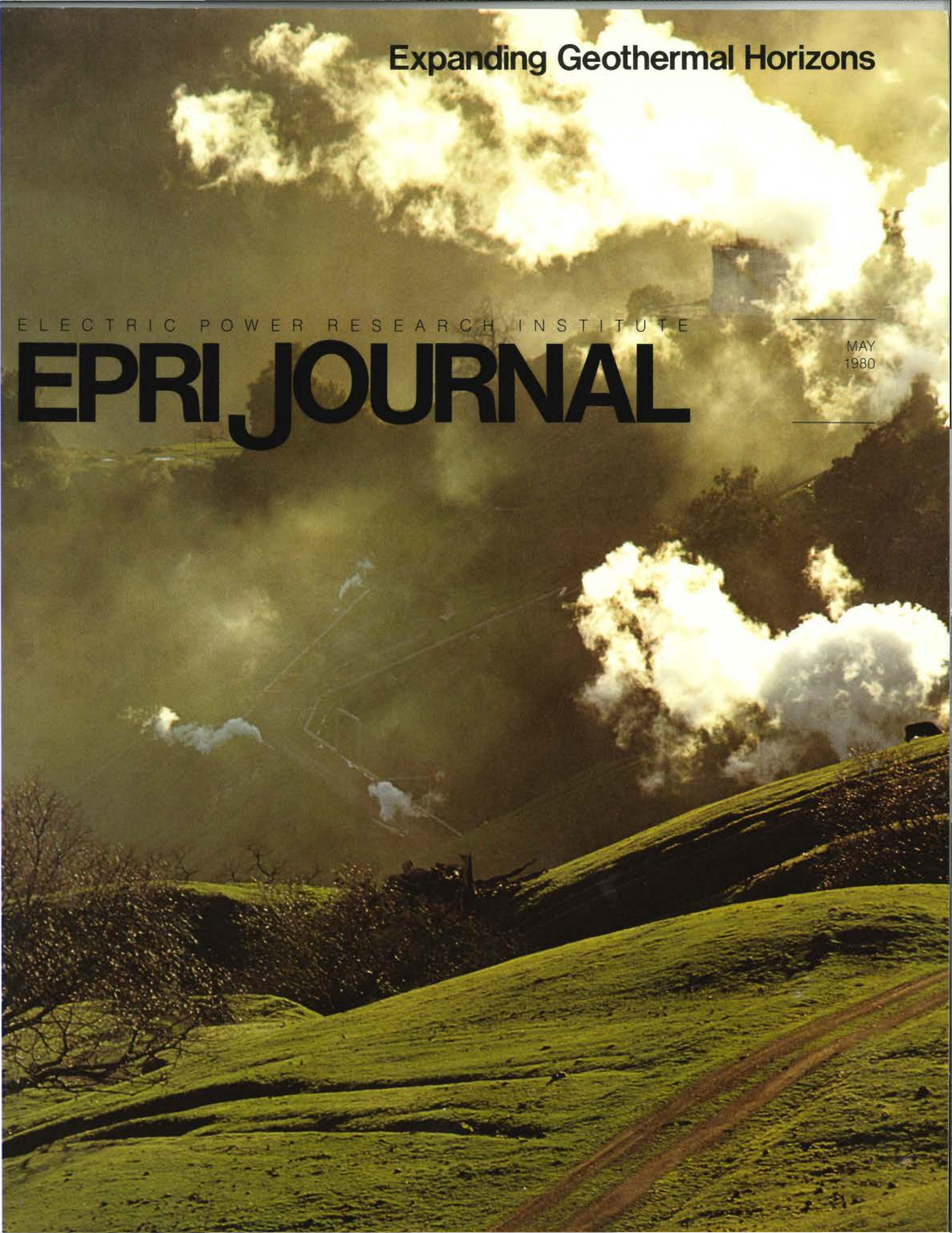
Expanding Geothermal Horizons
ELECTRIC POWER RESEARCH INSTITUTE
EPRI JOURNAL
MAY
1980

EPRI JOURNAL is published by the
Electric Power Research Institute.

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

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Cover: Geothermal steam fields are a spectacular energy resource, but reservoirs of geothermal water hold far larger and more widespread energy potential for electric power development.

Volume 5, Number 4 May 1980

## Renewed Interest in an Old Resource

Geothermal energy first found a place in recorded history when hot springs were tapped to channel heat and water into the baths of ancient Rome. Geothermal spas, often valued for their medicinal minerals, institutionalized the resource over the centuries that followed, but true commercial exploitation dates only from 1818, when a chemical plant at Larderello, Italy, used geothermal heat to produce boric acid. Larderello also pioneered geothermal electricity on an experimental basis in 1904 and then on a continuous commercial basis beginning in 1913. Worldwide, geothermal generating capacity today is about 1600 MW and is growing at an annual rate of about 19%. Steady development of U.S. geothermal power began in 1960, but the average rate of capacity growth has been about 24% annually, and the world's largest geothermal facility is now the 800-MW aggregation of Pacific Gas and Electric Co. units at The Geysers in California.

Aided by our utility industry advisers, we first defined EPRI's role in geothermal R&D six years ago. The program quickly focused on development of geothermal water reservoirs, particularly those in the temperature range defined as moderate: 150–210°C (300–410°F). Such systems are present in nine of the western states, as well as in Alaska and Hawaii, and have an identified power potential equivalent to 20–30 GW for 30 years.

EPRI-sponsored research thereafter led to a binary-cycle plant design for converting hydrothermal energy in the moderate-temperature range, to the conclusion that a commercial-scale demonstration was feasible and necessary, and to the selection of an appropriate plant site in the southern end of California's Imperial Valley. Following a period of uncertainty, San Diego Gas & Electric Co., DOE, EPRI, and several other organizations are now proceeding on this project. The 45-MW Heber plant should be an operating reality by the end of 1984.

EPRI has also aided in the assessment of other geothermal resources, particularly the geopressured zones of Texas and Louisiana, where dissolved natural gas is a significant energy component of the moderate-temperature brine in deep, heavily compressed sediments. We are aware of other geothermal resources, too, such as the lower-quality heat identified in the Appalachian region. Although the potential recoverable energy from these resources is uncertain, especially in terms of electricity generation, they may well have a role in the U.S. energy mix of the future.

We believe that any kind of geothermal energy development has important implications for national energy supply patterns. In particular, as the oil-burning utilities of the fast-growing West are able to bring geothermal capacity on-line, some quantity of imported oil should be avoided. Thus, although geothermal energy resources suitable for electric power production are only regional, their influence can have a far wider impact.

Dwain F. Spencer

Dwain F. Spencer, Director
Advanced Power Systems Division

# Authors and Articles

Alternative energy resources, especially renewable ones, tend to be overlooked because they have not been used for electricity generation. Geothermal energy is an exception. **Tapping the Main Stream of Geothermal Energy** (page 6) is not so much an introduction as it is an update on a resource that has been exploited for commercial electricity since the turn of the century in Italy, since the 1940s in several other countries, and since 1960 in the United States.

Written by *Journal* feature editor Ralph Whitaker, the article emphasizes what's new in geothermal energy today—more precise assessment of the resource and the technologies that can use more of it by converting the energy contained in geothermal water reservoirs, which are far more extensive than geothermal steam fields. As background, Whitaker drew on the expertise of two EPRI research managers, Vasel Roberts and Evan Hughes.

Manager of the Geothermal Power Systems Program since February 1975, Roberts was previously at Jet Propulsion Laboratory (California Institute of Technology) for more than 7 years, holding a succession of systems engineering responsibilities for aerospace technologies and their adaptation to business and industry. Earlier he worked for 10 years on missile systems engineering projects of a Sperry Rand Corp. division and subsidiary. Roberts is a mechanical engineering graduate of the University of New Mexico.

Evan Hughes, manager of advanced geothermal technology projects, came to EPRI in September 1978 after three years with the California Energy Commission, where he was manager of geothermal energy and alternative fuels, responsible for assessing them and encouraging their use. Hughes also worked for two years in the assessment and planning of energy resources and technologies for SRI International, and for six years he was an assistant professor of physics at Pomona College. He holds BS, MS, and PhD degrees in physics from California Institute of Technology.

■

Electricity distribution technology has always involved a search for quicker, surer ways to isolate outages and restore service around them. Today it addresses a new problem: how to control system loads in unobtrusive ways to conserve energy and to defer heavy capital investments in new power facilities. Both objectives can be accomplished by automating many distribution operations, but a key problem is the character and reliability of data links throughout the network.

**Two-Way Data Communication Between Utility and Customer** (page 16), by *Journal* feature writer Nadine Lihach, reviews the technologies that are competing for the task today. To explore R&D progress sponsored by EPRI, DOE, and teams of manufacturers and host utilities, Lihach worked with William Blair, distribution project manager in the Power Systems Department of EPRI's Electrical Systems Division.

Blair joined EPRI in May 1976, following nearly 12 years with SRI International, where he was a research engineer in detection and communication techniques, apparatus, and systems throughout the frequency spectrum. He holds BS and MS degrees in electrical engineering from Cornell University and a DSc degree in electrical engineering from the University of New Mexico.

■

Most people think of synthetic fuels as coal-derived liquids to replace oil. But solvent refining began as a process to make a clean-burning solid fuel. Seven years of research and pilot plant testing have seen the process evolve.

**Refining the Process That Refines the Coal** (page 20) compresses the work of those seven years into just two stages. This is an oversimplification, to be sure, but it is useful in pointing up key steps of laboratory and pilot plant research projects that have produced successive single-stage improvements and have led to an advanced, highly flexible coal liquefaction scheme.

The article was written by Ralph Whitaker, for whom EPRI's Howard Lebowitz traced the history of solvent refining. Lebowitz is technical manager for advanced liquefaction process development in the Advanced Power Systems Division. He came to EPRI in December

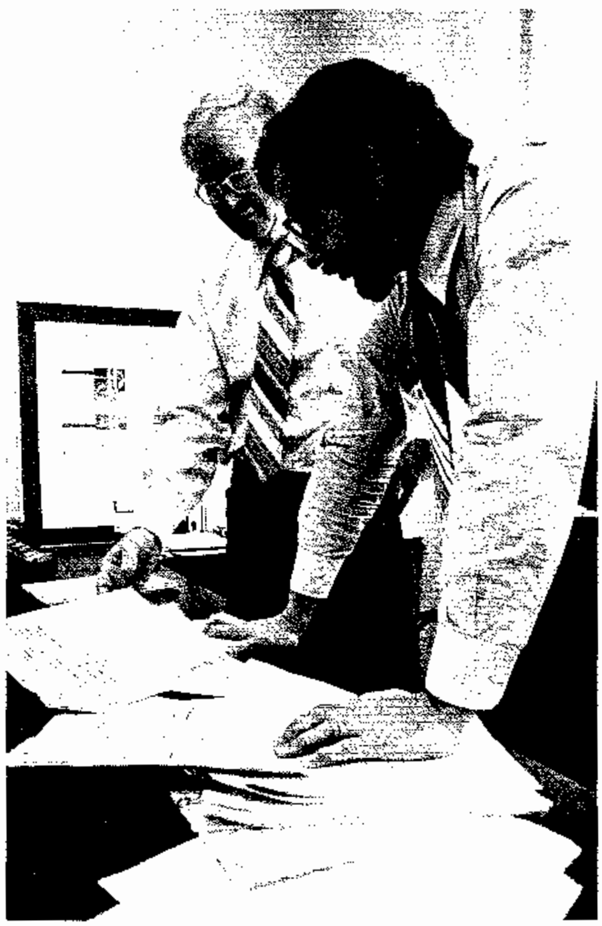
Lebowitz

Blair

1975, having worked more than seven years for Conoco Coal Development Co. as a research engineer and design group leader in coal liquefaction and fluidized-bed combustion. He also worked briefly as a research scientist for Battelle, Columbus Laboratories. Lebowitz is a chemical engineering graduate of Pennsylvania State University.

■

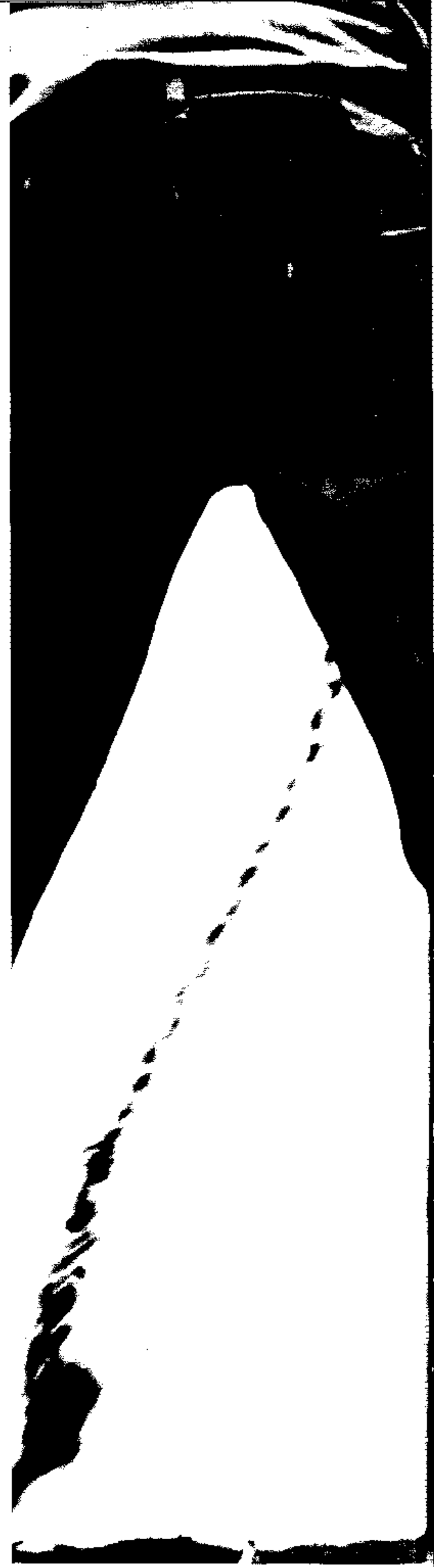
Determining energy policy calls for expertise in identifying, modeling, comparing, and evaluating factors throughout many economic sectors and time periods. The task is extremely difficult. But it is necessary and challenging. **Charles Hitch: Appraising Energy Policy** (page 26) presents a man who applies expertise to the challenge. This profile of an EPRI adviser and his thinking was drafted by Jenny Hopkinson, *Journal* feature writer, from an interview early this year.

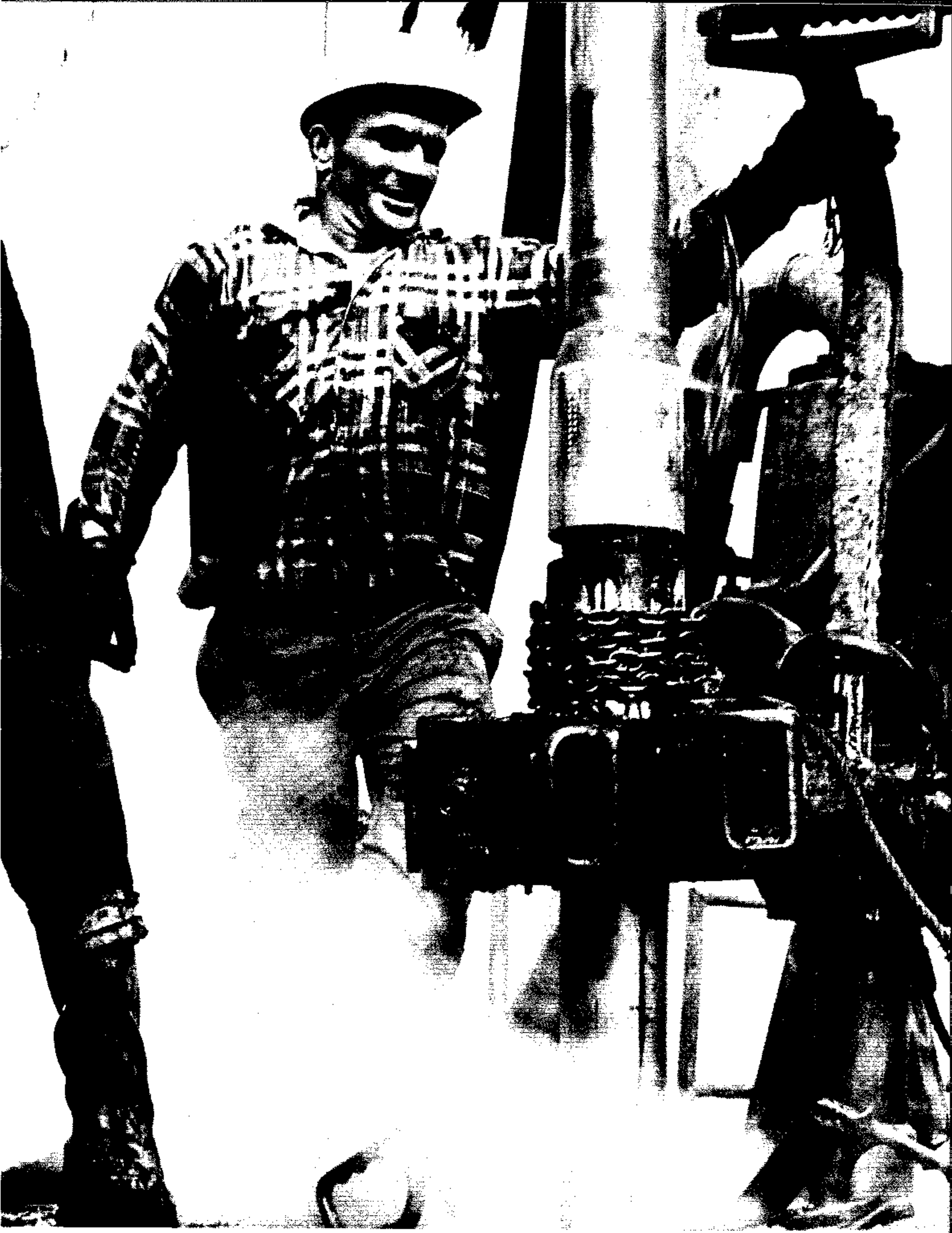


Roberts Hughes

*Naturally venting steam is only a tip-off to a far greater underground energy resource. Resource companies are also drilling for hot water, and utilities are tailoring power plant technology to the temperatures of geothermal reservoirs containing hot water alone. Before the 1980s have passed, full-scale generating plants will demonstrate the power potential of those reservoirs.*

# TAPPING THE MAIN STREAM OF GEOTHERMAL ENERGY





Opening the frontier of U.S. geothermal energy can be visualized as a continental migration. But instead of beginning at St. Augustine, Jamestown, or Plymouth Rock, it begins at The Geysers, some 90 miles north of San Francisco, California.

