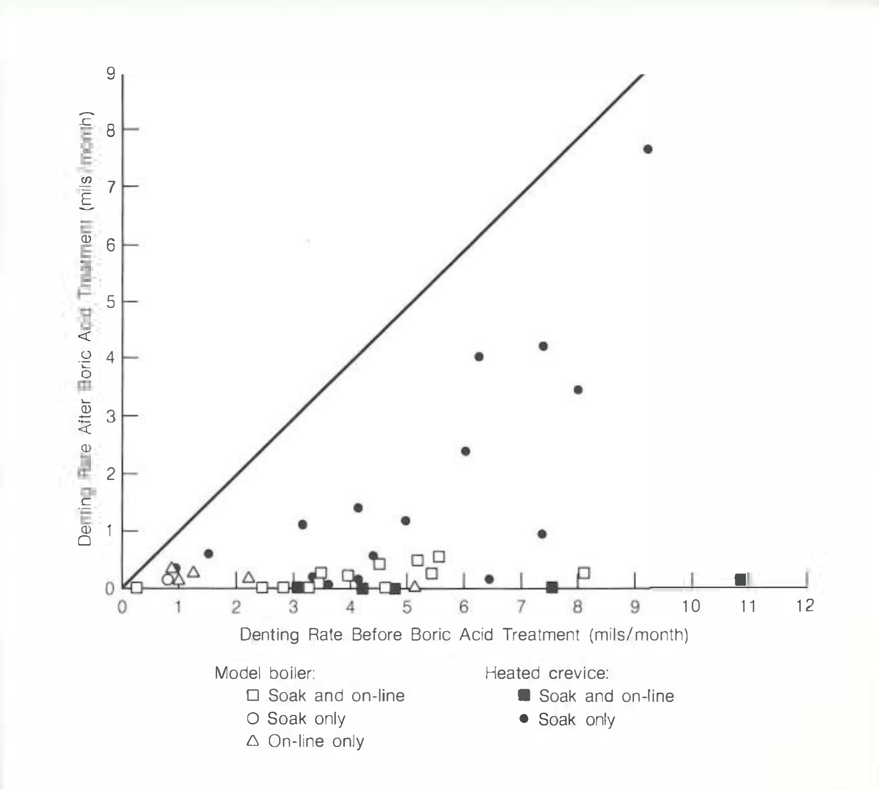


Figure 3 Denting rate correlation shows boric acid additions are beneficial. This figure shows denting rates before and after boric acid additions to heat transfer tests.

used as a soak followed by on-line treatment, the denting rate is reduced an average of 96%. Thus, under a wide range of conditions, boric acid is effective when used as a soak followed by on-line addition.

Destructive examination of tube–support plate intersections from boric acid–treated model boilers has shown the presence of various iron-boron compounds near the corrosion interface. Some of the iron-boron compounds are known to react with chloride and may prevent it from participating in corrosion reactions.

Field applications of boric acid

An experimental program is in progress to evaluate the effectiveness of boric acid in a field situation (S116). In the past, using boric acid in the field has produced mixed results. Corrosion hydrogen monitoring is generally used to evaluate boric acid effectiveness. Although this technique works very well in the laboratory, there are complicating factors in the field that tend to produce high levels of uncertainty. Changes in primary hydrogen concentration and the extent of hydrazine decomposition reactions make the evaluation of corrosion hydrogen difficult.

Although absolute values for corrosion hydrogen measured in field units may be subject to uncertainty, the trend with boric acid application is toward lower values. Current field efforts will use corrosion hydrogen measurements as well as eddy-current testing, tube gauging, flow slot photography, and profilometry in an attempt to quantify denting progression with boric acid treatment. The boric acid field demonstration project is currently at the halfway point and should be completed by mid-1982. Depending on the results, additional work may be undertaken to investigate potential balance-of-plant effects of boric acid application over extended periods of time. *Program Manager: R. G. Varsanik*

HUMAN FACTORS REVIEW OF NUCLEAR CONTROL ROOMS

Various studies of the Three Mile Island accident have concluded that one major contributing factor was an ineffective man-machine interface. An important part of this interface is control room design, where violations of human engineering principles have been well documented. In response to this situation, NRC has directed that all operational control rooms be enhanced to improve the safety and performance of nuclear power plants. This report describes a major EPRI study in this area (RP501-4).

In recognition of the importance of an effective man-machine interface and plant designs that comply with human engineering principles, the nuclear power industry has initiated a series of studies to provide utilities with human engineering guidelines for improving the safety and performance of their facilities. The objective of RP501-4 is to investigate approaches for enhancing nuclear power plant control rooms. The feasibility, methodology, and potential benefits of applying human engineering principles are being examined; violations of these principles, called human engineering discrepancies (HEDs), are being identified and ranked; and corrective retrofit measures that can be implemented during normal plant operation or during outages are being developed. The results of this work will be disseminated to the industry in the form of a how-to report.

Data were collected during one-week visits to four nuclear power plants whose managements had agreed to support the study. Methodological tools that had been found to be effective in earlier aerospace and EPRI-sponsored studies were used: checklists, anthropometric charts, structured interviews, task analyses, noise and lighting surveys, reviews of plant records, procedural walk-throughs and talk-throughs, and photodocumentation.

The R&D team consisted of personnel from Honeywell, Inc., and Lockheed Missiles & Space Co., Inc., and a representative from the Institute of Nuclear Power Operations (INPO). A highly skilled operator or design engineer was assigned by each plant to assist the team in data analysis to ensure that appropriate trade-offs were made between the resolution of HEDs and other criteria, such as engineering problems, cost, and potential negative transfer effects from the retrofit.