This technological quest began in 1960, when Pacific Gas and Electric Co. (PG&E) put 11 MW of capacity on-line and generated the nation's first commercial geothermal electricity. Its fuel was natural dry steam drawn from wells drilled among the vents, or fumaroles, that mark a relatively shallow zone of seismically fractured hot rock. Today the field supports 14 PG&E units totaling 800 MW, and at least 7 more units are under construction or planned by PG&E and others for operation between now and 1983. Most of the newer units carry 110-MW ratings.

Many routes of geothermal development now lead eastward from The Geysers. They radiate up into Idaho, across to Utah, over to New Mexico, and down to California's border with Mexico. Their goal is the economic use of underground steam and hot water at commercial scale, mostly for conversion to electricity. One long beckoning path curves along the Gulf Coast of Texas and Louisiana, where geologic processes trapped huge amounts of energy, in the form of natural gas dissolved in hot water, in deep sediments at great pressure.

The U.S. Geological Survey has mapped geothermal water resources (those above 90°C, or 194°F, to a depth of 3 km, or 2 mi) beneath 24 of the continental states. This wide distribution is attractive because it puts geothermal energy potentially within reach for process and space heating—the 35% of our nationwide requirements that can use lower temperatures. Only last July an exploratory well in Maryland established the presence of 60°C (140°F) water beneath the Atlantic Coastal Plain. Thus the first trails of geothermal energy development have spanned the continent.

#### Temperature-based technology

Our continental map suggests the broad extent of a resource that takes many forms. But the sites that hold early power generation potential for electric utilities are more limited. For example, natural dry steam occurs in very few places, notably The Geysers and Lassen Volcanic and Yellowstone national parks (the parks are precluded from development). Geothermal water, however, underlies most states, and such hydrothermal resources total some 2400 quadrillion ($2.4 \times 10^{18}$) Btu of recoverable energy.

Vasel Roberts, manager of the Geothermal Power Systems Program at EPRI, is quick to qualify this figure in two ways. "First, only about 900 quadrillion [$900 \times 10^{15}$] Btu is what we call electricity grade—that is, 150°C [300°F] or hotter. And all of that is in the western states.

"In addition," Roberts goes on, "the estimate of 900 quadrillion Btu includes resources so far only inferred, or assumed to exist, on the basis of geophysical data. When we narrow it down to the identified portion, we're talking about perhaps 220 quadrillion Btu."

Is this a meaningful figure? "Yes, indeed," Roberts affirms, "because it readily translates to a generating capacity of about 24 GW with a useful life of at least 30 years, clearly a feasible target for utility development in the next 20 years."

Hydrothermal temperatures and pressures (dry steam included) are well below those at the turbine inlet of a fossil-fueled power plant. At The Geysers, for instance, steam conditions are about 180°C (356°F) and 110 psi (760 kPa); in a modern coal-fired plant, 540°C (1000°F) and 2400 psi (16.6 MPa). Accordingly, the respective energy conversion efficiencies are about 15% and 33%, but the geothermal steam plant competes because its steam is ready-made and inexpensive and the plant availability is higher, often more than 80%.

If the hydrothermal fluid is above 210°C (410°F), its wellhead pressure can be reduced so that part of the water vaporizes (flashes) into steam. Conversion efficiency is about 15%, and what is important, this method uses the same kind of turbine as a geothermal steam plant. Such technology is well established, used for generating power not only at The Geysers but at many hydrothermal sites around the world: Italy (400 MW), New Zealand (190 MW), Mexico (150 MW), as well as the Philippines, El Salvador, Iceland, and Japan.

About half the electricity-grade hydrothermal energy in the United States is in this high-temperature range of 210°C (410°F) and above. The other half is in the moderate-temperature range of 150–210°C (300–410°F), for which the direct-flash technology is not assuredly economic. Inlet and exhaust steam conditions define the energy that can be extracted by a turbine, but operation of the condenser imposes its own lower limit on the cycle. If the flash temperature of the steam is too low, the available differential represents too little energy for economic operation.

A different technological approach is necessary for moderate temperatures, the binary cycle. It is this cycle that EPRI believes will afford the greatest reliability and lowest busbar electricity cost for utilities. Just this year cooperative negotiations have begun for DOE and EPRI to join with San Diego Gas & Electric Co. (SDG&E) and several other organizations to build a binary-cycle demonstration plant at commercial scale. The site is a 180° (356°F) reservoir of low-salinity geothermal brine at Heber in California's Imperial County, south of the Salton Sea and only four miles from the border communities of Calexico and Mexicali.

#### Demonstrating the binary cycle

The binary cycle is a way to make vapor that will run an expansion turbine when the available water temperature and

Electric power generation success at The Geysers in California has motivated nationwide identification and assessment of hydrothermal resources, as well as several research and pilot projects for energy conversion. Green areas indicate regions with known and inferred hydrothermal reservoirs. In the eastern and midwestern states, the temperature of the resource is less than 150°C; in the western states, some reservoirs contain water and steam of electricity-grade temperatures. Gray areas indicate known and inferred geopressured zones; the best known are those that extend along the Gulf Coast.


## REPRESENTATIVE U.S. GEOTHERMAL PROJECTS

| Location | Purpose | Technology | Capacity (MW) | Starting Date | Sponsors |
|---|---|---|---|---|---|
| The Geysers, California | Electricity, commercial | Natural steam cycle | 800 | 1960–1980 | Pacific Gas and Electric Co.; Union Oil Co. of California |
| Heber, California | Electricity, demonstration | Binary cycle | 45 | 1984 | DOE; EPRI; San Diego Gas & Electric Co.; Chevron Resources Co. |
| East Mesa, California | Electricity, pilot | Binary cycle | 11 | 1979 | Magma Power Co. |
| Raft River, Idaho | Electricity, experiment | Binary cycle | 5 | 1980 | DOE |
| Valles Caldera, New Mexico | Electricity, demonstration | Direct-flash steam cycle | 50 | 1982 | DOE; Public Service Co. of New Mexico; Union Oil Co. of California |
| Northern Nevada (site to be selected) | Electricity, commercial | Direct-flash steam cycle | 50 | 1984 | Sierra Pacific Power Co. and other utilities |
| Heber, California | Electricity, commercial | Direct-flash steam cycle | 41 | 1982 | Southern California Edison Co.; Chevron Resources Co. |
| Roosevelt Hot Springs, Utah | Electricity, commercial | Direct-flash steam cycle | 20 | (pending) | Utah Power & Light Co.; Phillips Petroleum Co. |
| Brawley, California | Electricity, pilot | Direct-flash steam cycle | 10 | 1980 | Southern California Edison Co.; Union Oil Co. of California |
| Boise, Idaho | District heat, commercial | NA | NA | 1981 | DOE; State of Idaho; City of Boise |
| Crisfield, Maryland | Hydrothermal, exploration | NA | NA | 1979 (reached 60°C water) | DOE |
| Brazoria County, Texas | Geopressure, exploration | NA | NA | 1979 (well complete) | DOE |

pressure (geothermal or any other kind) are too low for the direct-flash approach. It involves a second fluid (hence the term *binary*) that vaporizes at a much lower temperature than water and a way to transfer the thermal energy from one to the other. Usually this is a surface heat exchanger in which many thin-walled tubes carry geothermal water through a cylindrical shell containing the second fluid. Thus heated and vaporized, the second fluid is piped into a turbine; it is the working fluid.

Both systems are closed loops. Geothermal water from production wells passes through the heat exchanger and returns to the reservoir through injection wells. Significantly, a binary cycle requires only about two-thirds the water volume (at 180°C; 356°F) needed by a direct-flash cycle to produce the same amount of electric power. For any given water cost, this fact materially contributes to the binary cycle's lower busbar power cost.

Heber is a $130 million project, entailing about $84 million in capital cost and about $46 million for fuel and operation over a demonstration period of at least two years (1985 and 1986). These figures represent totals of current dollars for the years in which costs are incurred. To some extent, operating costs will be offset by electricity revenue.

Recommended since early 1977 by Vasel Roberts and his EPRI colleagues and advisers, Heber is now ready for detailed engineering design. Preliminary work, including environmental reports and vital permits, is in hand from earlier R&D sponsored by EPRI and SDG&E. At least four other participants will be involved: DOE, Imperial Irrigation District, Southern California Edison Co., and California's Department of Water Resources. Two vital suppliers and customers are ready: Chevron Resources Co., part owner of the hydrothermal field and producer of its brine; and Imperial Irrigation District, supplier of cooling water and buyer of electricity.

The turbine generator for Heber could be on order a year from now, followed by plant construction beginning in August 1982 and ending two years later. On this basis, Heber will be through its startup phase in the fall of 1984, ready for demonstration operation and power generation at 65 MW—pumping brine and running the plant with 20 MW and delivering 45 MW of baseload electricity—four times the capacity of the first geothermal steam plant at The Geysers in 1960.

The foremost feature of the Heber project is its size, which is representative of commercial binary-cycle hydrothermal plants to follow. Its demonstration is vital for data and experience in all aspects of equipment design, manufacture, operation, reliability, and overall economics.

### Heber project features

Scale-up of the turbine is the biggest question mark of the Heber plant. Similar but much smaller turbines (by a factor of 3) have precedent in the petrochemical industry, where hydrocarbon fluids at conveniently compatible temperature and pressure are vaporized and used in turbines to generate shaft horsepower for pumps and compressors.

Heber's single hydrocarbon turbine will generate 65 MW. In contrast, the 11.2-MW Magma Power Co. pilot plant at East Mesa, California, is using two 5-MW and one 1.2-MW turbines. That plant uses two hydrocarbon fluids (propane and isobutane) separately in a pair of binary cycles that power the turbines. Elsewhere, Freon is the working fluid of a 100-kW experimental binary cycle to be tested by Arkansas Power & Light Co. for generating auxiliary power in conjunction with a geothermal minerals recovery operation.

The Heber project will also help resolve key questions about sustained hydrothermal reservoir production, but it shares this purpose with another venture, the 50-MW demonstration of direct-flash technology using high-temperature geothermal fluids at Valles Caldera, New Mexico. DOE is also the major sponsor there, with cofunding and participation by Public Service Co. of New Mexico and Union Oil Co. of California.

At Heber, brine will be pumped from about 12 production wells at the center of the reservoir (the hottest part) and delivered to the heat exchangers at about 182°C (360°F). It will be returned to the reservoir periphery down six injection wells at about 71°C (160°F). The planned extraction rate is some 880 kg/s (7 million lb/h), but the more important measure is its equivalent heat content, initially seen as 470 Btu/kg (214 Btu/lb). Brine production will draw down the natural well level at the center of the field, encouraging inflow from surrounding strata. Because about 80% of the reservoir heat is actually contained in the solid material, the reinjected brine will continuously sweep the reservoir of heat as it flows toward the drawn-down center, to be pumped again for another heat extraction cycle.

Sustaining reservoir production flow over a plant's life is central to the use of hydrothermal resources, but the possibility of declining temperature and heat content is very real. How can this be hedged? Short of extensive turbine modifications, the answer is to alter the properties of the working fluid. For Heber, the initial design is a mixture of isobutane (90%) and isopentane (10%), to be delivered to the turbine inlet under supercritical conditions of about 150°C (300°F) and 575 psi (4 MPa).

By changing the proportions of the two hydrocarbons, molecular weight of the fluid can be increased, enhancing its kinetics so that reduced heat input has the least adverse effect on turbine performance and power output. As defined by inlet vapor conditions, the peak of the turbine efficiency curve is thus moved to compensate for declining brine temperature.

### Handling heat and minerals

Heat exchange ahead of a binary-cycle turbine and heat rejection beyond any thermal expansion turbine (to condense the vapor for recirculation) are two more geothermal research areas. Both have inherent problems of minerals control. Even though most hydrothermal resources are no more saline than seawater (34,000 ppm), they often carry significant amounts of calcium carbonate, silica, and metal sulfides and sulfates. These and other minerals precipitate at the reduced temperature in a binary-cycle heat exchanger or elsewhere in a direct-flash system. The scale problem is pervasive, reducing both fluid flow and heat transfer and requiring periodic removal.

EPRI concludes that corrosion is also a problem but probably not a serious one for moderate-temperature systems. Roberts observes that hydrothermal fluids tend to be slightly acid and contain little or no free oxygen. "Therefore, if we keep oxygen out of the water cycle during startup and shutdown and during cleaning, corrosion should be minimal."

Mineral-scale control has called for extensive research in anticipation of the development of many hydrothermal systems having different fluid mineral compositions. Notable in this regard are EPRI-sponsored computer programs that can simulate various water chemical compositions and the point-by-point scaling rates they produce throughout a given power plant under different temperature, pressure, and flow conditions.

Four related programs enable design parameters to be optimized for given geothermal fluid conditions, including those in the reinjection wells. The latter point is important. Although the binary-cycle water loop is closed (and many environmental problems thereby avoided), fluids may well cause additional scaling in the reinjection wells and silting when they are returned to the reservoir at reduced temperature.

Heat-exchange equipment must be considered in light of these problems. At the very least, its design must acknowledge the need for expeditious and economic cleaning at intervals of from months to years. There may be an alternative to the surface heat exchanger and its scaling problems. In direct-contact exchange, the fluids are mixed in a single vessel, the working fluid vaporizes and thus is separated for use, while the cooled water is pumped away for reinjection in the reservoir. This avenue is only experimental so far, but is being followed by DOE on the premise that it could be more economic.

The evident saving is avoidance of mechanical complexity. The technical problems, and possible further costs, derive from the possibility of incomplete fluid separation. Hydrocarbon fluid might need to be retrieved from the spent water, or makeup quantities might have to be constantly added. Similarly, the presence of residual water or water vapor in the working fluid might alter the efficiency and economy of its function in the turbine expansion cycle.

### Environmental effects

When geothermal water or steam is used in direct-flash cycles, noncondensable gases are a direct influence on thermal efficiency because of their effect on overall vapor kinetics, and some of them may be environmental problems as well. Ammonia, boron, and hydrogen sulfide are examples. Hydrogen sulfide is present in some 20–25% of all hydrothermal resource systems, emitting a disagreeable odor at a concentration of only 30 ppb and considered toxic at 10 ppm. The 200-ppm concentration in steam at The Geysers is not necessarily typical, but it emphasizes that this effluent must be controlled.

Any method of gas removal represents a parasitic energy load on the geothermal power plant; the objective is to minimize that load while eliminating pollutants. Scrubbing geothermal steam is one approach being tested by PG&E and DOE. This entails introducing copper sulfate to react with the hydrogen sulfide and permit its removal in an altered form.

Condensation and reevaporation of the steam is another approach, being investigated by EPRI. The noncondensable hydrogen sulfide is mechanically separated after the first step. Then, recirculated through a shell-and-tube heat exchanger, the water is again evaporated by heat that is extracted from the incoming steam that follows it through the unit.

Tests of the second technology at The Geysers have successfully removed 90–97% of the hydrogen sulfide, which can later be disposed of by chemical treatment. Furthermore, the vent gas retains enough energy to drive vacuum pumps on the power plant steam condensers, thereby reducing the parasitic load otherwise imposed on the turbine steam supply.

Heat rejection is the final practical problem of any thermal power cycle, especially for geothermal technologies because of their already low thermal efficiency and consequent need for extensive cooling capacity.

PG&E's plants at The Geysers get all their cooling water from the steam itself: turbine condensate passes through evaporative cooling towers and is recirculated for condenser cooling. Direct-flash power plants derive their cooling water in the same way. Binary-cycle power plants could use extra reservoir fluid in a cooling cycle, but purifying it for this purpose would add considerable cost.

"We're fortunate at Heber," Vasel Roberts acknowledges, "because we'll have fresh water from the irrigation district for five years. After that we plan to use agricultural drain water." Beyond these examples, he adds, geothermal power applications and their economics will depend on the results of concurrent R&D in water-conserving combinations of wet and dry cooling.

## CLASSIFYING GEOTHERMAL RESOURCES

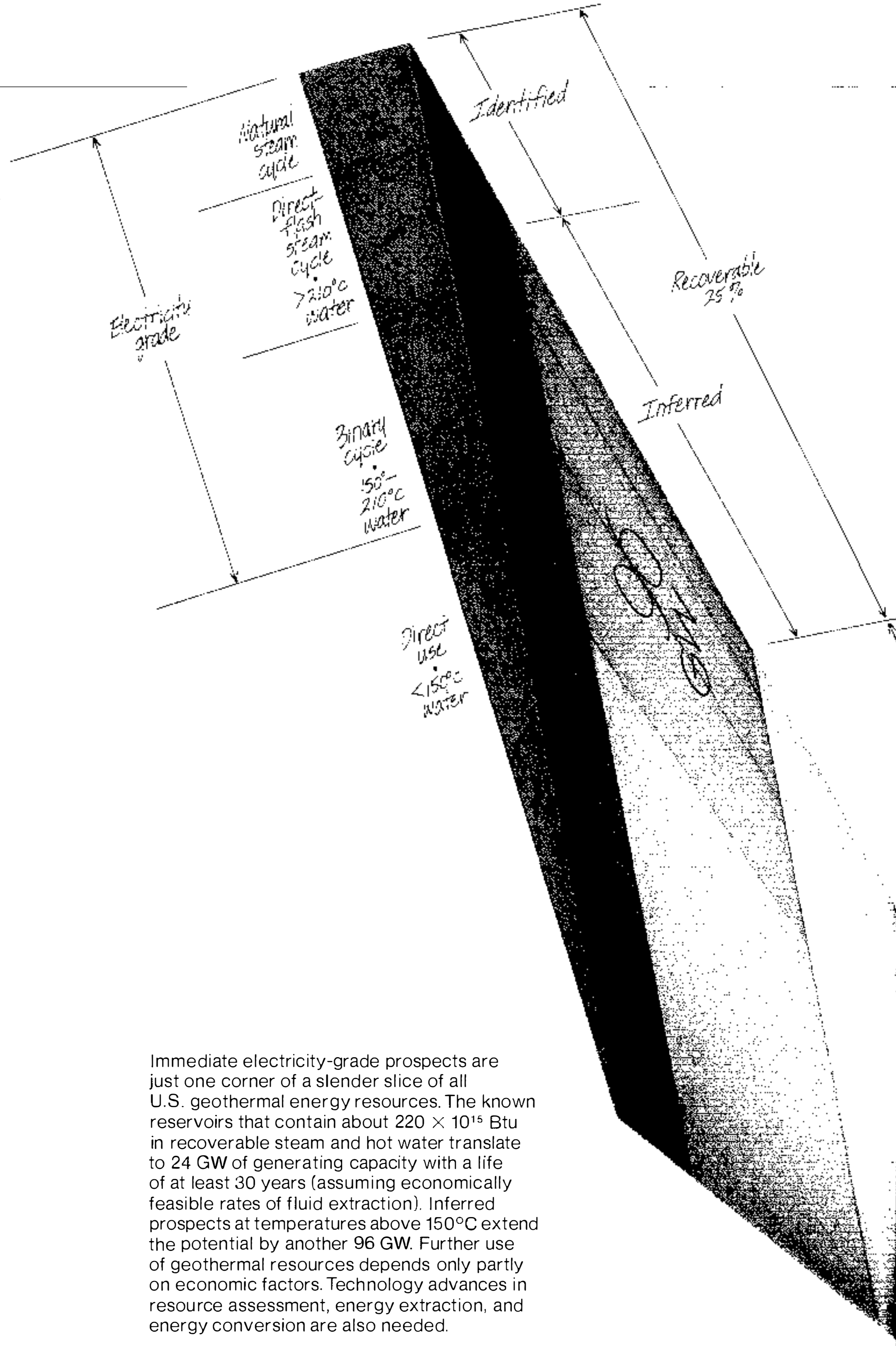
The earth's high internal temperature means that heat underlies every square foot of its surface. But no discernible path yet exists for developing most of it.

Where the earth's crust is structurally consistent, its temperature increases about 25°C (77°F) with each kilometer of depth, the result of heat conduction from the earth's mantle. Attractive quantities of this normal-gradient heat are at least 3 km (2 mi) down, but more like 5–7 km (3–4 mi) if the criterion is a temperature suitable for generating electricity (at least 150°C; 300°F).

Excluding normal-gradient heat, the accessible U.S. geothermal energy in place falls into three very broad categories, petrothermal, geopressured, and hydrothermal, which total about 1.2 million quadrillion ($1.2 \times 10^{21}$) Btu. This estimate covers resources at temperatures greater than 15°C (59°F) as both identified and inferred by the U.S. Geological Survey to a depth of 10 km (6.2 mi).

Petrothermal energy accounts for some 85% of the total. This is in molten igneous material (magma) that has been intruded relatively close to the earth's surface by volcanic activity and faulting and in crystalline rock that has cooled from magma. Even though the resulting temperature gradients are steeper (depths therefore less than those for equivalent normal-gradient heat) and U.S. petrothermal regions are well charted, this energy form cannot now be counted as recoverable for electric power production.

Methods and materials for drilling into magma do not exist. In hot rock alone, the best foreseen method of energy extraction calls for injecting water that would be heated and then pumped back up; but the energy and monetary costs involved may not be




Immediate electricity-grade prospects are just one corner of a slender slice of all U.S. geothermal energy resources. The known reservoirs that contain about $220 \times 10^{15}$ Btu in recoverable steam and hot water translate to 24 GW of generating capacity with a life of at least 30 years (assuming economically feasible rates of fluid extraction). Inferred prospects at temperatures above 150°C extend the potential by another 96 GW. Further use of geothermal resources depends only partly on economic factors. Technology advances in resource assessment, energy extraction, and energy conversion are also needed.

economic. Furthermore, the complexity of underground strata, especially their varying porosity and permeability, poses practical problems in retrieving the injected water. And water itself is becoming a scarce resource for energy processes.

Continued research may overcome these problems. The technology focus now is on mechanisms of reservoir development: how to drill into dry hot rock, how to induce its fracturing, and how to circulate water in and out of a system of wells for efficient and reliable heat extraction. DOE is funding a $14 million program in petrothermal energy, with Los Alamos Scientific Laboratory doing much of the research.

Geopressured resources make up the next largest class, perhaps 165,000 quadrillion ($165 \times 10^{18}$) Btu, or 14% of the accessible geothermal energy in place. Geopressured zones lie beneath the Gulf Coast, formed by southerly drainage and deposition from the rivers of past geologic times. Impermeable shale caps were deposited above sediments that contained water and organic material, and the latter decomposed to form natural gas. As a result of subsequent settlement and compression, the sediments now exhibit pressures well above the natural hydrostatic values for their depth—as much as 10,000–15,000 psi (70–100 MPa) at 2–6 km (1–4 mi). Those pressures will be the key mechanism for bringing up the hot water (100–180°C; 220–356°F) and the natural gas now dissolved in it.

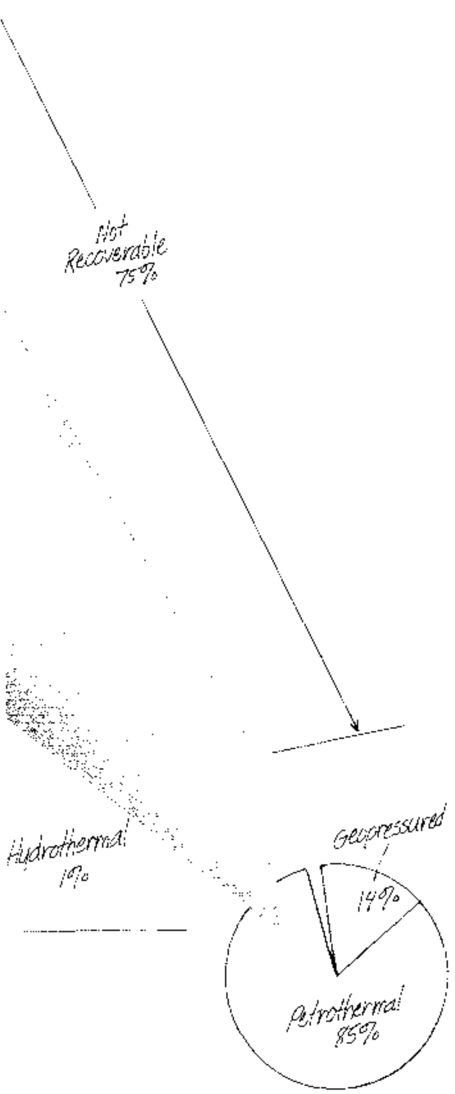
As with any underground resource, the recoverable energy is only a fraction of the accessible total in place. In the case of geopressured resources, the concern today is whether they are sufficiently concentrated to be economically attractive.

Hydrothermal systems of steam and water are the smallest geothermal resource class, about 9600 quadrillion ($9.6 \times 10^{18}$) Btu, or barely 1% of the total; and most of it is in the West. The anticipated recoverable portion, however, is about 2400 quadrillion ($2.4 \times 10^{18}$) Btu, a far higher proportion than for geopressured energy.

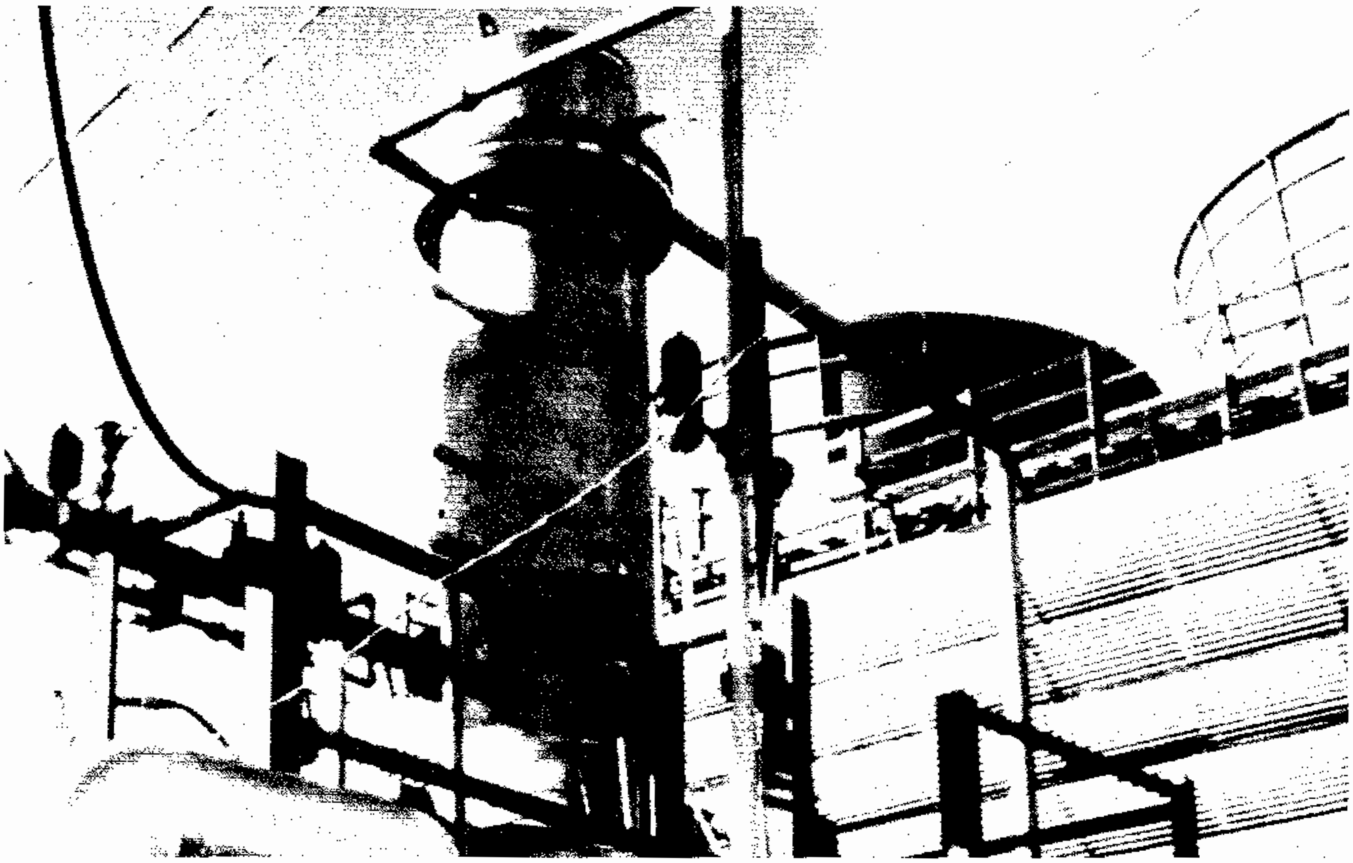
Dry steam occurs where geologically recent volcanic activity is combined with paths for water to percolate deeply and flow into contact with very hot rock. The spectacular eruption of Washington's Mount St. Helens has so far been driven largely by steam, but this is a special circumstance. The percolation of the past 123 years has produced tremendous steam volume and pressure directly beneath an acutely weakened and vulnerable rock mass, the volcano's plug. This is one of nature's relief valves at work.

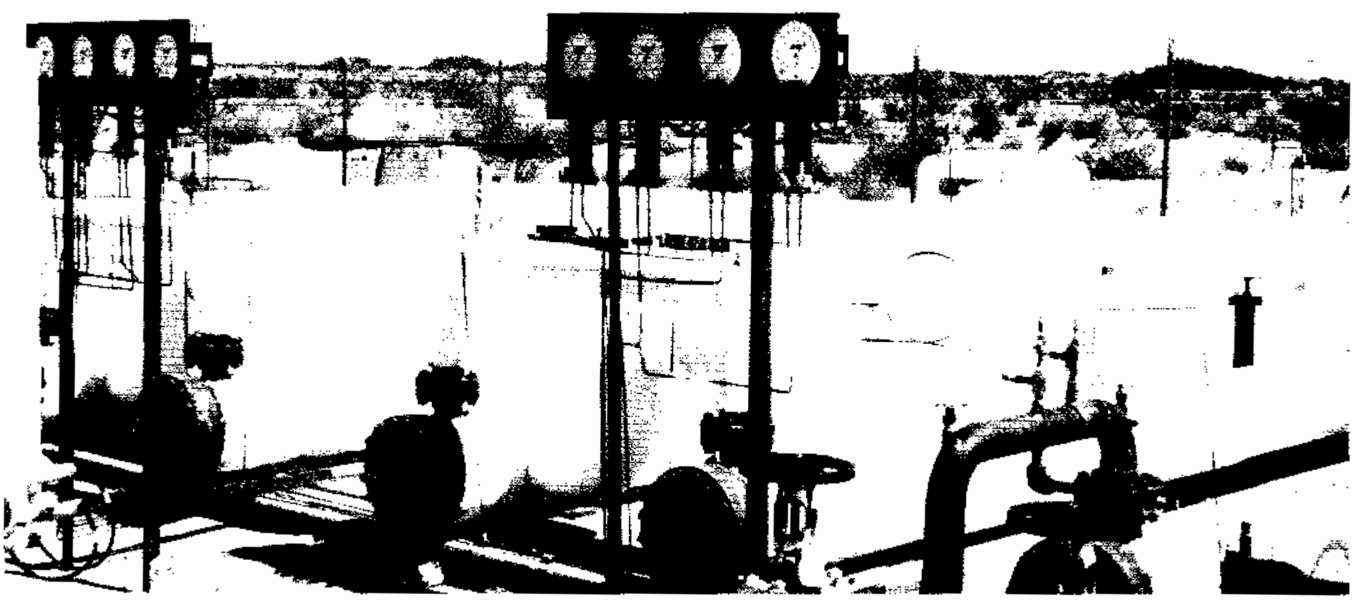
Natural steam systems, although obvious, are the rarest geothermal resource, perhaps only 40 quadrillion ($40 \times 10^{15}$) Btu, and a quarter of that is represented by the 2000 MW of capacity already in place or planned at The Geysers in northern California. Closely akin to dry steam systems are hot water systems. Deep geologic heat warms water-bearing strata, creating vast, slow-moving thermal convection patterns that rise, blossom, and spread into overlying sediments.

Such hydrothermal reservoirs make up most of the recoverable hydrothermal resource base, and about 900 quadrillion ($900 \times 10^{15}$) Btu of their energy content may be above the 150°C (300°F) threshold useful for electricity production with today's technology. Such hydrothermal systems require thorough definition and economic justification; they are the major focus of today's electric power R&D by EPRI, DOE, and others.



Experimental falling-film evaporator at The Geysers separates noncondensable hydrogen sulfide gas from incoming steam during successive stages of steam condensation and reevaporation. The steam flow through this unit (shown before insulation was installed) is about 1000 lb/h (0.13 kg/s), only a fraction of the total supply to PG&E's 55-MW Unit No. 7.





Field experiments have verified the thermal performance of geothermal brine and hydrocarbon fluid to be used in binary-cycle power generation at Heber, California. A series of six heat exchangers (four shown) operates at a rate of about 5 MW/h (th), equivalent to the requirements of a 500-kW (e) turbine-generator, producing superheated vapor at about 150°C (300°F).

### Future technologies and resources

Even direct-flash and binary cycles are not the full spectrum of generation possibilities, according to Roberts. "There is the total-flow concept—how to use both flashed steam and the residual water to improve energy efficiency. We've field-tested a 20-kW rotary separator–turbine at Roosevelt Hot Springs in Utah. It could get an extra 15–20% efficiency from a direct-flash generation unit."