During the course of the study, two technical information exchange meetings were held. The first included two utilities that had recently completed a control room review to obtain a near-time operating license from NRC. Also attending were representatives from INPO and two human factors firms (Essex Corp. and General Physics Corp.) that have conducted control room reviews under individual contracts with a number of utilities. The second meeting was held with a task force committee established by the BWR Owners Group, which is actively reviewing a number of BWR plants. The purpose of these meetings was to compare the types of HEDs being identified and to evaluate the feasibility of alternative retrofits.

Following analysis of the data obtained during the plant visits, proprietary reports (both oral and written) were presented to the management of each plant participating in the study. The identification of HEDs was adopted as a convenient way of documenting interim findings and soliciting comments from plant management about the technical practicality of retrofit solutions. It was emphasized that the HED results should in no way be interpreted as a report card or an audit-type assessment. Rather the information, along with plant management's evaluation of it, will be used as a basis for providing the industry with a guide on control room enhancement.

The written report submitted to each plant management contains a summary of all HEDs identified at the plant. For example, here is a list of panel element discrepancies taken from an actual report.

- Many critical controls are located higher than recommended by current human engineering guidelines.
- Many displays are placed too high for readability and access.
- Rod drive control levers on nuclear instrumentation system and rod control panel are placed too close to the edge of bench board and have been accidentally activated in the past.
- Rod drive control levers violate human engineering stereotype; operator shifts control forward (up) to drop rods into core and shifts back (down) to pull rods out.
- All grip handles have a pull-to-lock feature, but pull-to-unlock is preferable.
- Steam isolation valve is poorly labeled and is not easy to differentiate from surrounding controls; accidental activation in past has led to trip.
- Operators are required to translate percentage readings into various absolute values; conversion tables are poorly labeled.
- Meters are inconsistently banded; some bands have worn off; violations of color conventions exist.

For each HED listed, a retrofit evaluation form was prepared that indicates the significance of the discrepancy and presents one or more corrective measures for consideration. Plant management was given another form on which to evaluate the retrofit recommendations for each HED in terms of advantages and disadvantages; estimated cost of implementation; technical feasibility of implementation during normal operation or during planned or unplanned shutdowns; impact of the HED on system performance and operator attitudes toward the system; and effect of the HED on safety, equipment protection, and plant availability. If retrofit implementation was not found to be feasible, management was asked to document the reasons. This is consistent with the NRC policy that a HED does not have to be corrected if sufficient reasons can be given.

The individual evaluations conducted as part of this study, while not as comprehensive as those required by NRC, do provide an excellent foundation for a more extensive review and do identify the more obvious HEDs. The final report, scheduled for publication early next year, will provide a useful reference document for other plants in planning and conducting their own reviews. The cooperation of the participating plants has been exemplary and is gratefully acknowledged.

The study results reveal a fairly wide variance in the extent to which the control rooms violate human engineering principles, but they also reveal a commonality of deficiencies from plant to plant. The most frequent areas in which control rooms violate the principles included labeling, alarm and display systems, functional groupings, noise and lighting, design conventions, and anthropometric limits.

Use of retrofits to correct HEDs should be based on a deliberate examination of trade-offs, with input from human factors engineers, design engineers, and operators. A major problem in assessing trade-offs is the lack of qualitative information with which to determine the impact of changes. In some cases, however, deficiencies are obviously amenable to correction, and retrofit measures are required to make needed information more accessible, to eliminate confusion about how to interpret displayed values, to reduce the probability of human error due to inconsistent labeling and poor readability, to eliminate the potential for inadvertent activation of controls, and to improve control room illumination.