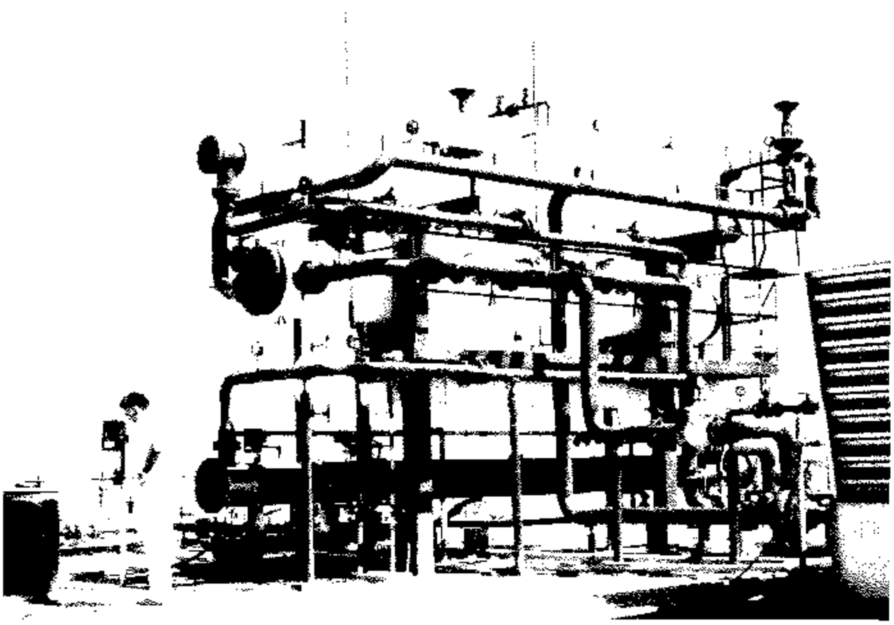
The rotary separator is a disc with a flanged rim. When flashed steam is directed against the disc, the water droplets are caught by the inner surface of the rim; that is, the flange acts as a single large bucket and delivers the droplets into the cups of a hydraulic turbine. Steam in the separator chamber is piped into a conventional steam turbine, and the hydraulic turbine output is essentially a bonus.

This approach to total flow is distinctive because it employs the liquid and vapor phases of the geothermal fluid separately. It perhaps represents EPRI's longest reach toward advanced technology for flashed-steam power cycles. Lawrence Livermore Laboratory and Jet Propulsion Laboratory (California Institute of Technology) have studied and tested other approaches, notably a turbine designed for two-phase fluids (liquid and vapor in a single stream) and a positive-displacement mechanism. In one such configuration, fluid is admitted to the cavity between two meshing helical screws. Fluid flow and expansion against the surfaces of the screws causes their shafts to rotate.

Roberts also acknowledges the possible combination of combustion and steam or binary cycles in geothermal energy technology, perhaps to exploit the methane and thermal content of some geopressured resources.

In general, geopressured resources are not yet a large prospect for electric power generation. On the basis of work by Southwest Research Institute, EPRI acknowledges perhaps 1100 MW of capacity that might be developed and installed by the year 2000. This estimate comes from a study of 20 specific prospects in Texas and Louisiana. All together, Southwest Research concludes that the potential exists for extracting $7 \times 10^{12}$ ft$^3$ ($200 \times 10^6$ km$^3$) of methane containing 7 quadrillion ($7 \times 10^{15}$) Btu, plus hot water containing 13 quadrillion ($13 \times 10^{15}$) Btu, for a total that is equivalent to about 5300 MW over 30 years. Economic feasibility would depend, for one thing, on a methane price of at least \$5/1000 ft$^3$ (\$17.75/m$^3$).

The biggest shadows hanging over this resource, however, are the methane content of the geopressured fluid, the cost of production, and reservoir life. For example, early indications are that methane content runs about 20–25 ft$^3$/bbl of fluid and that reservoirs are small because of their geologic structure. Data for full evaluation of the resource potential are being developed in a \$39 million DOE program.



After throttling, the fluid is condensed and cooled in successive stages to 49°C (120°F) for recycling. Portions of the cooling tower appear at the right. The condenser is insulated for safety and for precise measurements of its performance.

### Free energy at least cost

When all is said and done, geothermal heat itself is indeed free in the sense that any natural resource in place is free. More important, it is renewable and essentially inexhaustible if not withdrawn at excessive rates. But the fluids that contain and convey that heat are quite evidently a spectrum of resource forms and temperatures, site-specific in their energy and mineral content, their ease of access, and their reliability of production. Familiar thermal power cycles are being carefully adapted to deal with these characteristics. The cost of adaptations and the cost of the fluids must meet the competitive market set by other fuels and technologies.

The bottom line is still a combination of reliability and busbar electricity cost. As fossil fuels escalate in price, the trend favors geothermal energy in general; and it especially favors the 24 GW of capacity that can be developed from known hydrothermal resources with the direct-flash and binary-cycle technologies soon to be demonstrated.

A winter storm pelts a suburban area with rain one evening, and in the midst of it an electric utility pole topples, taking with it the distribution line that provides a neighborhood's power supply. Phone calls deluge the local electric utility, and guided by those calls, engineers laboriously approximate the location of the fault. Linemen are dispatched to grope through the darkness and rain to find the downed line. An hour later, the break has been located, and nearby feeder lines have been manually sectioned to isolate the fault and restore service to all except a few houses. But utility customers have already eaten their half-cooked dinners by candlelight.

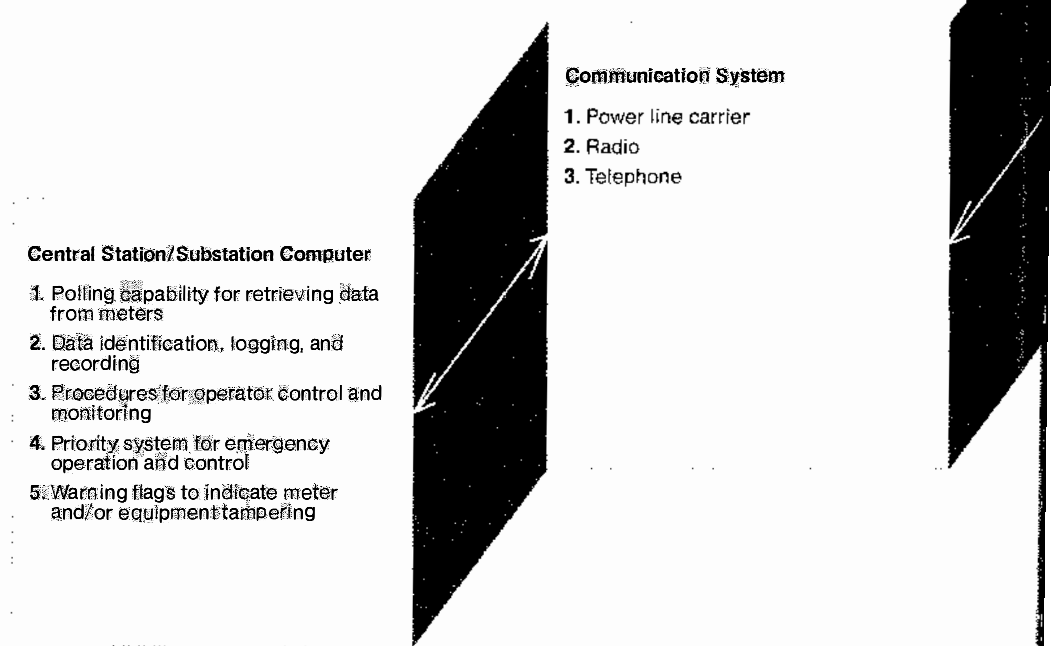
### Automatic control

The fault could have been detected—and most of the candlelight vigil averted—by distribution automation, according to William Blair, project manager in EPRI's Distribution Program. Distribution automation is the remote control of the distribution network that carries power from local substations to customer meters. In this case the information telling when and where the fault occurred could have been automatically speeded to the utility along communication lines. Adjacent feeders could then have been remotely sectioned to isolate the fault and restore power to most of the affected area. Fewer customers would have had their evening interrupted.

Fault location and service restoration are not the only jobs distribution automation could do for utilities, explains Blair. Capacitors, devices that utilities use to keep line voltages within specified limits, could be switched automatically when voltages fluctuate. Time clocks that switch capacitors regardless of voltage and load conditions are frequently used

# Two-Way Data Communication Between

*Before electric distribution networks can be automated, electronic two-way data communication systems between utility and customer must be perfected. A joint EPRI–DOE program explores power line, radio, and telephone communications.*



today. Through the large-scale automatic switching of capacitor banks, utilities could reduce the power losses that occur on lines. And by operating near the preferred voltage limits, customer appliances would function more efficiently.

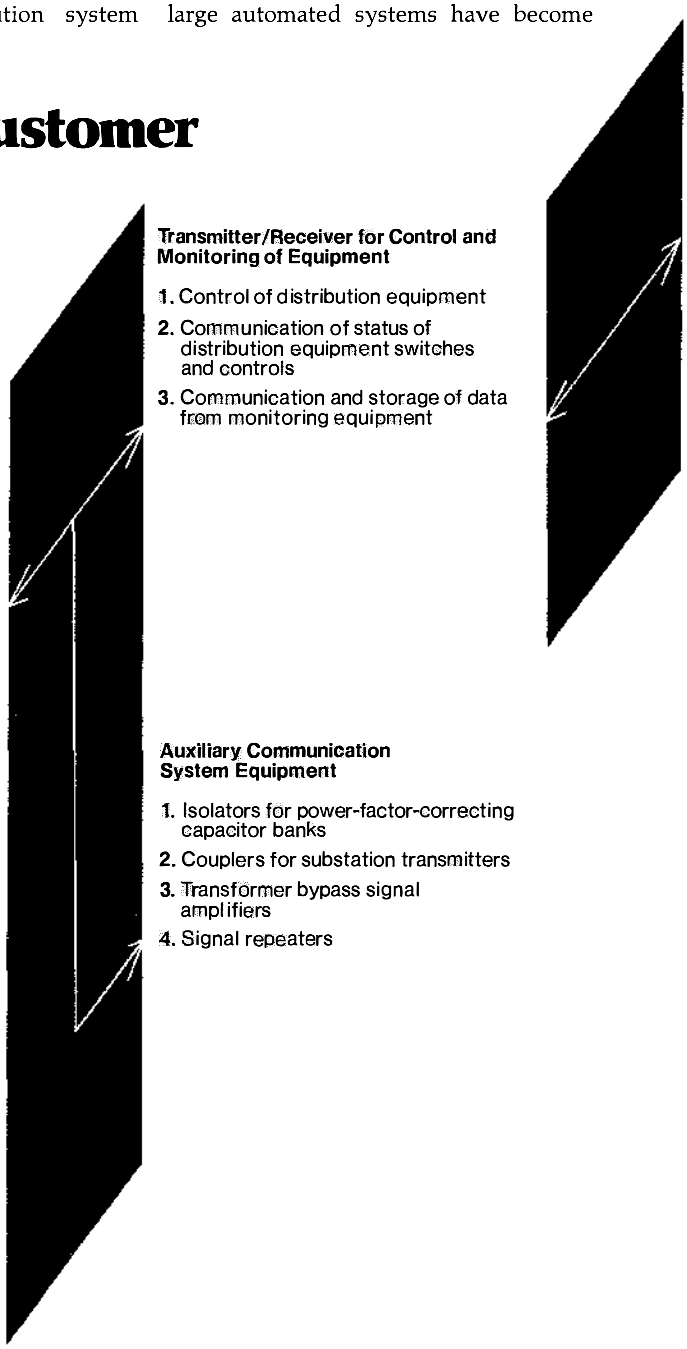
Perhaps one of the biggest advantages of distribution automation, notes Blair, is that by controlling such customer loads as air conditioners and electric heaters for brief periods or by facilitating time-of-day metering, electricity could be used more economically and brownouts and blackouts might be averted.

An automated distribution system could also be used to swiftly perform the more pedestrian utility tasks, such as meter reading. This job presently costs the utility about 50¢ per meter per month and necessitates a small army of meter readers nationwide. Meter tampering, too, could be detected by continuously monitoring meters for illegal energy diversion.

The electronics network necessary for distribution automation is obviously complex and extensive; until recently it was not practicable. But today, real systems seem within grasp. "In recent years, large automated systems have become

The performance requirements of a data communication system for distribution automation are many, as this illustration shows. The system must be able to store and retrieve data from customer meters, control distribution equipment, alert operators to meter tampering, and more. Without such a comprehensive communication system, distribution automation is impossible.

# Utility and Customer



feasible and practical because of the increased reliability of electronics, the improved performance of integrated circuits, and the reduced cost of computers and microprocessors," says Blair. The computer systems, microprocessors, and auxiliary equipment required for distribution automation are now available. The biggest obstacle remaining is perfection of a communication system that links thousands of utility customers with the utility's distribution control center. The system must provide for two-way communication between utility and customer; not only must the utility operator be able to issue commands to automated equipment but the customer's meter must be able to answer the controller, reporting status and relaying data.

Through a four-year, $10 million joint program, EPRI and DOE are trying to determine whether such a two-way communication system is feasible, and if it is, whether it would be cost-effective. Contract manufacturers have developed five different communication and load control systems and have installed them for field tests on host utility distribution networks throughout the United States. Each system encompasses at least 700 customer meters on urban, suburban, and rural distribution feeder lines varying from 2 to 12 miles long, according to Blair, who manages EPRI's share of the joint program. The systems are being tested in residential, commercial, and industrial conditions. Trials are expected to be completed this year, and results should be available by early 1981.

Three types of communication systems are being investigated: power line carrier, telephone, and radio. Each system has its own special capabilities and limitations that must be defined before commercial automated distribution systems can be designed.

### Power line, telephone, and radio

Power line carrier (PLC) systems use electricity distribution lines for the transmission of communication signals. "The PLC system has the advantages of complete coverage of the entire electrical system and complete control by the utility," emphasizes Blair. Yet he warns that under extensive damage to the distribution system, this communication system could also fail. "If lines are broken, the communication link would be broken, which could prevent the feeder sectioning necessary for service restoration."

A PLC system developed by Westinghouse Electric Corp. is being tried at Detroit Edison Co. under EPRI auspices; another PLC system by Compuguard Corp. is being tested at Carolina Power & Light Co. for EPRI. Yet a third PLC system, by American Science & Engineering, Inc., is undergoing testing at San Diego Gas & Electric Co. for DOE.

Telephone carrier systems use existing telephone lines for signal communication. "This system has the potential advantage of being the least expensive communication channel because it exists as a communication system in most homes and businesses," says Blair. However, electric utilities would not have full control of telephone systems, and existing telephone tariffs may boost operating costs into steep price ranges. Finally, not all electricity meters have phone service at or near them, necessitating potentially costly connections between, say, a meter on one end of a house and a phone on the other end. A telephone carrier system developed by Harris-Darcom, Inc., is being tested for DOE by Omaha Public Power District and Metropolitan Utilities District with the support of Northwestern Bell Telephone Co.

In radio carrier systems, communication signals are transmitted point-to-point via radio waves. Such systems would be owned and operated by electric utilities. Blair points out that these systems would also be independent of the power distribution system and thus unaffected by distribution outages. However, radio signals can be jammed or blocked, either accidentally or intentionally. External antennas are also required at or near the meter, and optimal locations for such antennas might not be available. A radio carrier system developed by Westinghouse Electric Corp. has been installed by Long Island Lighting Co. and is now undergoing tests under EPRI contract. A smaller, one-year EPRI project is also under way, which involves the development of another radio system by Altran Electronics, Inc. Fifty units will be fabricated and field-tested for six months on Southern California Edison Co.'s system. Tests in this smaller project will be completed this year, and results should be available in early 1981.

The major responsibility of each manufacturer and host utility team from now through the end of the test period is to evaluate the performance of each of the five communication and control systems being tested. Data rates, equipment failures, and ease of installation and maintenance are among the areas that will be evaluated. Manufacturers must also measure communication system characteristics, such as component failure and power line noise that could garble signals; host utilities will make evaluations of communication system convenience, reliability, versatility, accuracy, and speed.

While EPRI and DOE singled out power line, telephone, and radio carriers as the most promising systems for their research, other communication techniques are certainly possible. However, these other techniques involve greater uncertainties. For example, cable television might be used to transmit signals, but CATV coverage of homes and commercial buildings is certainly not as extensive as telephone coverage. Ripple systems, a form of power line carrier that uses low-frequency signals, are already used overseas (and to a lesser extent, in the United States) to control such loads as electric water heaters. However, these are traditionally one-way communication systems with limited control capabilities compared with PLC systems. Two other communication possibilities are fiber-optics systems and synchronous satellites. However, both those technologies are still unproved and probably too expensive to consider seriously at this point. All these alternative technologies are improving in performance and dropping in cost with each passing year, comments Blair, and EPRI is keeping an eye on their progress for future utility communication applications.

"Each communication technology has its own mix of advantages and disadvantages, relative to others," sums up Blair. Utilities might capitalize on the strengths of a technology while avoiding its weaknesses by matching communication systems to the service areas they suit best. A radio carrier, for example, might prove to be best for long-distance communication with utility customers in rural areas, where lengthy distribution feeders or telephone lines would increase the cost of distribution automation per customer. PLC systems might be most advantageous in suburban areas with feeders of relatively short to average length; telephone communication might be most suitable for congested urban areas, where feeders are heavily loaded and electrically noisy.