In addition to HEDs, outstanding examples of design (called human engineering features) were identified in the study and will be shared with the industry in the final report. *Project Manager: Howard Parris*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP1509-6	Solar-Thermal Full-System Experiment: Manufacture and Assembly	3 months	1998.1	Boeing Engineering & Construction *J. Bigger*
RP1654-10	Planning Assessment of Improved Gasification–Combined-Cycle Plant Operability	4 months	40.0	Systems Control, Inc. *G. Quentin*
RP1971-2	Evaluation of Magnetic Confinement Fusion Engineering on Existing and Planned Facilities	11 months	195.3	McDonnell Douglas Astronautics Co. *K. Billman*
RP1995-1	Assessment of Distributed Solar Power Systems	8 months	98.4	Science Applications, Inc. *R. Taylor*
Coal Combustion Systems				
RP982-26	High-Sulfur Emission Control Test Center	7 months	79.7	Radian Corp. *C. Dene*
RP1260-24	Computer Model for Estimating Coal Ash Disposal Costs	21 months	24.9	GAI Consultants, Inc. *D. Golden*
RP1266-25	Feasibility of Using Microwave Technology to Thaw Frozen Coal	4 months	18.3	SRI International *I. Diaz-Tous*
RP1689-5	Recommended Design and Procurement Guidelines for Steam Surface Condensers in Large Power Generating Units	18 months	52.6	Heat Transfer Consultants, Inc. *I. Diaz-Tous*
RP1855-1	On-Line Laser Doppler Monitor for Torsional Vibration of Turbine Generator Shafts	16 months	190.0	General Electric Co. *A. Armor*
RP1871-3	Construction Materials for Wet Scrubbers	15 months	109.0	Battelle, Columbus Laboratories *C. Dene*
Electrical Systems				
RP1713-3	Detection of PCBs in Transformer Oil	1 year	12.7	Salt River Project *V. Tahiliani*
RP1764-5	Fault Line Protection for High-Phase-Order Transmission Lines	18 months	37.3	Auburn University *J. Lamont*
RP1764-7	Harmonic Power Flow Studies	18 months	49.5	Purdue Research Foundation *J. Mitsche*
RP1782-1	Characterization of Failed Extruded Solid-Dielectric Cables	37 months	1000.6	Battelle, Columbus Laboratories *B. Bernstein*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP2016-1	Transmission Line Structure Development	2 years	1052.4	Southwest Research Institute *R. Kennon*
RP2025-1	Analysis of Radio Interference From Transmission Lines	17 months	40.0	Washington State University *R. Kennon*
RP7887-1	Field Testing of Extruded Transmission Cable Systems: Phase 1	2 years	387.7	Pirelli Cable Corp. *F. Garcia*
RP7892-1	Low-Temperature Extruded Dielectric Cables	30 months	393.1	Cable Technology Laboratories, Inc. *M. Rabinowitz*
Energy Analysis and Environment				
RP1434-3	Nighttime Transformation of Sulfur Oxides: Particulates and Cloud Droplets	2 years	608.7	Desert Research Institute *P. Mueller*
RP1630-13	Air Quality Model Development: Coastal Regimes	3 years	596.1	San Jose State University Foundation *G. Hilst*
RP1633-2	Compensation Mechanisms in Fish Populations	1 year	48.8	Science Applications, Inc. *R. Brocksen*
RP1727-1	Nitrogen Deposition on Forested Watersheds	3 years	527.3	Tennessee Valley Authority *J. Huckabee*
RP1759-1	Environmental Impacts of an Electricity Shortage: Heat Stress	1 year	104.3	Dames & Moore *R. Wyzga*
RP1785-3	Estimating Differential Lead Times for Power Plants	1 year	215.0	Applied Decision Analysis *S. Chapel*
RP1826-5	Risk-Cost Analysis of Selected Toxic Chemicals Proposed for Regulation Under the 1977 Amendments to the Clean Water Act	11 months	199.9	The Rand Corp. *P. Ricci*
RP1844-1	Risk Assessment of Low-NO_x Configuration	1 year	164.3	Acurex Corp. *R. Wyzga*
RP1908-1	Effects of Acid Precipitation on Agricultural Crops of the Midwest	3 years	892.5	Argonne National Laboratory *J. Huckabee*
RP1946-1	Risk-Benefit Analysis of Controlling Hazardous Substances Emitted by Coal-Burning Power Plants	1 year	248.6	Arthur D. Little, Inc. *P. Ricci*
RP1947-2	Test and Transfer of the Carolina Power & Light Co. Fuel-Purchasing Model	6 months	60.0	ICF Incorporated *T. Browne*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1981-4	Supply-Side Revenue and Capital Requirements	4 months	18.5	Southwest Energy Associates *J. Delson*
RP2022-1	Cloud Model Application to Identify Important Chemical Mechanisms	15 months	70.0	Battelle, Pacific Northwest Laboratories *P. Mueller*

Energy Management and Utilization

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP370-25	Iron Redox Battery Test	6 months	89.8	Research Triangle Institute, Inc. *W. Spindler*
RP1677-6	Market Potential for Dispersed Fuel Cell Power Plants	6 months	50.5	Energy Management Associates, Inc. *D. Rigney*
RP1967-2	Impact of High-Temperature Industrial Process Heat Pumps on Electric Utilities	10 months	117.8	General Electric Co. *J. Brushwood*

Nuclear Power

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP810-10	Seismic Soil-Structure Interaction: Review and Evaluation	7 months	28.9	Institute for Dynamic Response, Inc. *Y. Tang*
RP891-9	DASS Design, Phase 2	6 months	50.1	General Atomic Co. *A. Long*
RP891-11	On-Line Analysis of Power Plant Alarms and Disturbances	6 months	57.1	Babcock & Wilcox Co. *A. Long*
RP891-12	DASS Design, Phase 3	6 months	68.1	Systems Control, Inc. *A. Long*
RP891-13	DASS Design, Phase 3	6 months	24.7	Quadrex Corp. *A. Long*
RP891-14	DASS BWR Systems Analysis	6 months	96.3	General Electric Co. *A. Long*
RP1074-4	Tight-Pitch Plutonium-Fueled LWR Lattice Experiments	18 months	99.6	Torrey Pines Technology *O. Ozer*
RP1162-6	Effect of Gas Thickness on Hydraulics and Thermal Behavior of Tube Support Plates	4 months	19.6	Northwestern University *S. Kalra*
RP1171-2	Linear Growth Mechanisms of Oxide Scales on Chromium Alloy Steels	1 year	209.6	Central Electricity Generating Board *R. Varsanik*
RP1171-3	Effects of Oxygen and Oxidizing Ions on Denting	20 months	244.5	Central Electricity Generating Board *R. Varsanik*
RP1327-2	Preliminary Criteria for Designing Feed Pump Suction	9 months	39.4	Tennessee Valley Authority *N. Hirota*
RP1391-4	Data Systems Research Criteria and Performance Analysis: Value Assessment	5 months	48.1	Southwest Research Institute *J. Huzdovich*
RP1542-4	Structural Reliability Methodology	8 months	20.0	Babcock & Wilcox Co. *S. Tagart*
RP1543-4	Reliability of Piping and Fittings	5 months	19.7	Echo Energy Consultants, Inc. *R. Nickell*
RP1544-2	TMI-2 Mechanical Component Information and Examination	6 months	178.0	International Energy Associates Limited *G. Sliter*
RP1581-6	Duplex Fuel Pellet Manufacturing Feasibility	1 year	122.5	Babcock & Wilcox Co. *D. Franklin*
RP1707-5	Nuclear Plant Operation Environmental Study	7 months	50.0	Torrey Pines Technology *G. Sliter*
RP1756-3	Test Material Acquisition System	10 months	39.9	Product and System Engineering *T. Marston*
RP1933-2	Conversion of RSYST Computer Programs Into DATATRAN	4 months	20.7	Technology Development of California *O. Ozer*
RP1933-3	Severe LWR Accident Analysis: Modes of Vessel-Concrete Interactions	11 months	103.1	Massachusetts Institute of Technology *O. Ozer*
RP1934-1	Plant Demonstration: BWR Radiation Control	4 years	900.0	NWT Corp. *M. Naughton*
RP2006-3	Crack Growth Measurement Techniques	11 months	179.9	General Electric Co. *J. Gilman*
RP2006-4	Model of Failure Time for BWR Piping With IGSCC	9 months	24.7	Failure Analysis Associates *R. Jones*
RP2018-1	High-Gain Light Water Breeder Reactor	1 year	60.0	Touro College *A. Adamantiades*
RP2026-1	Stress Corrosion Cracking of Zircaloy Cladding: SPEAR-Gamma	17 months	140.0	Stanford University *T. Oldberg*
RP2055-2	Fracture Toughness of Support Structures	11 months	57.2	Materials Research and Computer Simulations *T. Marston*
RP2065-1	Development of High-Efficiency Flow Couplers for Large LMFBRs	2 years	1577.6	Westinghouse Electric Corp. *R. Winkleblack*