#### Hybrid systems

Utilities might also choose to use hybrid systems: two or more different communication systems between utility and customer. For instance, a radio carrier might be used between the control station and the distribution transformer, and a power line carrier between the transformer and the customer's meter.

In another possible variation, the command (forward) link might be one communication system, broadcast radio, for example, and the return (data) link might be another system, such as VHF radio. The many combinations possible must be thoroughly examined before utilities can decide what communication systems are best for them.

Completion of the EPRI–DOE communication system tests will by no means supply all the answers about distribution automation. Based on project results, the systems will have to undergo modifications and equipment redesign before a commercially acceptable communication system can be achieved. Cost is also a big consideration, and EPRI and DOE will take a look at the projected unit, installation, operation, and maintenance costs of the five systems.

Beyond communication systems, distribution automation requires appropriate computers and microprocessors. These are available, as noted earlier, but must still be developed for application on distribution automation systems. Engineers must also perfect new watthour meters compatible with distribution automation systems. In an ongoing EPRI project, contractors McGraw-Edison Co. and Texas Instruments Inc. are attempting to develop just such a fully electronic meter.

Only when more is known about distribution automation's performance can truly accurate estimates of cost-effectiveness be made. But even then, admits Blair, the analysis will be complex; furthermore, "A system that's cost-effective for one utility may not be so for another." Individual utilities will have to perform independent analyses to determine the cost-benefits of various distribution automation systems. Extended equipment lifetime resulting from reduced overload periods, lower manpower costs from remote meter reading, and recovered revenue from the automatic location of tampered meters are considerations that will have to justify the capital, operation, and maintenance costs of a distribution automation system that entails thousands of customer communication terminals.

#### Customer acceptance

Even if the price is right, there is one more test ahead before utilities and their customers can sample the benefits of distribution automation: customer acceptance. "For most functions, the customer will never know distribution automation exists," says Blair. "Such functions as remote fault sensing and automatic feeder switching would provide the customer with fewer outages, faster restoration of service, and more stable operating voltage. All this means more reliable service."

Customers can readily appreciate such advantages, but they might be hesitant to permit utilities to install electronic equipment that could control electricity service to reduce peak loads. Although essential services, such as electric lighting, would not be interrupted, load control could conceivably interfere with such services as water heaters, air conditioners, clothes dryers, and electric heaters. These loads might be selectively switched off for short periods of time to level peak loads, thereby reducing the utility's need to provide costly peaking power. The resultant savings in the cost of electricity would benefit utility and customer alike.

Load control could also be used to improve service in other ways. For example, should significant numbers of new power plants be delayed because of licensing, siting, or construction problems, load control might be used to avoid overloads. Construction and licensing of a power plant takes about 10 years, but a distribution automation system could be installed and operating within 2–5 years to help cope with potential brownouts or blackouts, according to Blair.

As an alternative to load control, distribution automation systems could be used to facilitate time-of-day metering, whereby higher rates are charged for electricity consumed during peak demand periods and lower rates are charged for electricity used during off-peak periods. If customers cooperated in such a metering program, the results would be more efficient and economic use of energy, as well as fewer brownouts and blackouts.

Although electric utilities are still a long way from communicating with their customers through distribution automation, the EPRI–DOE communication system research will provide key information on what these systems can and can't do, opening the way for future options.

# Refining The Process That Refines The Coal

*First operated in 1973 to refine a sulfur-free solid fuel from coal, EPRI's small pilot plant at Wilsonville, Alabama, is now a focal point for R&D in coal liquefaction. Today Wilsonville is resolving process details for DOE's design of a 6000-t/d demonstration plant. Tomorrow its solvent-refined coal (SRC) will feed a new process that yields improved liquid fuels for clean electricity production.*

Refining a clean burning fuel from coal requires thorough removal of sulfur and residual ash. Doing it economically also requires recycling enough high-quality solvent to run the process in balance. Pulverized raw coal is the pilot plant feedstock at Wilsonville—the 2-t contents of three steel tote bins tip against an input hopper every 24 hours. Smooth, shiny SRC is the end product—3.5–4 t of it, fine-textured and friable, breaking away from a taffylike slab that crawls steadily off the end of a chilled conveyor or vibrating tray.

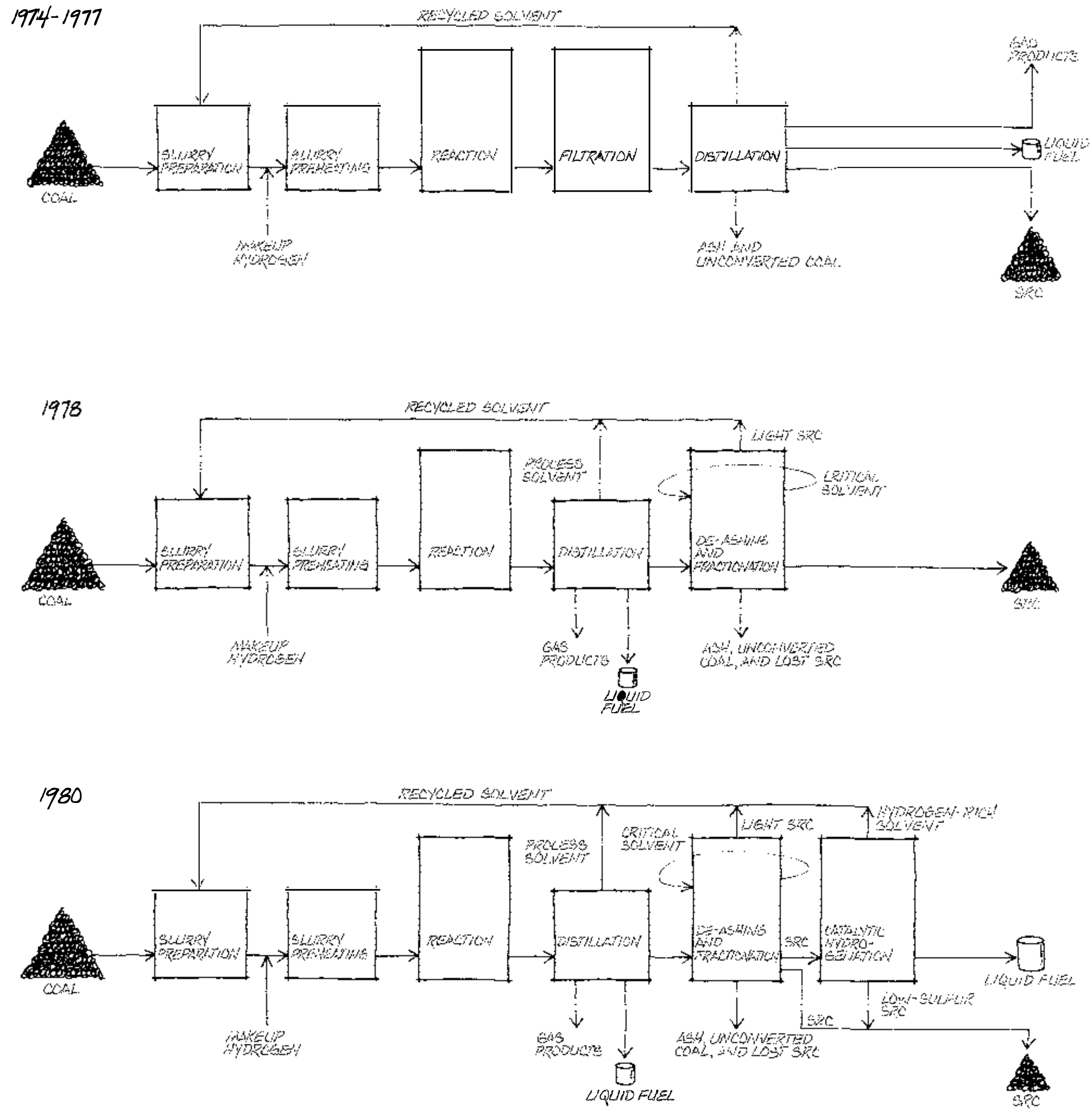
Solid coal going in. Clean solid product coming out. That has been the SRC-I process at the 6-t/d Wilsonville pilot plant near Birmingham, Alabama, operated for Southern Company Services, Inc., under the joint sponsorship of EPRI (35%) and DOE (65%). SRC is largely free of ash and so low in sulfur content that it can be burned without flue gas desulfurization.

Pilot testing of the SRC-I process began at Wilsonville in 1973, with Catalytic, Inc., operating the plant under sponsorship of EPRI and Southern Company Services. The original goal was quite limited and was readily attained: production of a solid fuel that would meet environmental standards. The result was SRC with less than 0.16% ash content and a yield of less than 1.2 lb (0.5 kg) of sulfur dioxide per million Btu when burned.

After demonstrating the basic feasibility of the SRC-I process, Wilsonville researchers went on to gain experience with a wide variety of feed coals and to investigate various combinations of plant operating parameters. DOE joined the development effort in 1976, assuming responsibility for most of the operating expense. EPRI retained ownership of the plant and responsibility for capital improvements. As increasingly subtle questions are addressed and as last-minute problems of SRC-I commercialization are resolved, the pilot plant is becoming more complex.

The segment of the process that is the principal focus today is the separation of ash and unconverted coal residue from the SRC stream after it leaves the reaction section of the plant. Several techniques have been tested at Wilsonville: filtration (used exclusively until 1978), solvent extraction, and centrifugal separation. The solvent extraction method known as critical solvent de-ashing

Two major developments in solvent refining at EPRI's Wilsonville pilot plant have improved the SRC-1 process performance since 1977 and extended its usefulness beyond the production of solid fuel alone. Critical solvent de-ashing (1978) separates solids more effectively and yields a light SRC that cuts the requirement for makeup hydrogen. Catalytic hydrogenation (1980) will take full advantage of operating flexibility in the fractionation stage, using it to produce more of the SRC that can be readily upgraded to liquid boiler and turbine fuel.



(CSD) now looks better than filtration for getting the residues out. It also yields collateral benefits that should extend the flexibility of the SRC-I process well beyond the production of solid fuel alone. A new hydrogenation section is now being built to test this possibility. Combined with the original liquefaction reactor and the CSD unit, it will permit investigation of a new and distinctive process for converting coal to liquid fuels.

### The solids-separation problem

The basic SRC-I process is not designed to remove all the sulfur chemically. Much of it remains in the mineral matter of the coal, to be eliminated with the ash by physical solids separation. The technique used is important because the final sulfur content depends on it and also because both the specialized equipment and its operation are expensive.

A horizontal-leaf filter was first used at Wilsonville, but it proved difficult and costly to maintain because of its complexity, which led to the conclusion that it could not readily be scaled up to full plant size. A vertical-leaf filter has also been tested, and a candle filter is being considered now.

Performance of these filters is compromised by properties of the SRC process stream. Temperature and pressure conditions of about 315°C (600°F) and 1.03 MPa (150 psia) are greater than available filters are designed to withstand. Particle sizes of ash and unconverted coal tend to run extremely small (mostly finer than 10 $\mu$m) for mechanical filtration; furthermore, the particles are sticky.

Dealing with these problems at commercial scale would require installing many filters in parallel and using valves to switch the process stream from one to the next when a filter must be taken offline for cleaning. Each such change entails a long sequence of discrete steps to add wash solvent, wash the filter cake, drain the solvent, dry the cake, remove it, restore temperature and pressure conditions, introduce precoating materials, drain the excess, and then bring the filter back on-line. In sum, such filters would operate in a batch mode, whereas the process calls for continuous operation.

Laboratory experiments at bench scale suggested that continuous solvent extraction would resolve the problems of solids separation, and a self-contained, skid-mounted process unit was installed at Wilsonville. Developed and built by Kerr-McGee Corp., the CSD unit is so named because it operates under temperature and pressure conditions that are near the critical point for the solvent; that is, the point where it exists as a single phase not definable as either liquid or gaseous. The importance of this solvent regime is that it exhibits both high solubility (similar to a liquid) and low density (similar to a gas). The latter property is markedly and advantageously different from that of the process liquids with which the solvent interacts. However, the critical temperature tends to be relatively high, and this is a penalty that increases the severity of conditions at which the CSD unit operates.

### Fractionation by CSD

CSD rejects solid residues and ash in the first of two or three successive stages. In this respect it meets the main objective of the SRC-I process sponsors, and for this reason it is being incorporated into the design of a 6000-t/d DOE demonstration plant planned for construction near Newman, Kentucky. But the collateral benefits of CSD are also significant. So far they have been observed in laboratory work only. It is hoped that Wilsonville will confirm the following at pilot scale.

▫ In the final fractionation stages, CSD yields a controllable slate of light to heavy SRC products, still in molten form. The lighter of these act as a chemically superior solvent for the dissolution of coal in the reactor of the SRC-I process.

▫ The superior properties of the CSD-derived solvent show up in potentially reduced SRC-I reaction severity, that is, lower temperature and pressure and a shorter residence time for the process stream (therefore a more economic operation in terms of throughput as well as coal conversion).

▫ Solvent is first recovered from distillation steps that follow the reaction section of the SRC-I process. But it is the added solvent from CSD that should now make it possible to run the pilot plant at more moderate conditions and in balance so far as solvent is concerned. Technically, this is most important if the SRC liquids are to be used as intermediate products in the new process. Also, several side reactions that consume hydrogen are minimized under moderate reactor conditions. This affords operating economy by reducing the need for makeup hydrogen.

▫ The SRC fractions produced (depending on how they are split in the CSD unit) promise to be much improved feedstocks for further hydrogenation and upgrading to liquid fuel end-products. Exploring this potential is also an objective of the Wilsonville sponsors. Pilot-scale tests will begin later this year when a new hydrogenation unit, an expanded-bed hydrotreater supplied by Hydrocarbon Research, Inc., is in place.

Much of the Wilsonville work during the current five-year R&D program (now in its second year) originated in several earlier bench-scale projects. These projects sought controllable ways to enhance the hydrogen transfer reactions that occur in coal liquefaction. Hydrogen transfer refers to the mechanisms whereby carbonaceous coal molecules gain hydrogen atoms and thus become hydrocarbons functionally equivalent to petroleum products. Ronald Wolk and his colleagues in EPRI's coal conversion projects (as well as other researchers) theorized that certain of the higher-boiling liquids derived from coal are particularly effective transfer agents, either of themselves or as catalysts.

Parallel work at Wilsonville and by various EPRI contractors tended to support the theory. Better than 90% coal conversion was achieved in the presence of solvent recycled from the process, while the process severity (temperature, pressure, and residence time) was reduced. Analysis showed that the composition of the recycle solvent played a key role in process performance. This confirmed the correlation, first noted by EPRI's Norman Stewart, between the proportion of a high-boiling, heavy-liquid fraction in the recycled solvent and the conversion efficiency of the process.

Increasing the concentration of high-boiling solvent in the SRC-I reactor became an objective, and one means was seen to be that of extracting the desired fraction from the reactor exit products and recycling it into the reactor with the feed coal and other process solvent (which is recovered in a separate distillation step). CSD affords the capability of this fractionation of the process stream.

Review of several successive process schemes at Wilsonville, even in barest block-diagram form, shows the circumstances under which different roles of the CSD unit can dominate, whether for solids separation or for producing different SRC splits.

**UTILITY SYNFUELS FROM COAL**

Solvent refining was first conceived specifically to produce a clean solid fuel substitute for direct firing under pulverized-coal-burning utility boilers. That was the genesis of the SRC-I process, now being carried toward commercialization by DOE in the design of a 6000-t/d demonstration plant to be built near Newman, Kentucky.

But it wasn't long before other developers thought of using SRC, still in liquid form, as an intermediate product to be further upgraded into liquid boiler and turbine fuels. This prospect has continued to intrigue EPRI and has come to be the basis for more recent developments at its Wilsonville pilot plant.

Still another approach involves recycling part of the process stream back into the original reactor. This technique was used by Gulf Oil Corp. in developing its SRC-II process. DOE is also planning to demonstrate that technology in a 6000-t/d plant near Morgantown, West Virginia.

Two other coal conversion processes, H-Coal and Exxon Donor Solvent (EDS), are receiving significant EPRI support. Large pilot plants (each 250-t/d) have been built at Catlettsburg, Kentucky, for H-Coal, and at Baytown, Texas, for EDS. Startup tests are under way at both sites.

Together with the new work at Wilsonville, these processes are at the forefront of coal liquefaction development today. Synthetic fuels from all of them bid to be readily and economically transportable, their essential Btu content retained in a smaller volume. They should be suitable for replacing pulverized coal and petroleum in a wide range of existing power plants, without stack gas scrubbers and their attendant problems of sludge disposal. They will thus compose the spectrum of coal-derived fuels needed for U.S. utilities to reduce their consumption of petroleum fuels and produce electricity with far less environmental pollution than is possible with raw coal.

### Separating the process stream

Howard Lebowitz is EPRI's technical manager for development of advanced liquefaction processes. The Wilsonville work is his responsibility, shared with Conrad Kulik, project manager for bench-scale studies, and William Weber, EPRI's site engineer at the pilot plant. On a rainy day last winter, Weber traced out the hardware relationships, one subsystem after another, including concrete footings for the hydrotreater soon to be added. It is a seemingly random configuration after seven years of R&D evolution—some of the equipment is old, some is new; some is obsolete, some is current; some has been cannibalized, most is intact—but the process perked steadily, producing solid and liquid SRC samples for analysis in an adjacent laboratory, plus solid data for economic evaluation.