New Technical Reports

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

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

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ADVANCED POWER SYSTEMS

Gas Turbine Combustor Performance on Synthetic Fuels

AP-1623 Final Report, Vol. 2 (RP989-1); $18.50

This volume presents complete data from a test program to determine the behavior of several coal-derived and shale-derived liquid fuels when burned in state-of-the-art combustion turbine engines. The methods used in analyzing the test results are described. The heat transfer effects on gas turbine combustors are discussed, as well as NO_x and other emissions effects and predictions. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Arthur Cohn*

Performance of Air-Cooled Power Plants Using Gas From Coal

AP-1844 Final Report (RP986-3); $14.00

This report details a study to determine the thermal performance and water use of various coal gasification systems integrated with power plants under minimum water use conditions. Results are given for the Texaco, British Gas Corp., and Combustion Engineering oxygen-blown gasifiers and the C-E air-blown gasifier. The performance of these dry-cooled power plants is compared with that of wet-cooled integrated gasification-combined-cycle systems and conventional coal-fired plants. The contractor is General Electric Co. *EPRI Project Manager: B. M. Louks*

Gas Turbine Combined-Cycle Plants: Guidelines for Making Forecasts

AP-1848 Topical Report (RP1188); $12.50

This guidelines manual describes procedures for predicting the reliability of thermomechanical components of gas turbine combined-cycle plants. The procedures cover cases in which data exist on identical or similar components used in the same or different applications and also the case in which no data exist. The appendixes contain data factors, methods, and techniques used in the procedures. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Jerome Weiss*

Gas Turbine Combined-Cycle Plants: Reliability Forecast Techniques

AP-1849 Final Report (RP1188); $9.50

This report presents results from a project to develop and validate reliability forecast techniques for selected thermomechanical components of gas turbine combined-cycle plants. It describes current forecasting methods, particular cases for which these methods are applied, and the development of a new forecasting method. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Jerome Weiss*

Combustion and Emission Characteristics of Coal-Derived Liquid Fuels

AP-1878 Interim Report (RP1412-5); $17.00

A laboratory-scale study was conducted to determine combustion and emission characteristics of several coal-derived liquids produced from the SCR-II, Exxon Donor Solvent, and H-Coal processes. The fuels were evaluated in both staged and unstaged firing modes, with particular emphasis on NO_x and particulate formation levels. These levels were then correlated with fuel properties, composition, and origin. A review of previous coal liquid combustion tests is included, and the experimental system, procedures, and results are detailed. The contractor is KVB, Inc. *EPRI Project Manager: W. C. Rovesti*

Technical and Economic Assessment of Solar Thermophotovoltaic Conversion

AP-1940 Final Report (RP1415-1); $17.00

This report presents the methodology and results of a technical feasibility study and economic assessment of the solar thermophotovoltaic conversion concept for large-scale electric utility application. It details a conceptual system configuration and performance characterization, optical subsystem design and analysis, converter subsystem analysis, and system performance and cost analysis. Potential technical and engineering problems are identified, and recommendations for future work are included. The contractor is Science Applications, Inc. *EPRI Project Manager: E. A. DeMeo*

Workshop Proceedings: Deposition in Utility Gas Turbines

WS-80-121 Proceedings; $21.50

A workshop on deposition in gas turbines was held in October 1980 in Palo Alto, California. The workshop presented the results of several EPRI projects having tasks in this area. These results were compared with other laboratory and field data on deposition, and a round table discussion concerned with reconciling differences in the data was held. The contractor is Coecorp. *EPRI Project Manager: Arthur Cohn*

COAL COMBUSTION SYSTEMS

The Magma Cooling-Tower Process Pilot Plant Demonstration

CS-1838 Final Report (TPS79-740); $14.00

This report documents the test procedures and results of a demonstration of the binary cooling-tower process at Nevada Power Co.'s Sunrise station. In the process waste heat is extracted from warm plant condenser cooling water to evaporate cooling-tower blowdown. Two modes of operation, which used different water-treatment methods, were tested: the chemical softening mode and the crystallization mode. The contractor is Tower Systems, Inc. *EPRI Project Manager: Winston Chow*

Control Systems in Coal Preparation Plants

CS-1880 Final Report (RP1338-1); $12.50

Results are presented from a survey to determine the status of instrumentation and automation systems in U.S. coal preparation plants, and a rationale is suggested to determine the cost-effectiveness of applying control systems. Twelve coal preparation plants were visited and their managers interviewed, and four plant designers were surveyed. Details are provided on unit process controls, and the use of computers in process plant optimization is described. The contractor is Envirotech Corp. *EPRI Project Manager: Randhir Sehgal*

On-Line Acoustic Emission Monitoring of Fossil Power Plants: A Critical Assessment

CS-1896 Final Report (RP1266-9); $11.00

This report reviews acoustic emission technology as applied to incipient failure detection of fossil plant components. Application to failure detection of rotating equipment (particularly early detection of generator shaft cracks) and monitoring techniques for heat exchanger tube leaks are described. The payoff and the probability of success for each potential application are reported, and R&D plans are presented for those components promising high payback and probable success. The contractor is Science Applications, Inc. *EPRI Project Managers: A. F. Armor and J. B. Parkes*

Advanced Concepts Test (ACT) Facility Summary Safety Report

CS-1915 Interim Report (RP422-3); $6.50

Safety analyses and considerations in connection with the Advanced Concepts Test, a large-scale test of wet-dry cooling with the ammonia phase-change system, are summarized. Industrial code application, safety management, and operational and emergency procedures are detailed. The results show that the facility is safe and should be reliable for a power generation application. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: J. A. Bartz*

Deposition and Corrosion Phenomena on Aluminum Surfaces Under Deluged Dry Cooling-Tower Conditions

CS-1926 Interim Report (RP422-3); $9.50

This report summarizes the results to date from a comprehensive, continuing corrosion and deposition study of the interaction of air, cooling water, and aluminum alloys under simulated wet-dry cooling-tower operating conditions. The rate and conditions of heat exchanger deposition buildup are described, and the control of deposition from supersaturated solution by attention to water chemistry, pH, water conditioning, and good heat transfer design is detailed. A discussion of corrosion-deposition loop cyclic results is included. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: J. A. Bartz*

Failure Cause Analysis: Air Preheaters

CS-1927 Final Report (RP1265-8); $15.50

This report describes one of several surveys being conducted to define more clearly the major generic equipment and/or operating problems responsible for utility power plant outages. These major air preheater problem areas were identified: corrosion, fouling, plugging, soot blowers, water wash system, seals, fires, and drive and bearing systems. Recommendations for improving the reliability of existing air preheaters are presented, and generic problems requiring future research and the application of existing technologies are identified. The contractor is KVB, Inc. *EPRI Project Manager: I. A. Diaz-Tous*

Workshop Proceedings: Applications of Fire-Side Additives to Utility Boilers

WS-80-127 Workshop Proceedings: $15.50

A workshop on the application of fire-side additives to utility boilers was sponsored by EPRI in August 1980 in Boston. Presentations reviewed a literature search and utility survey on the topic (published as EPRI CS-1318) and described the use of additives in both oil- and coal-fired boilers. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: J. P. Dimmer*

Seminar Proceedings: The Use of Coal in Oil-Design Utility Boilers

WS-80-141 Proceedings; $18.50

This report presents 15 papers given at a seminar on the use of coal in oil-design utility boilers that was held in December 1980 in Lake Buena Vista, Florida. The seminar was cosponsored by EPRI and Florida Power & Light Co. Topics include the conversion from oil to coal firing at Kwinana power station in Western Australia, fundamentals of coal boiler design, effects of coal ash in oil-design boilers, and recent utility experience with coal-oil mixtures. *EPRI Project Manager: S. G. Drenker*

ELECTRICAL SYSTEMS

Graphical and Tabular Results of Computer Simulation of Faulted URD Cables

EL-1605 Final Report (RP797-2); Vol. 1, $11.00; Vol. 2, $24.50

This report describes work to extend the usefulness of the BCAB program, a general computer program for calculating "touch and step" potentials of faulted underground residential distribution (URD) cable. Volume 1 presents the background theory, describes the approach used, and documents the expanded simulation program. Volume 2 is a handbook of curves and graphs generated by the program for determining "touch and step" potentials for a wide variety of URD cable fault conditions. The contractor is the Georgia Institute of Technology. *EPRI Project Manager: T. J. Kendrew*

Experimental Techniques to Investigate the Degradation of Electrical Insulation

EL-1854 Final Report (TPS79-723); $14.00

Experimental techniques for measuring aging-induced changes in electrical insulating materials used on utility systems, with emphasis on solid-dielectric insulation, were identified and evaluated. This report, containing papers presented at a workshop of the Committee on Dielectrics of the National Research Council's Assembly of Engineering, covers studies on electron spin resonance, chemiluminescence, radiography, Fourier transform infrared spectroscopy, nuclear magnetic resonance, gel permeation chromatography, rheological tests, and high-performance liquid chromatography. The contractor is the National Research Council. *EPRI Project Manager: B. S. Bernstein*

Backfill Materials for Underground Power Cables, Phase 2

EL-1894 Interim Report (RP7841-2); $21.50

Continuing work on soil treatments for backfill materials for underground power cables is summarized. Results are presented from laboratory studies of backfill additives, particularly wax; studies of the effect of thermal "driving" mechanisms on moisture flow in trench-cable systems; and work at a field test facility built to study simulated buried cable. A one-dimensional explicit finite difference program using the Philip and de Vries Theory is described, and measured trench temperature profiles are compared with those predicted by a finite element heat conduction program. The contractor is the University of California at Berkeley. *EPRI Project Manager: R. W. Samm*

Development of a High-Power Vacuum Interrupter

EL-1895 Final Report (RP754-1); $27.50

Analytic and experimental work to assess the feasibility of designing and building a vacuum interrupter is described. The report summarizes four major problem areas addressed by the study: arc physics, vacuum breakdown, mechanical problems, and interrupter fabrication and testing. The design, construction, and testing of three sealed vacuum interrupters, each of a design to provide information on specific segments of the high-duty vacuum interrupters, are detailed. The contractor is General Electric Co. *EPRI Project Manager: N. G. Hingorani*

ENERGY ANALYSIS AND ENVIRONMENT

Trace Element and Phase Relations in Fly Ash

EA-1822 Final Report (RP1061); $9.50

The major chemical compounds in ash and the distribution of trace elements among these compounds are identified. Results of direct studies of ash before and after contact with a disposal site are presented. Also covered are studies of fly ash exposed to sluice ponds; the separation and characterization of mullite-quartz, glass, and magnetic phases; and fly ash specimen sources, pollution, and resource recovery. The contractor is Oak Ridge National Laboratory. *EPRI Project Manager: R. M. Perhac*