Back at the trailer that serves as Weber's office, Lebowitz turned to a chalkboard to describe one major transposition in the pilot plant equipment train since the CSD unit was brought in. He sketched two blocks, a reactor followed by a filter. "The process stream from the reactor has three main constituents: liquefied coal that will become SRC and its by-products, the process solvent, and a residue of solids (ash and unconverted coal). All of it used to go straight to solids separation, where we filtered out the ash and coal residue."

Lebowitz then added a vacuum column, where the filtrate was distilled into its final fractions: process solvent for recycling, some further distillable by-products, and the heavy SRC liquid, which can be sprayed on a water-cooled surface to solidify. "Now, however," Lebowitz went on, "the stream from the reactor is distilled first."

He erased the filter and added a new block, the CSD unit with its own critical solvent supply, placing it beyond the vacuum column. "This way, the process solvent and distillable by-products come off first, continuously, and we have an ash-rich feed going into the CSD. We can adjust the distillation to get the feedstock we want for de-ashing. When we first tried it in 1978, it was simply a tradeoff for filtration. We removed only the ash and other solids and then delivered the SRC into the cooling unit, just as before. This was two-stage de-ashing. We still depended on the vacuum distillation alone for recovering the process solvent."

A later modification by EPRI introduced three stages of extraction. Now the CSD produces three streams. "The first is still the solids," Lebowitz explained, "the second is the normal SRC fraction, and the third is what we call a light SRC. This is the important one for the future. It's the extra solvent that goes back into the slurry preparation unit ahead of the main reactor. It's what improves the coal conversion operation and keeps the process in solvent balance when reactor severity is reduced."

### Solvent enrichment

Without resorting to the specialized jargon of coal and petroleum chemistry, Lebowitz found it difficult to explain how CSD works. Saturated and unsaturated hydrocarbons; aromatic, aliphatic, paraffinic, and naphthenic molecules; high- and low-boiling compounds; distillable and nondistillable fractions; polymerized or condensed molecular chains and rings all figure in possible reactions catalyzed by heat, pressure, and time in the dissolution of coal and the subsequent distillation and precipitation of various liquids and gases. Lebowitz, however, hit upon an imprecise but evocative analogy.

"Assume that you have a solution of ordinary sugar and salt in water, along with a bedload of gravel. Those are analogous to the normal and light SRC fractions dissolved in the process solvent, along with the ash solids. Actually, of course, the SRC liquids are a continuum, not separate compounds like sugar and salt, but we'll overlook that."

Postulating such an aqueous solution, Lebowitz observed that the gravel would immediately settle out. He then described two stages of cooling as the remaining solution is transferred into successive vessels. In the first vessel, mostly sugar precipitates out as a solid, though probably some of the salt as well.

"The point is, as the process stream exits the first vessel, it leaves behind a sugar-rich solid. When the now salt-rich solution is cooled once more, in the second vessel, a salt-rich solid precipitates out. The water is left over, and it can be recycled to dissolve more sugar and salt. This kind of process," Lebowitz concluded, "is known as fractional crystallization."

Solvent fractionation in a CSD process is functionally similar. One salient difference is that heat must be added, not removed, between stages, because SRC liquids become less soluble in the critical solvent at higher temperatures. Increased temperature causes the fractionation, first, of normal SRC liquids and, second, of light SRC liquids. The degree of heat and the time involved control the split point between the two fractions and thus their respective quantities and relatively heavy or light character. Additional stages are possible, too, for achieving more than two fractions. In all cases, the CSD solvent is recovered for reuse.

With respect to design refinements for DOE's upcoming SRC-I demonstration plant, the desired end product at Wilsonville is solid fuel. The fractionation will be adjusted so that sufficient light SRC is obtained to recycle as solvent in balancing the entire process and enabling it to operate at less severe reactor conditions. The adjustment is delicate, however, because the sulfur removal capability of the process depends on reaction severity; if conditions are too mild, the process stream and the eventual solid fuel retain a sulfur content exceeding EPA limitations.

### Upgrading by hydrogenation

Sulfur removal, among other things, makes the addition of a hydrotreater an intriguing prospect for a series of tests planned during the next two years at Wilsonville. Catalytic hydrogenation becomes more efficient than the SRC reaction alone when high-quality products are desired. But the major role of this new step, which hinges on the character of feedstock coming from a three-stage CSD unit, is to upgrade the process stream to a coal liquid equivalent to distillate fuel for turbine or boiler use.

Whatever ash that inevitably remains in any of the SRC liquids is poisonous to the catalyst used in the hydrotreater. But there is far less ash in SRC fractions flowing from the CSD unit, and this is what makes them excellent feedstocks for upgrading. The CSD unit is thus central to a modified SRC-I process that will be capable of great flexibility in solvent-refining a slate of end-product fuels.

Lebowitz concluded his comments about the prospects for Wilsonville research by comparing its advanced process technology with the two other coal conversion technologies in which EPRI is a participant, Exxon Donor Solvent (EDS) and H-Coal. "The benefits of our approach include the improved characteristics of both the SRC recycle solvent and the hydrotreater feedstock. These distinguish it from EDS and H-Coal, respectively."

Realizing those prospects must await the later years of the current five-year Wilsonville research program, which runs through 1983. Closer at hand is providing a design basis that will ensure the operability of the relevant portions of DOE's 6000-t/d SRC-I demonstration plant. That plant will probably incorporate a hydrotreater for converting a portion of the plant's output to liquid fuels.

Specific beneficiaries of the Wilsonville program, in addition to EPRI, are DOE as SRC-I demonstration sponsor and Southern Company Services as principal contractor for the work so far. A new corporation, International Coal Refining Co. (a joint venture of Air Products & Chemicals, Inc., and Wheelabrator-Frye Inc.), is responsible for the overall Newman design. Catalytic has been responsible for the SRC-I flowsheet to be used in that design.

Southern Company Services holds research and engineering responsibility for the operating utilities of The Southern Company. As prime contractor at Wilsonville, Southern Company Services is the utility host for the pilot plant, which is on Alabama Power Co. land adjacent to that company's 1960-MW coal-fired Gaston steam station. ■

# Charles Hitch: Appraising Energy Policy

*If the economy has time to adjust, U.S. production will not necessarily shrink in direct proportion to contracting energy supplies, says economist Charles Hitch. EPRI's Advisory Council member recommends that the United States stockpile oil, tax oil imports, and change energy forecasting methods.*

High energy prices are not the problem, as so many people think both in and out of Congress. They are the solution, or at least the unavoidable first step to a whole family of possible solutions."

Speaking with quiet but firm conviction, Charles Hitch, president emeritus of the University of California and a member of EPRI's Advisory Council, leans back and props his feet on the desk, preparing to elaborate on the course of energy policy in the United States. His office at the Lawrence Berkeley Laboratory is modest in size and furnishings, but it has a comfortable air of culture and humanity, suggesting that this economist has interests and concerns that expand beyond his speciality. Around the room are a number of oil paintings—one floral, others abstract—and to one side of the ceiling-high bookshelves hang two old prints of Queen's College, Oxford, his alma mater.

Hitch continues: "At long last, we are moving in the right direction with natural gas prices, but ever so gradually and uncertainly, after years of underpricing and wasting our cleanest and most convenient fuel. We are still holding domestic oil prices below world prices and thereby subsidizing insecure imports from the Middle East. President Carter is attempting to break the logjam with phased price decontrol by executive action coupled with a so-called windfall profits tax accomplished through congressional action. It now appears that this attempt will probably succeed, but the battle has been and will continue to be highly emotional, and the ultimate outcome is not certain. If we really achieve decontrol of oil and gas during the next few years, we will have taken a giant stride toward the development of alternative sources of energy and effective conservation—the possible solutions I mentioned earlier."

With his long and distinguished career as an economist, Hitch commands an extensive view of national and international economic issues. After receiving his BA with highest distinction from the University of Arizona, Hitch crossed the Atlantic to England, where he studied at Oxford University on a Rhodes scholarship. There he took his Master's degree and in 1935 was the first American Rhodes scholar to become a don at an Oxford college when he was elected a Fellow of Queen's College, a position he held until 1948.

Following his years in England, Hitch moved to Santa Monica, California, where he headed the economics division of The Rand Corp. and later became chairman of its research council. At Rand, Hitch pioneered the planning, programming, budgeting system (PPBS) that he later introduced in the Pentagon when he was appointed assistant secretary of defense by President Kennedy in January 1961. The PPBS uses a cost-benefit technique to compare defense expenditures and provides a quantitative basis for selection of weapons systems and forces.

In his unpretentious way, Hitch is inclined to reminisce about some of his experiences. "The purposes of PPBS were twofold: The first was to get some linkage between the planning and budgeting, which up to the time we went to the Pentagon in 1961 had been entirely separate activities. The budget was prepared by the comptroller organization of the Defense Department, and the planning was done by the Joint Chiefs of Staff and the military planners of the services. There was really no linkage between the planning and the budgeting.

"The other purpose of PPBS we called cost-effectiveness analysis. We initiated an attempt to get economic thinking into the planning and programming of the department. We developed cost analysis to a point where we were able to compare to a degree the costs of achieving the same strategic objective by different weapons systems and forces, and we installed a regular procedure to review cost-effectiveness each year."

In September 1965, the pragmatic economist became vice president, business and finance, of the University of California; from 1968 to 1975, he was president of the university.

Only a year ago, his commitment was a little different. As president of Resources for the Future, Inc., a research and development institute in Washington, D.C., he was directing its race for new funding sources. Recounting his struggles to keep RFF both financed and independent, he explains how the Ford Foundation (its principal support up to 1979) was unable to continue the level of its funding. It was suggested that RFF become a division of the Brookings Institution, but the board and staff of RFF preferred to remain independent. This meant a push for diversification of funding sources. On condition that RFF raised $7 million in nine months, the Ford Foundation offered to match that figure.

With extraordinary rapidity and only a slightly extended deadline, RFF managed to raise the money from a diversity of foundations. Listening to Hitch, one is struck by the contrast between his low-key manner and the evident forcefulness that pervades his work.

After four years at RFF, Hitch is no longer attached to one organization but devotes his time and expertise to consulting, giving speeches, and serving on a number of boards. He is presently putting his energies into his commitments to the advisory councils of EPRI and the Gas Research Institute, as well as the Energy Research Advisory Board of the Department of Energy and a National Academy of Sciences committee that is evaluating solar power satellites. He also sits on the board of trustees of The Aerospace Corp., a nonprofit company that provides architect-engineering services to the Air Force.

### Economic adjustment

Looking at the present energy situation, Hitch maintains that the U.S. economy will need time to adjust if foreign oil supplies are interrupted. "If, for example, we lost most of our oil imports quite suddenly," he says, "or if there is an embargo or a war, the results could be catastrophic."

How can we lessen the danger of economic damage precipitated by a potential cutoff of Middle East oil? Hitch's answer is definitive: "There are only two courses we can take that are, in a quantitative sense, important in reducing our demand for imported oil over the next decade. One is conservation, and the second is completing the electric power plants that are now planned or in construction, each of which could affect our imports to the extent of perhaps 6 million barrels of oil a day. So they are big factors, and the only ones. We aren't, I think, going to make much progress in the other alternative fuel sources in that period."

One reason for Hitch's pessimism is that he believes the windfall profits tax will work against indigenous exploration for oil (and therefore for gas, because a lot of gas coexists with oil). Hitch plainly states his opinion. "The windfall profits tax is an excise tax on each barrel of domestic oil that's produced, old and new. [Old oil is defined as oil discovered before 1979; new oil is that discovered after 1978.] The calculation does not involve profits. I think that's most unfortunate—we will be taxing domestic oil and not taxing imported oil, and we ought to be doing it just the other way around."

Returning to the subject of conservation, Hitch comments on the obstacles to ways it could effectively be put into action. "I think the most important thing is to decontrol oil and gas. That we are doing, but slowly and uncertainly. Nevertheless, the prices have been going up because of increases in cost and the prices of imported oil; it has led to a lot of conservation. Our consumption is down quite decisively from earlier projections, and it's going down further, there's no question about it, because of the price rises that have already occurred or are anticipated."

But there are initial hurdles to conservation, such as institutional factors and, everywhere, ignorance. "People don't know, for example, how to insulate their houses; it's a big job and not many people are expert in that sort of work. We need professionals, so we have to train people, to get the information to them, and to provide financing. In addition, obsolete building codes prevent us from doing much of what has to be done. Furthermore, we've got the whole problem of renters." The renter has little incentive to spend any money on appliances or on weatherproofing, nor in many cases, does the landlord because it is usually the renter who pays the utility bill.

### Changing projections

Even though there is still a considerable lack of incentive to conserve, Hitch (who serves on the senior advisory panel of the Energy Modeling Forum at Stanford University) observes that all our future projections of energy consumption are coming down. As the price goes up, people find ways of doing with less energy, almost indefinitely.

On the other hand, the effects of higher prices or expected higher prices are felt over an extended period of time, and as Hitch explains, "You don't achieve conservation all at once; you achieve only a small part of it at once. The rest depends on the turnover of energy-using equipment and appliances. We are still seeing effects of the big 1973–1974 price jump."

The passage of time, it seems, is a prerequisite of change, and Hitch has a warning. "While the economy can adapt to scarcer and more costly energy in the long run, it cannot do so in the short. How long is long, and how short is short? This depends on how quickly labor and capital can be substituted for energy. And while some conservation, for example, turning down thermostats, can be achieved almost immediately, much requires replacing the capital stock of cars and trucks, houses and commercial buildings, and industrial equipment with more energy-efficient forms, which takes years, or in some cases, decades. A recent estimate, consistent with U.S. experience since the quadrupling of imported oil prices during 1973–1974, is that only about 10% of the potential savings are achieved in the first year and 10% of the remaining potential in each subsequent year."

And what does Hitch think are the implications of all this for energy demand 30 years from now? "We can't say precisely. But if energy prices approximately double, the demand for energy in 2010 will be less than many think, closer to 100 quadrillion Btu than to 200 (compared with 75 now), despite continuing economic growth. This makes the long-run supply problem look manageable."

Nevertheless, Hitch emphasizes that this relatively optimistic outcome can occur only if prices are permitted to reflect true costs and scarcity. "Consumers of energy will find ways to conserve if, but only if, prices are equal to incremental, or replacement, costs. And underpricing is not limited to the fluid fuels. Thanks to our utility regulatory mores, we are charging much less than incremental costs for electricity in many regions, in some cases less than half."

By regulatory mores, Hitch explains, he refers to the almost universal criterion used by utility regulatory commissions: fair return on historical capital costs. "This means that when new higher-cost plants are built, the higher costs are 'rolled in,' that is, averaged with the lower capital costs of earlier, cheaper plants. As a result, in a period of rising costs—whether real costs or simply inflated money costs—consumers never have to pay, as they should, the incremental costs of new supplies, and accordingly use utility-provided electricity and gas inappropriately and wastefully."

> "Our problem is to get to 2000, or 2010, or 2025. And that problem is going to be terribly difficult if while we reduce our dependence on imported oil, severe constraints are imposed on coal and nuclear — as they well may be — because of public fears of catastrophic outcomes."

The United States is not alone in holding down energy prices. In fact, according to Hitch, all the industrial nations have succumbed to the same temptation. "The Organization for Economic Cooperation and Development [OECD] has recently taken its members to task for trying too hard to shield their people from the full effects of OPEC price increases. Other industrial nations (except Canada) have historically levied heavy taxes on oil imports or the use of petroleum products, particularly gasoline, so that their consumers have paid higher prices than U.S. or Canadian consumers. The most striking consequence has been their development and use of smaller, lighter, more fuel-efficient automobiles.

"But since 1972, other OECD countries have behaved much as we have. In particular, they have permitted inflation to erode the real value of their energy taxes. Between 1972 and 1978, a rise of nearly 400% in imported oil prices translated into a 22% rise in real, that is, relative, prices of energy to industrial and private users. In 7 of 14 major industrial countries, gasoline prices at the pump were actually lower, in real terms, in 1978 than in 1972."

Looking to the relationship of energy to GNP in the future, Hitch emphasizes that "while some loss is inevitable, the amount of the loss, given time for adjustment, is less than you might intuitively expect, and the adverse effect on GNP much less than proportional to the reduction in energy supply. If, for example, we should meet again in 2010, 30 years from now, and energy costs and prices have only doubled over that period, we would find that the effect on productivity of the higher energy costs would have been a maximum of one-third of 1% per annum. This is not a trivial drag on the growth of GNP; indeed, it would amount to many tens of billions of dollars annually, but it certainly would be consistent with continued economic prosperity if we can return to anything approaching past norms of productivity increases, that is, on the order of 2–3% per annum."

To produce reasonably accurate projections of future energy consumption, Hitch believes forecasting methods, such as regression analysis, which is based on historical data, will have to change. "Certainly, projecting the relations that held good before 1973 is not going to work in the future, because in the period up to 1973 we had very cheap energy, plus, in general, falling prices of energy and no period of rising prices. So we have no historical period in which we had rising energy prices. All the econometric projections based on the relations before 1973 have led to gross overestimates for energy demand. Since we don't have any econometric projections and won't have for some time, except on a very short base, we must use a different method: end-use analysis." This is the time-consuming and laborious method of calculating the energy consumed in end use, that is, in each and every commercial and household appliance and industrial process.