Ecological Investigations at Power Plant Cooling Lakes, Reservoirs, and Ponds: An Annotated Bibliography

EA-1874 Final Report (RP877); $14.00

This report contains citations and abstracts of published and unpublished reports on ecological investigations at power plant cooling lakes, reservoirs, and ponds. Data are provided on facility location (region and state), operator, unit name, capacity, status, year on-line, fuel, water body, and cooling system. The contractors are Atomic Industrial Forum, Inc., and Oak Ridge National Laboratory. *EPRI Project Manager: I. P. Murarka*

Biocide Usage and Ash-Handling Practices at Selected Operating Steam-Electric Plants

EA-1886 Final Report (RP877); $9.50

The Atomic Industrial Forum Power Data Base was expanded to include information on biocide usage and ash-handling systems at steam-electric power plants. The data contents are summarized and categorized by cooling system, cooling-water type, biocide usage, heat treatment, use of mechanical tube-cleaning systems, and ash-handling and disposal methods. Tables are presented to indicate what types of information are held in the data base on plants with a generating capacity greater than 100 MW (e). The contractor is Atomic Industrial Forum, Inc. *EPRI Project Manager: I. P. Murarka*

Pathogenic Amoebae in Power Plant Cooling Lakes

EA-1897 Final Report (RP1314-1); $8.00

Cooling water and associated algae and sediment from eight power plant cooling lakes were sampled for the presence and distribution of pathogenic amoebae. Samples obtained at the test sites and from unheated waters at control sites were compared; the results indicated a higher proportion of thermophilic amoebae, thermophilic *Naegleria*, and pathogenic *Naegleria* in the test site samples. The results are discussed, and conclusions are presented. The contractor is Oak Ridge National Laboratory. *EPRI Project Manager: R. W. Brocksen*

Hydroelectric Operation at the River Basin Level: Research Needs to Include Ecological Issues in Basin-Level Hydropower Planning

WS-80-155 Proceedings; $8.00

EPRI, Tennessee Valley Authority, and DOE (through Oak Ridge National Laboratory) cosponsored a workshop on ecological issues in basin-level hydropower planning in Oak Ridge, Tennessee, in September 1980. Recommended research priorities and topics, including impact of water-level fluctuation, instream flow requirements, and water quality alteration, are summarized. The contractor is Science Applications, Inc. *EPRI Project Manager: I. P. Murarka*

NUCLEAR POWER

Studies on Section XI Ultrasonic Repeatability

NP-1858 Interim Report (RP1570-3); $15.50

A block representative of a nuclear component was welded to contain intentional defects. Acoustic emission data taken during the welding correlate well with ultrasonic data. Repetitive ultrasonic examinations were performed by skilled teams using a procedure based on ASME Section XI. The examinations were performed in such a way that the effects of changes in operators on the reproducibility of results, and also the effects of using different equipment, could be estimated. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: J. R. Quinn*

Early Response of Pressurized Hot Water in a Pipe to a Sudden Break

NP-1867 Final Report (RP687-1); $17.00

Experimental and analytic studies that explain the details of early pressure variations during rapid depressurization in water-cooled reactors are presented as a means of assessing sudden break consequences in a coolant pipe. The report includes (1) a description of the experiment, (2) an analysis of a new law for thermally controlled growth of vapor bubbles in an exponentially varying pressure field, and (3) a review of previous studies and additional observations of blowdown behavior. The contractor is the University of Kentucky Research Foundation. *EPRI Project Managers: B. R. Sehgal and G. S. Srikantiah*

RAMONA Analysis of the Peach Bottom-2 Turbine Trip Transients

NP-1869 Final Report (RP1119-2); $17.00

This report documents the RAMONA computer code analysis of three turbine trip tests conducted at the Peach Bottom-2 BWR in 1977. Simulations were performed with the point kinetics model and the one-dimensional and three-dimensional neutron kinetics models. Emphasis was placed on the systematic comparison of different core model approximations and on results from the simulation using the three-dimensional neutron kinetics model. The contractor is Scandpower Inc. *EPRI Project Manager: J. A. Naser*

Development of Sensors and Instrumentation for the TMI-2 OTSG Tube Vibration Measurements Program

NP-1875 Topical Report (RPS140-1); $15.50

The mechanical and sensor-related aspects of engineering planning, system design, hardware and software fabrication, and equipment installation and removal are described. The report documents the feasibility of installing biaxial accelerometers at various depths within steam generator tubes, with up to four weldable strain gages in a single tube at one elevation. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: D. A. Steininger*

Flow-Induced Vibration Analysis of Three Mile Island Unit 2 Once-Through Steam Generator Tubes

NP-1876 Final Report, Vol. 1 (RPS140-1); $15.50

This volume documents work performed to measure tube vibration characteristics associated with an operating steam generator. Problems that arose during the project and the data reduction effort are detailed. On the basis of the analyzed data, it appears that tube vibration alone, in the absence of other mechanisms such as corrosion, will not cause tube cracking or failure due to fatigue. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: D. A. Steininger*

Summary of Fundamental Developments for Quantitative Acoustic Emission Measurements

NP-1877 Interim Report (RP608-1); $9.50

This report describes a study of an acoustic emission (AE) technique using passive surface-mounted sensors to detect surface disturbances in nuclear plants when the structure is under load. Topics discussed include calibration capability for AE transducers, a theoretical basis for moving defects, correlation of theory and experiment using transparent materials, and AE measurements in structural steels. The contractor is the National Bureau of Standards. *EPRI Project Manager: J. R. Quinn*

Air-Water Spray Analysis

NP-1879 Topical Report (RP443-2); $11.00

An analytic and numerical investigation of the aerodynamic behavior of a gas-liquid spray system is described. Detailed work is presented on spray droplet flow, and the key analysis momentum transfer between spray droplets and the surrounding medium is reported. Similarity solutions are presented for the plant turbulent spray system, and a numerical scheme is proposed to solve the two-phase fluid dynamic equations. The contractor is Dartmouth College. *EPRI Project Manager: K. H. Sun*

Pipe Missile Impact Experiments on Concrete Models

NP-1883 Final Report (RP393-1); $14.00

Scale model experiments to determine the local response of reinforced-concrete panels to pipe missile impacts are summarized. The experimental methods and the scale model missiles and targets, similar to those used previously in full-scale tests, are described. Scale model test results on front face penetration, back scabbing threshold, internal cracking in the panel, and missile deformation are reported. Comparisons with full-scale test results show that scale modeling is a cost-effective approach for providing missile impact data. The contractor is SRI International. *EPRI Project Manager: G. E. Sliter*

Locating Failed Fuel in LMFBRs: Selection of Candidate Solid Tags

NP-1887 Final Report (RP1704-10); $9.50

Six elements (Pb, Sn, Ti, Zn, Ge, and Cd) were selected as candidates for use as LMFBR fuel cladding breach monitors. The data used, their sources, and the compilation methods are discussed. A computer program for systematically comparing the element and nuclide properties against input criteria to be supplied by the user is also described. The contractor is General Electric Co. *EPRI Project Manager: R. K. Winkleblack*

Flow-Induced Vibration Analysis of Oconee-2B OTSG Tubes

NP-1888 Final Report (RPS176-1); $12.50

This report describes a program to measure once-through steam generator (OTSG) tube vibration response at the Oconee nuclear power station. Vibration data for four B-loop OTSG tubes are presented, and the analysis of data for displacement, frequency, and damping trends is described. The results are compared with those from a previous measurement effort at TMI-2 (RPS140-1). The contractor is Babcock & Wilcox Co. *EPRI Project Manager: D. A. Steininger*

Nuclear Power Plant Building Wake Effects on Atmospheric Diffusion: Simulation in Wind Tunnel

NP-1891 Final Report (RP1073-2); $11.00

This report describes work to determine the aerodynamic effects of large structures on the dispersion of atmospheric plumes. Results are presented from a wind tunnel mock-up test designed to simulate a previous field study (NP-1380). Experimental and field results are compared to evaluate the applicability of the mock-up to meteorological simulations. Methods for maximizing plume dispersion from vent releases and for predicting near-field plume concentration are detailed. The contractor is Colorado State University. *EPRI Project Manager: H. A. Till*

Analysis of Extrapolated Failure Rates

NP-1892 Final Report (TSA80-324); $6.50

Three approaches were investigated as alternatives to the Chi-squared statistical technique for making bounding estimates of failure rates: single-point, multiple-point, and continuous-time extrapolations. This report examines failure rate definitions and summarizes the numerical results for each approach. The study demonstrated that all three extrapolation approaches produce estimates larger than those of the Chi-squared technique at commonly used levels of confidence. The contractor is Engineering Decision Analysis Co., Inc. *EPRI Project Manager: G. S. Lellouche*

Low-Temperature Solute Segregation and Crack Age Studies

NP-1893 Final Report (RPT110-2); $8.00

Changes in grain boundary composition leading to low-temperature sensitization (LTS) of type-304 stainless steel were investigated, and crack age studies were conducted. Grain boundary composition of weld-heat-affected zones in several LTS conditions were determined, and the role of decreased Cr and increased P concentrations in type-304 stainless steel susceptibility to intergranular stress corrosion cracking was assessed. The crack age studies examined changes in morphology, composition, and thickness of corrosion products on the fracture surface of stainless steel BWR components as crack age indicators. The contractor is Science Center Div., Rockwell International Corp. *EPRI Project Manager: M. J. Fox*

Correlation of Critical Heat Flux Data for Application to Boiling Water Reactor Conditions

NP-1898 Final Report (RP1751-1); $12.50

This report describes the development and qualification of a critical heat flux (CHF) correlation that can be used to predict thermal limits in a BWR. This critical quality–boiling length correlation includes the effects of rod-to-rod (local) peaking factor, different axial heat flux profiles, pressure, rod diameter, and bundle geometry. The final form of the correlation was compared with applicable data sets and with four previous CHF correlations. The contractor is S. Levy. Inc. *EPRI Project Manager: B. A. Zolotar*

Characteristic and Linear Dispersion Analyses of the RETRAN Two-Velocity Model

NP-1917 Interim Report (RP958); $11.00

Results of a study of the mathematical properties of the RETRAN two-velocity two-phase flow model are given. The contractor is Energy Incorporated. *EPRI Project Manager: L. J. Agee*

Anthropometric Data Base for Plant Design

NP-1918-SR Special Report; $6.50

This anthropometric data base describes the body-size variability of the men and women who operate and maintain power plants. The data collection and analysis efforts are detailed, and a sample survey is provided. The systematic use of this data base will result in a more effective man-machine interface in power plant designs. *EPRI Project Manager: H. L. Parris*

FIBWR: Steady-State Core Flow Distribution Code for BWRs

NP-1923 Final Report (RP1754-1); $11.00

This report describes the development and verification of the FIBWR steady-state BWR hydraulic computer code. Experimental data were used to evaluate the ability of the recommended models to predict various pressure drop components and void distribution. Descriptions of the fuel assembly, inlet orifice and lower tie plate, and various bypass flow paths are included. The contractor is Yankee Atomic Electric Co. *EPRI Project Managers: J. A. Naser and B. A. Zolotar*

Solution Methods for Simulation of Nuclear Power Systems

NP-1928 Interim Report (RP1381); $14.00

Methods were developed for reducing computer time and costs for the numerical solution of large nonlinear initial value problems. Details are provided on techniques for partitioning dynamic systems according to time scales and for solving the dynamic equations by multirate integration methods. Alternative schemes for model decoupling, multirate integration algorithms, numerical experiments with three dynamic systems, and the development of a simplified PWR plant model are described. The contractor is the University of Arizona. *EPRI Project Manager: P. G. Bailey*