### EPRI, energy, environment

This elaborate aid to forecasting, end-use analysis, is very much part of EPRI's work. In commenting generally on EPRI's role, Hitch says he regards EPRI as a highly professional organization, whose influence is extremely beneficial. The EPRI Advisory Council, on which he serves, is made up of 26 leaders in science, education, government, and business. It meets quarterly to communicate the public's views and requirements of electric utilities to EPRI's Board of Directors and staff. Hitch reiterates his point that EPRI is "absolutely necessary to the sustenance of a rational energy R&D program, both on the conservation side and on the side of increasing supply."

To the question of whether electricity supply will be affected in the future by the environmental movement, Hitch replies that "the seriousness of the energy problem and the imported oil problem is at last being recognized by people generally, and I think we are going to go ahead with energy projects in a way that's not been possible for the last five years." However, Hitch thinks the protection of the environment is critically important. "Some of the energy sources, particularly coal, have very serious threats to ecosystems." In addition, there are dangers to workers in using coal to generate electricity. When asked if that is a greater danger than converting uranium to electricity, Hitch answers affirmatively but points out that such accounting ignores the contribution nuclear power might make to weapons proliferation and terrorist activities, a genuine international concern. Despite the fact that "there are some people who argue that there are many other ways of making nuclear weapons that do not involve commercial power reactors, the commercial reactor can be an awfully good cover. What is clear to me is that other countries that do not have our options are pressing forward with nuclear—Japan, France, Britain, Germany. By and large, these countries don't have the coal option, don't have the shale option or the natural gas option or the unconventional natural gas option. What can they do except use nuclear power?"

> “The windfall profits tax is an excise tax on each barrel of domestic oil that's produced, old and new. The calculation does not involve profits. I think that's most unfortunate—we will be taxing domestic oil and not taxing imported oil, and we ought to be doing it just the other way around.”

### Policy implications

From his wide knowledge of energy policy here and abroad, Hitch suggests certain directions in which decision makers might move, directions that "at least develop nuclear, synthetics from coal, oil from shale, and other technologies that promise to provide a long-run ceiling for energy costs at about double present prices." He acknowledges, "We may not need some, or any, of them, and so may never fully deploy them. Fusion, solar, hot rock geothermal, unconventional sources of natural gas, or something else may come along and bail us out. But we'd better have them ready to deploy if necessary. This means, in my opinion, carrying development through commercial-size plants."

Hitch strongly supports the building up of a large reserve stockpile of oil as quickly as possible. He further recommends taxing oil imports or oil products like gasoline at the point of use to discourage imports.

In backing a push for conservation to "damp down the amount of energy we need to supply in the long run and thereby the quantities of insecure oil we have to import," Hitch once again points to higher prices, plus regulation and the removal of institutional barriers. In addition to conservation, he believes, fossil fuels and light water reactors will suffice for the next few decades. "As we move from decades to centuries, of course, renewable or essentially inexhaustible sources must take over from the fossils, but that is a challenge to our great-great-grandchildren, which I am confident they will meet."

Looking to the not-too-distant future, however, Hitch considers that "our problem is to get to 2000, or 2010, or 2025. And that problem," he reckons, "is going to be terribly difficult if while we reduce our dependence on imported oil, severe constraints are imposed on coal and nuclear—as they well may be—because of public fears of catastrophic outcomes. Some of these fears are justified and some are not, but they are all real in the sense that they exist and must be addressed by those who make energy policy." ■

# CONSERVATION: DOE's High-Priority Program

DOE is requesting nearly $1 billion for its wide-ranging conservation programs for FY81. Interaction with private industry is a key aspect.

Conservation, to the consumer, is often synonymous with curtailment, doing without, lowering the thermostat, turning out the lights.

DOE conservation officials admit that this is certainly one aspect of conservation, but they place major emphasis on another definition—the efficient use of energy. The deputy assistant secretary for conservation, Maxine Savitz, explains that conservation means reducing energy waste, which can run as high as 30–60% in buildings, transportation, and industrial processes. It means making use of waste heat, using more efficient equipment, tightening buildings. William J. Raup, assistant director of the Office of Government Conservation Programs, defines conservation as "the efficiency or frugality of means, rather than the curtailment of ends."

Conservation is a high-priority item at DOE. For FY81, the agency is requesting almost $1 billion in budget authority for conservation programs. In testimony before the House Science and Technology Committee in January, Energy Secretary Charles Duncan explained that conservation is one of four major efforts DOE has under way to constrain energy demand and thus to cut the nation's dependence on imported oil 50% by 1990. (The other efforts are phased decontrol of energy prices; oil import limitations, such as ceilings; and contingency planning, such as rationing.) DOE's conservation programs, according to Savitz, are targeted to reduce oil imports 2.5 million barrels a day by 1985 and 4.9 million barrels a day by 1990.

"The best way to reduce our oil imports is by using the energy we have more efficiently," she asserts. "There is no reason why we have to burn fuel in our homes at 65% efficiency; we can do it at 80%. There is no reason why energy should be leaking out of buildings; we can tighten them up. There is no reason why industrial processes can't make more use of their waste heat; industry has already done a lot of housekeeping activities to reduce this waste."

Savitz sees no conflict inherent in energy conservation on one hand and energy production on the other. "I think they are very compatible," she insists. "Even with increased production, energy is going to be much more expensive than it was prior to the embargo, and so from an economic point of view, people are going to want to use it as efficiently as possible. They are going to want more efficient automobiles so they are not paying $30 every time they fill the tank."

She also says conservation doesn't need to be thought of as having a negative effect on growth or employment. It can open new opportunities for employment or innovative business practices. For example, Savitz thinks that electric utilities can have a significant role in delivering conservation to customers.

"The homeowners can get mad at the utilities but they also have to trust the utilities' technical expertise. After all, the lights do go on when they flip the switch." Utilities are vital, she affirms, to DOE's programs for conservation in the residential sector through the utilities' energy audits and conservation advice to customers, and they are vital to DOE's programs in the industrial sector, particularly those involving technology for using waste heat.

"It's a partnership," she says in commenting on government-industry interaction in the conservation area. "No energy is going to be saved just by what we do. It's really saved by what the private sector itself does in promoting and implementing conservation. We can't do things that the private sector thinks are outrageous because that sector is the one that has to implement the programs. And yet we can help catalyze the private sector by getting good data and undertaking the more-risky projects."

DOE approaches conservation by several key routes: grants and other types of assistance to state and local governments to aid in carrying out conservation measures; research, development, and demonstration (RD&D) and regulatory activities geared toward specific energy end-use sectors; and public education. These programs are grouped generally under two deputy assistant secretaries in the office of the Assistant Secretary for Conservation and Solar Energy, Thomas E. Stelson.

Savitz has responsibility for the pro-


Savitz

grams geared toward improving energy efficiency in buildings and community systems, industry, and transportation, as well as for technology development in advanced energy conservation (an area recently assigned that includes research on batteries and other energy storage technologies and work in advanced conversion technologies). Melvin H. Chiogioji is deputy assistant secretary for State and Local Assistance, which includes the grants programs.

Of DOE's nearly $1 billion budget request for FY81, some $650 million is for grants and other assistance to states and localities to help them implement energy conservation measures.

"There's an awful lot you simply can't do at the federal level," says William J. Raup, referring to the State and Local Assistance Program. "Most conservation and renewable energy strategies are by their very nature small in scale, dispersed, and particular to localities. Fuel-use patterns vary tremendously, and unless you are there on top of the situation, you really can't do an effective job in identifying opportunities for energy conservation. If you look at what an area like Portland, Oregon, has done and compare it with Davis, California, you may see some common building blocks, but you'll find a different arrangement on the whole."

Raup explains that DOE's role is to provide technical and financial assistance to help the states and localities get started in building conservation capability. "We can also be a facilitator by providing a network for the states and localities," he explains. DOE's approach to its state and local program is decentralized in the sense that most of the activities are administered by the agency's 10 regional offices.

## Grants for Conservation

Two highly visible grants are the weatherization and institutional buildings activities. The weatherization activity provides grants to states and native American tribal organizations for conservation measures that will weatherize homes of low-income families. Funds can be used for insulation, storm windows, caulking and weatherstripping, and minor furnace repairs. Funds go from states to local organizations that select the dwellings and complete the work.

The federal weatherization activity began on an emergency basis in 1973, and was formally set up in 1975 under the Community Services Administration. Responsibility was transferred to DOE in November 1978. From 1975 through October 1979, officials estimate that work was completed on 614,000 dwellings. The goal for this year is to weatherize an additional 310,000 dwellings.

The institutional buildings activity provides grants to match nonfederal funds for projects to improve the energy efficiency of schools, hospitals, and local government and public care buildings around the country. The grants include funds for statewide audits that were conducted last summer by state energy offices to provide information on present energy use and potential savings in institutional buildings. Funds are also available for more detailed audits of schools and hospitals and for the adoption of energy conservation measures recommended by the audits. Recipients of $157 million in grants for detailed audits and conservation measures were announced by DOE this spring.

The State and Local Assistance Program also administers the Energy Extension Service, the State Energy Conservation Program, and the Emergency Energy Planning Program. These three activities would be consolidated by the Energy Management Partnership Act (EMPA) submitted to Congress by President Carter on May 15, 1979.

"The department and this office strongly support passage of EMPA legislation because it will streamline the application process for state grant programs and will enable states and local governments to strengthen their energy planning and management activities," said Stelson February 5, 1980, to the House Subcommittee on Energy Development and Applications. "Accrued benefits from this activity will include more cost-effective administration of federal programs and improved management at the national level."

Under the State Energy Conservation Program established in 1975, DOE provides financial and technical assistance to aid states in implementing various energy conservation measures. To qualify for this assistance, the states must develop energy conservation plans designed to reduce consumption at least 5% by the end of 1980. The plans must include several mandatory conservation measures, such as lighting efficiency standards for nonfederal public buildings; programs to promote the availability and use of carpools, vanpools, and public transportation; and a traffic law permitting a right-turn on red after stopping. Fifty states and six territories are currently participating in the program.

The Energy Extension Service grants enable states to work with families, owners of small companies, and local government officials on an individual basis, helping them take practical steps in saving energy and switching to renewable energy sources. Beginning as a pilot program and consisting of a two-year demonstration in 10 states, the program was extended nationwide last year by DOE. Examples of services provided include a self-help solar workshop in New Mexico, low-income volunteer training in Connecticut, a homebuilders' workshop in Texas, and an information clearinghouse in Michigan.

Other grant activities included under the State and Local Assistance Program are emergency planning (for set-aside petroleum allocations, monitoring of supply and consumption, and other such measures), energy development impact assistance (which provides aid through the Farmers Home Administration to areas experiencing higher employment as the result of significant energy supply development), and small grants for appropriate technology and energy-related inventions.

## Target Sectors

As a second major part of its conservation effort, DOE administers programs to increase energy efficiency in target energy end-use sectors: the transportation sector, which uses 26% of the nation's total energy; the buildings sector, which accounts for 37%; and the industrial sector, which uses about 37%. According to Savitz, whose authority extends over these areas, all sectors have had an equal amount of waste and show great potential for improvement.

"The industrial sector has been the most responsive to date," she reflects, "mostly because they have the know-how but also because they understand the economic implications and the problems energy shortages could cause. The transportation sector is progressing very rapidly because of the miles-per-gallon improvements [mandated by the Corporate Average Fuel Economy Standards] and because automobiles typically turn over every 10 years. The buildings area is slower to turn over. Here we are dealing with 74 million homeowners and renters who often just don't know what to do or don't make the same decisions at home on an economic basis as they do at their businesses. So that is probably the area where the most can be done."

DOE's Office of Buildings and Community Systems, directed by John Millhone, seeks to improve energy efficiency in both new and existing buildings. The office does this through research, development, and demonstration; formulation of regulations; and public education. Millhone says that the goal is a 45% increase in energy efficiency of new buildings constructed in 1985 over those constructed in 1975. Through retrofit programs, he seeks a 30–40% increase in energy efficiency in existing buildings during that same 10-year period.

Of the major activities in the buildings area, the regulatory programs are currently drawing the most attention, notes Millhone. Of particular interest at the present time are the proposed Building Energy Performance Standards (BEPS) that DOE issued in November to encourage energy-conserving designs for new commercial and residential buildings. DOE was mandated to develop these standards by the Energy Conservation Standards for New Buildings Act of 1976. The standards were subject to public comment through April and the agency plans to issue final standards in August. At that time, Millhone explains, Congress will decide whether private builders must comply with BEPS in their construction work if they are to be eligible for any kind of federal assistance, such as loans from federally insured banks. Even without such requirements, the standards would still apply to the federal government's own construction, but "the major application to the private sector would not occur unless Congress decides to use sanctions."

BEPS would require that new buildings be designed in accordance with an energy budget expressed in Btu per square foot per year. The budget would specify the maximum amount of energy that the entire building could consume and would allow the architects, engineers, and builders to decide what proportion of the total energy would go for heating, cooling, lighting, hot water, and other purposes. Millhone says DOE expects these new standards will lower energy consumption in buildings 25% below what would otherwise be consumed.

Because of the methodology used by the proposed standards in computing the energy budget, the utility industry has been concerned that BEPS would penalize buildings designed to use electric heat and result in increased use of oil and natural gas at the expense of coal and nuclear. The concern results from the required use of a multiplier in calculating how many Btu to charge against the energy budget for heating. The multiplier is higher for electricity (2.79 and 3.08 for residential and commercial or apartment buildings, respectively) than for natural gas (1.0 for each) or oil (1.22 and 1.20, respectively). Savitz says that DOE has addressed this concern by asking for comments and data from the industry for use in developing the methodology for the final standards. Although the multipliers used in the proposed standards are based on national average fuel prices, DOE is currently studying region- and utility-specific prices.

Another high-visibility program co-

ordinated by the Office of Buildings and Community Systems is the Residential Conservation Service (RCS), which should be in effect in most states by January 1981. Under this program, utilities of a certain size are required to conduct energy audits for their customers, recommend conservation measures, and arrange for the financing and implementation of the work. State governments would take responsibility for administering the service or, if they chose not to, DOE would work directly with the utilities to develop a program. Millhone observes that it looks as if most states will participate.

DOE issued final rules for RCS in November. Although some utilities believe the rules are still too rigid, Savitz feels the final rules are much more flexible than the initial ones proposed in March of 1978. She credits the hearing process and the utility industry's comments on the proposed activity as an influence in bringing about the change.

"I keep pointing to RCS as an example when utilities talk about BEPS," she comments. "We took their comments seriously then and made RCS a much more flexible program. BEPS can go the same way."

Savitz says that one of the problems with RCS as it now stands is that a utility is prohibited from financing or installing conservation or renewable energy measures unless it has done so before. "We hope we can get those prohibitions removed," she remarks, "so a utility that wants to be involved in such a business can be."

The DOE buildings program also includes research on materials and innovative structures, as well as such questions as the interior air quality of buildings.

The community systems component of the program includes efforts to foster such energy-conserving and renewable resource concepts as district heating and cooling and integrated energy systems in communities. It also includes a program with the Environmental Protection Agency to plan for plants that would extract energy from municipal solid waste.

Federal energy officials admit that among the end-use sectors, transportation is the major culprit in consumption of petroleum. "The transportation sector uses more petroleum-derived fuel than all other energy-consuming sectors in the United States combined," stated Savitz in testimony February 13 before the House Subcommittee on Transportation, Aviation, and Communications. "Effective programs in the transportation sector can make substantial contributions to solving the nation's petroleum problem."

During the next five years the greatest savings in transportation energy will come as the result of the Corporate Average Fuel Economy Standards, she notes. Other near-term savings can be achieved through improvements in current vehicle technology and by conservation in ride sharing, mass transit, and trip planning. The long-term solution, she explains, requires vehicles that are not dependent on petroleum-based fuels, such as advanced heat engines or electric vehicles.

DOE's transportation program seeks to improve energy-use efficiency to achieve a 10% reduction in gasoline use from the levels projected for 1990 and a 25% reduction in the use of all types of transportation fuels from the consumption levels currently projected for the year 2000. Major program activities include electric and hybrid vehicle RD&D, vehicle propulsion RD&D, alternative fuels utilization, and transportation systems utilization.

Of major interest to the utility industry is the electric and hybrid vehicle RD&D mandated by Congress in 1976. This activity seeks to encourage the commercialization of electric vehicles by research and demonstration of some 10,000 vehicles by 1988 in the private sector, federal agencies, state and local governments, and universities. Consolidated Edison Co. of New York, Inc., and Long Island Lighting Co. were among the groups in the private sector participating in the first round of DOE demonstrations in 1978. The electric vehicle activity includes research to improve battery performance. In her testimony February 13, Savitz said that the major emphasis is on increasing reliability and cycle life of batteries and on lowering costs. Battery engineering and systems integration work is continuing on improved lead-acid batteries, nickel-iron batteries, and nickel-zinc batteries. A fourth candidate added to the effort is the zinc-chlorine battery, which is also being considered as a promising technology for electric utility application. Early in FY81, field testing of 5–10 experimental vehicles containing newly developed batteries will be conducted.

The vehicle propulsion RD&D is placing development emphasis on the gas turbine and the Sterling engine because DOE officials believe these technologies offer the potential of significantly improved fuel economy, low exhaust emissions, and the capability of using virtually any combustible liquid or gaseous fuel.