Simulation Methods for Nuclear Power Systems

WS-81-212 Proceedings; $32.00

This report constitutes the proceedings of a conference on nuclear power plant simulation that was sponsored by NRC and EPRI in Tucson, Arizona, in January 1981. Papers from government, industry, national laboratories, and universities are presented; the topics covered include simulation needs, simulator design and performance, engineering simulations, model development, solution methods, and verification. *EPRI Project Manager: P. G. Bailey*

POLICY PLANNING

Research Results and Applications

P-1929-SR; $20.00

This report presents 38 examples of EPRI research project results that have been beneficially adopted by electric utilities. It also describes 75 new near-term research accomplishments that are ready for utility application. These examples cover the entire spectrum of electric power R&D: fuel processing, power generation, transmission and distribution, energy storage and management, energy analysis, and environmental assessment and control.

Patents

Each issue of the *Journal* includes a list of newly filed patent applications. The EPRI identification number, title, and abstract filed with the application are reprinted below. Information on obtaining a license under EPRI patent or patent application can be obtained from the Manager, Patents and Licensing, P.O. Box 10412, Palo Alto, California 94303; (415) 855-2866.

Information on other licensable inventions, as well as computer codes available from EPRI, is published quarterly in the *EPRI Guide*. This publication can be obtained from Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081.

Arc by-products evacuation and neutralization system
ED0213-80-06

An arc by-product evacuation and neutralization system is disclosed. The system includes a vacuum cleaner having an input port for receiving air containing powdery arc by-products. The vacuum cleaner also includes a noncorrosive plastic tank that contains an alkaline solution for neutralizing the powdery arc by-products. The neutralization is achieved by jet action, causing the alkaline solution to be agitated and thereby absorb the powdery arc by-products.

Apparatus for remotely positioning sensing devices in a reactor during operation thereof
ED1459-80-32

An apparatus for remote positioning of sensing devices within a reactor. The apparatus comprises a pressure-tight housing located adjacent to the reactor wherein the housing has a port connected by a passageway to an inlet of the reactor. Valve means are provided within the passageway for isolating the housing from the reactor. A plurality of cylinders are rotatably mounted within the housing about an axis thereof so that each of the cylinders may be aligned with the port in the housing. Each of the cylinders has a piston and a ram. The ram includes a sensing device, such as a thermocouple. Means are provided for moving the piston within the cylinder so that when a cylinder is registered with the housing's port, the sensing device may be positioned in the reactor.

Coal liquefaction process
ED1715-80-07

A coal conversion process produces an increased yield of distillable products through an efficient use of hydrogen. Coal is contacted with a liquefaction solvent composed of a process-derived light-phase residuum and a process-derived distillate under liquefaction conditions to form a coal conversion product effluent. The effluent is admixed with a process-derived hydrogenation residuum to supply hydrogen-donors and to cool and stabilize the effluent against regressive reactions. Distillables boiling below about 1000°F are then separated from the combined stream. A portion of the distillables can be recycled for use as solvent or hydrogenated and then recycled. The remaining residuum is admixed with a de-ashing solvent and thereafter de-ashed and fractionated under elevated temperature and pressure conditions. The residuum is separated to form a light-phase residuum, which is recycled for use as solvent, and a heavy-phase residuum suitable for further upgrading. The heavy-phase residuum is admixed with a process-derived hydrogenation distillate and introduced into a hydrogenation zone. At least a portion of the heavy-phase residuum is hydrogenated to form a hydrogenation distillate that has a boiling temperature below about 1000°F. The hydrogenation distillate is recovered as a product, and a portion is recycled to provide the process-derived hydrogenation distillate that is admixed with heavy-phase residuum. The remainder of the hydrogenated heavy-phase residuum is recycled as the process-derived hydrogenation residuum that is admixed with the liquefaction effluent.

A detector for fault detection in sealed electrical apparatus, using direct fluxgate magnetometry
KD1360-02-12

The device detects the ac magnetic field produced when a fault occurs in sealed electrical power apparatus. The detector includes a single-axis fluxgate magnetometer for placement in close proximity to the outer housing of the apparatus to detect the axial component of the ac magnetic field. An ac electric signal is applied to the magnetometer, and the output voltage of the magnetometer is detected to indicate the location of the fault.

Integrating circuit for use with Hall-effect sensors having offset compensation means
KD1420-01-03

An integrating circuit for generating control signals representing watthour consumption for connection to an electronic watthour meter. The circuit includes a Hall-effect sensor for sensing watthour consumption, a circuit for integrating the sensed watthour consumption, and a circuit for compensating for dc offset voltage generated by the Hall-effect sensor.

Fail-safe surge arrester
KD1470-01-01

A surge arrester including an outer porcelain housing and an ablative heat shield liner is disclosed herein, along with a number of techniques for making the surge arrester break-resistant. In accordance with one of these techniques, a blowout or relief valve is provided on at least one end of the arrester housing for venting internal pressure due to electric arcing therein. In this embodiment, an arrangement is provided for preventing the components therein from escaping during the venting procedure. The liner is constructed from a material that is sufficiently ablative to produce its own gas within the housing in response to electric arcing therein.

Surge arrester having a nonfragmenting outer housing
KD1470-01-04

A surge arrester including an outer elongated housing and an inner liner is disclosed herein. The outer housing is constructed from a material that will not break as a result of internal electric arcing, specifically a relatively resilient, electrically insulating and nontracking material, which in a preferred embodiment is EPDM rubber. To add structural integrity to the arrester, its inner liner is constructed of a high-strength material, preferably resin-impregnated fiberglass.

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