The alternative fuels utilization activity is examining such possibilities as alcohol and alcohol-gasoline blends for powering vehicles. The transportation systems utilization activity provides a single overview of the transportation operations of federal, state, and local governments, industry, and the general public with the objective of promoting energy conservation.

## Improved Energy Productivity

Of all sectors, industry has made the greatest strides in recent years in improving energy productivity, officials note. Douglas Harvey, director of DOE's Office of Industrial Programs, says that industry reduced energy consumption some 14% from 1972 to 1978. However, industry relies heavily on oil and natural gas, and in spite of recent conservation achievements, its consumption is expected to increase appreciably by 1985. DOE therefore seeks to improve the energy efficiency of industrial processes through RD&D, as well as through monitoring and evaluating how well industry is doing on its own. Efforts to speed the introduction of energy-efficient technology into the marketplace are also part of the program.

According to Harvey, the RD&D component of the program falls into two basic categories: development of advanced technologies, such as waste heat recovery devices, that apply to a number of different industries; and development of technologies that can aid in reducing consumption in the most energy-intensive industries (e.g., steel, aluminum, glass, cement, textile, and pulp and paper).

Examples of work supported by the industrial energy program include a process to convert waste carbon monoxide to methanol; demonstrations of waste polypropylene conversion to fuel oil; an industrial cogeneration program; a high-efficiency slot-forge furnace; ceramic recuperators for capturing waste heat; high-efficiency welding systems; industrial heat pumps; and foam dyeing for the textile industry.

Harvey explains that his program undertakes high-risk projects that industry is either unable or unwilling to pursue itself. "We hope we're a catalyst in accelerating the introduction of new technology," he remarks. Although his program has only been in operation four years, he estimates that it has already saved 5 trillion ($10^{12}$) Btu. The effort is targeted to save some 1.5 quadrillion ($10^{15}$) Btu each year in the near term and 5.5 quadrillion Btu in the mid-term.

Supporting the end-use sector programs in DOE's conservation effort is the new Office of Advanced Conservation Technologies. The office will combine the functions of DOE's Energy Storage Systems Program and a new activity aimed at developing advanced conversion technologies. Maxine Savitz views this fourth office as an opportunity for helping to close what she has seen as a gap in the conservation program—the development of a good technology base.

The Energy Storage Systems Program seeks to develop and demonstrate reliable, low-cost, safe, and environmentally acceptable storage systems, such as batteries, for buildings, industry, transportation, and utilities. DOE estimates that some 30% of its storage projects are cost-shared with industry. DOE and EPRI are jointly supporting development of several advanced storage batteries for utility applications, such as the sodium-sulfur and zinc-chlorine batteries. The two organizations are also supporting demonstration efforts for batteries, including the Battery Energy Storage Test facility and the Storage Battery Electric Energy

Demonstration. The BEST Facility is an installation for testing utility load-leveling batteries and is scheduled to begin operation this fall in Hillsborough Township, New Jersey, on the Public Service Electric and Gas Co. System. The SBEED will demonstrate the operation of a battery storage facility on a utility grid.

In the utility demonstration efforts, the Energy Storage Systems Program is closely coordinated with the Electric Energy Systems Division in the Office of Resource Applications. As expressed by Assistant Secretary Stelson, the division of responsibilities between these two programs is that development of energy storage technology is carried out in the Energy Storage Systems Program, and demonstration of that technology on the utility grid is carried out in the Electric Energy Systems Division.

The Energy Storage Systems Program also includes projects on aquifer storage of hot and cold water for heating and cooling buildings; electrochemical processes and retrofit thermal storage for heat recovery in industry; and thermal, mechanical, magnetic, and underground storage for utility load leveling and for use in solar electric technology.

Plans are now being made for a new advanced energy conversion program. Activities envisioned in this area include work on combustion, materials processes, and biochemical technologies.

### The Conservation Message

DOE's third major route for encouraging conservation is through public education. The agency uses public service announcements, brochures, and general and technical publications to communicate the conservation message to the public. It has also conducted pilot advertising campaigns that have proved successful by agency estimates. DOE hopes to expand this effort in the coming year.

# Reporting to the Nation on TMI

An industry report to President Carter concluded that TMI was a serious but not highly dangerous accident.

A five-man industry delegation called at the White House late in March to present "Report to the President and the American People: One Year After Three Mile Island," which summarizes industry response to the accident and progress in making nuclear power even safer. The industry delegation was received by Kitty Schirmer, who is on President Carter's Domestic Policy Staff. The report reaches five principal conclusions:

- TMI-2 was a serious but not a highly dangerous accident.
- The nation's electric power industry responded quickly and forcefully to correct inadequacies indicated by the accident.
- Other developments during the past year in the energy field have demonstrated the serious dangers of our continuing to depend heavily on imported oil and the risks of not developing nuclear power.
- Several major new energy policy studies have emphasized the pressing need to move ahead with our only logical energy strategy: conservation and development of all existing U.S. resources—largely coal and nuclear power.
- The national energy direction has taken us farther away from domestic energy adequacy rather than closer to it.

"The compelling evidence of the past 12 months demonstrates not only that nuclear power is adequately safe but also that it is absolutely necessary," the report declares. "We are proud of the exceptional safety record of nuclear power over its quarter-century of use and of the industry's prompt and substantial response to the accident to ensure that nuclear plants are even safer in the future."

Members of the delegation were Floyd Lewis, chairman of the board of EPRI and of Middle South Utilities, as well as of the industry's Oversight Committee; Edwin Zebroski, director of NSAC; Carl Walske, president, Atomic Industrial Forum; John Selby, president, Consumers Power Co.; and Robert Partridge, executive vice president, National Rural Electric Cooperative Association.

## Acoustic Monitoring of Nuclear Valves

Acoustic sensors that may help prevent accidents, such as the one that occurred at the Three Mile Island nuclear power station last year, have been tested and evaluated under an EPRI-sponsored project. The sensors, which respond to the sound of steam rushing through a valve, are designed to indicate whether the pressure relief valves of a nuclear reactor are open or closed, even when the valve controls malfunction.

By measuring the rush of steam through a valve rather than the operation of the valve control, an acoustic sensor can effectively indicate valve position. Recent tests conducted for EPRI have shown that even a small leak through a valve can be detected.

An acoustic sensor is essentially a contact microphone, similar to those used on guitars that respond to vibrations in a solid material. Signals from the sensors are displayed to reactor operators in the same way that total sound level is indicated in a stereo amplifier: as a reading on a meter or as an illuminated string of lights. Because such sensors can be attached to the outside of a valve casing, they can be quickly installed on existing reactors during routine maintenance. Several reactors in the United States have already been retrofitted with acoustic monitors for steam relief valves, and they are likely to become standard equipment on new reactors.

Once reactor operators know a relief valve has malfunctioned, they can quickly begin to bring the plant into a safe, stable condition by using the plant's backup systems. The new sensors should help avoid the two-hour delay in operating these systems that occurred at Three Mile Island. During that accident, operators thought a valve was closed because they had received a signal that the valve control mechanism had functioned. In fact, however, steam was still escaping.

EPRI's work on the acoustic sensors was presented to utility representatives at a workshop last August, thus facilitating immediate action to improve the safety of existing reactors. According to EPRI Project Manager Gordon Shugars, full documentation of the test procedures and results have been published in EPRI report NP-1313, *Acoustic Monitoring of Relief Valve Position.* ■

## Utility Team to Set Battery Criteria

EPRI and the Energy Storage Program Committee have established the Utility Battery Operations and Applications Team (UBOAT) with the following objectives.

- Identify applications of batteries in the utility industry and among its customers
- Define specifications for battery energy storage systems
- Establish operating and maintenance guidelines for batteries
- Identify potential safety and environmental issues
- Develop demonstration objectives
- Evaluate battery commercialization strategies

As James Birk, project manager for battery research, explains, "UBOAT is unusual among EPRI's advisory committees because its primary focus is to actively develop utility perspectives about technology use rather than to review projects, programs, budgets, and plans." Birk went on to point out that active utility involvement is a must in developing technology criteria and ensuring its commercialization.

UBOAT is presently composed of eight members with diverse backgrounds and geographic locations who represent utilities that have over 100,000 MW of generating capacity. Membership is open to any utility willing to contribute the time of its staff to the objectives of UBOAT.

UBOAT held its first meeting March 30–April 2, 1980. At this meeting the team listened to representatives of U.S. battery developers, who discussed system design, and to other speakers, who reviewed demonstration plans and safety issues. Officers were elected, assignments identified, and strategy reviewed. UBOAT plans to publish a report of its findings, conclusions, and recommendations in 1982. ■

## Perhac Named Department Head

Ralph Perhac has been named director of the Environmental Assessment Department, EAE Division. Formerly manager of the Physical Factors Program, Perhac was named acting director of the department following the death of Dr. Cyril Comar on June 11, 1979.

Perhac joined EPRI in 1976 from the National Science Foundation, where he was director, Environmental Effects of Energy. Earlier, he spent several years as a laboratory researcher, including positions at Exxon Products Research, the University of Tennessee, and Oak Ridge National Laboratory. At one point he was involved in the lunar soil investigation. He received his PhD in geochemistry from the University of Michigan in Ann Arbor. ■

## Defining Research in Water Resources

Water resource experts and electric utility managers from around the country participated in an EPRI-sponsored workshop, Water Supply for Electric Energy, in Palo Alto, California, March 19–21, 1980.

Resulting from the conference was an inventory of priority research needs in the field of water supply for electricity. The following were among the topics most urgently recommended for EPRI consideration.

- Studies of social trade-offs involved in allocating scarce water resources (in particular, the growing competition between farmers and other water users)
- Review of public participation experience in water resource decisions
- Development of procedures affecting in-stream flow requirements
- Consideration of two-way slurry pipeline systems, with particular attention to specific legal barriers
- Determination of realistic upper limits of hydroelectric potential, taking into account the institutional problems now facing small-head hydro
- Analysis of drought patterns, considering uncertainties in the data base as well as developing strategies for worst-case scenarios

In welcoming remarks to the workshop participants, René Malès, director of EPRI's Energy Analysis and Environment Division, noted that the problem utilities face is "not one of identifying water scarcity per se, but rather one of discerning where relative water availability, institutional processes, and technical development will lead and how this should affect the electric utility research and development effort. Consideration of this problem is particularly timely because we're approaching the point when all water rights in the United States have been allocated either explicitly or implicitly." Malès then asked the participants to help EPRI identify critical water-use issues, provide a list of crucial research topics, and help define EPRI's role in these areas.

Malès

During the workshop, a recurring theme was how to improve communications between utilities and other parties interested in water resources. Professor Leonard Ortolano of Stanford University warned that the public "will not sit still for being informed of decisions by means of a formal public hearing in the late stages of planning. The public is now calling for opportunities to inform planners of their values and concerns, as well as opportunities to be informed of planning progress."

Dr. Ruth Love, a sociologist with the U.S. Army Corps of Engineers, stressed the need for utilities or regulatory agencies to appoint "a liaison person who would be visible and available to local residents, help troubleshoot problems, and identify opportunities for new undertakings that could result from the project's presence."

Translation of the workshop recommendations into an aggressive research agenda will take place in several steps, according to Edward Altouney, a project manager in EPRI's Water Supply Program. The workshop proceedings will be prepared by consultant Ray K. Linsley and distributed to participants for comment. Altouney said it is possible that specific research proposals could be solicited by EPRI late this year. ■

## Energy Workshop at Stanford

More than 80 participants and observers attended a workshop on energy and the developing nations at Stanford University's Hoover Institution, March 18–20. Sponsored jointly by EPRI and the Stanford International Energy Program, the workshop featured discussions on future energy supply for the developing nations, changes in energy demand, and the problem of balance of payments.

A consensus seemed to emerge among the participants that developing countries had survived the energy crisis of 1973–1974 better than had been expected, but it was also agreed that new problems will face less-developed countries in the 1980s. Among other considerations, the supply-demand balance for oil is now much tighter than in the mid-1970s and the indebtedness of many countries is now much higher.

The workshop produced several suggestions on what the best overall strategy should be for less-developed nations that face mounting energy problems. Various speakers, however, emphasized the great diversity among individual nations in the group and concluded that much more research will be needed to develop better consumption models from which strategies could be produced on a case-by-case basis. ■

## At ET7

Chauncey Starr (left), vice chairman of EPRI, received one of four Founders' Awards presented during the 7th Energy Technology Conference and Exposition (ET7) in Washington, D.C. Starr received the award for "the application of his scientific planning and management talents to the successful establishment of the innovative concept of an industrywide energy technology R&D establishment, the Electric Power Research Institute." Other Founders' Awards recipients were J. R. Kiefer, manager of Energy Conservation for Cameron Iron Works, Inc.; Arthur R. Seder, Jr., chairman of the board and president of American Natural Resources Company; and James Kane, associate director of Basic Energy Sciences, DOE.


Participating in the state-of-energy press briefing during ET7 were (from left) Carl Bagge, president of the National Coal Association; David Morrison, director of IIT Research Institute; Floyd Culler, president of EPRI; and Len Fish, senior vice president of the American Gas Association.

## CALENDAR

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

### JUNE

**18–20**
**Environmental Analytical Chemistry Symposium**
Provo, Utah
Contact: Ralph Perhac (415) 855-2586

### JULY

**14–17**
**National Fuel Cell Seminar**
San Diego, California
Contact: Diane Suiters (202) 296-8100

### OCTOBER

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

**13–16**
**Coal Conversion Technology Conference**
San Francisco, California
Contact: Seymour Alpert (415) 855-2512

**21–22**
**Turbine-Generator Nondestructive Evaluation Workshop**
Washington, D.C.
Contact: Anthony Armor (415) 855-2961

**27–29**
**Coal and Ash Handling Systems Reliability Workshop**
St. Louis, Missouri
Contact: I. Diaz-Tous (415) 855-2826

# R&D Status Report
# ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

## TURBINE SYSTEMS SUPPORT RESEARCH

*Combustion turbine systems research is part of the Power Generation Program of EPRI's Advanced Fossil Power Systems Department. The main objective of this program is to develop and demonstrate simple and combined-cycle power plant systems that can fire coal-derived fuels with acceptable reliability, cost-effectiveness, and environmental compatibility (*EPRI Journal, *June 1978, p. 17; March 1980, p. 22). To achieve this goal, as well as improve the efficiency and operating characteristics of existing simple and combined-cycle gas turbine power plants, work is being conducted in the areas of alternative fuels, emissions reduction, turbine cooling techniques, and high-temperature materials technology.*

A major project is under way to develop the data base necessary for the design of a fuel-flexible, combined-cycle power plant with significantly higher reliability (particularly in firing low-grade petroleum or synfuel) than is currently available (RP1187).

To achieve the goals of high reliability and high availability, supporting R&D in the areas that affect engine reliability is being performed. These projects seek to develop engineering data bases for improved technology in cooling, corrosion control, combustion, and materials that may be used in future combustion turbine systems. The results will provide input to the high-reliability combined-cycle design project, as well as promote technological advances in existing stationary gas turbines.

### Alternative fuels

A series of tests were conducted to identify the characteristics and problems associated with burning various coal- and shale-derived liquid fuels in a standard gas turbine combustor (RP989-1). Fourteen coal-derived liquids (CDLs) and three shale liquids were burned in both a scaled-down combustor and a full-scale combustor. The principal measurements of interest were $NO_x$ emissions, smoke, and combustor metal temperature.

All the CDLs behaved as viable operating fuels except SRC-1 recycle solvent (a product of the solvent-refined coal process), which had water miscibility problems. The 400–650°F (200–340°C) fraction of Exxon Donor Solvent (EDS) fuel emitted the least $NO_x$ of the fuels tested; emissions were in the same range as those from No. 2 fuel oil. Shale oil had the highest $NO_x$ emissions, but its heating effect on the combustor walls was minimal. The H-Coal fuels emitted less $NO_x$ than SRC-I and SRC-II. To meet EPA's $NO_x$ specifications, the lighter fractions of H-Coal fuels may require only water injection, whereas the SRC-II full-cut fuels will also require blending with No. 2 oil. Tests confirmed the theoretical prediction that water injection is much less effective in decreasing $NO_x$ emissions from fuels with high fuel-bound nitrogen (FBN).

The fuels tested did not smoke appreciably more than No. 2 oil at a combustor exit temperature of 2000–2100°F (1090–1150°C), but they did smoke more than No. 2 at idle. It was possible to start up on full-cut SRC-II, which is near the low end of the quality spectrum for the fuels tested. This implies that a dual-fuel system like that required with petroleum residual oil would not be necessary. The final report on this work is expected to be published in mid-1980.

Another project was conducted to identify the characteristics and problems associated with burning CDLs in a catalytic combustion system (RP989-3). In this project two CDLs (SRC-II blend and H-Coal middle distillate) were tested on a rig in rich-lean combustion modes with three catalyst configurations. No. 2 distillate fuel was used as a baseline. The conclusion from this work is that CDL use in this application will require advances in catalyst technology. State-of-the-art catalysts are more easily deactivated by CDLs than by petroleum distillates.

A related project on alternative fuels undertook to design, fabricate, and test three utility gas turbine combustor configurations capable of burning medium-heating-value (MHV) gas (300 Btu per standard ft$^3$) produced by the Texaco coal gasifier in Montebello, California. The goal 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. This corresponds to approximately 55 ppm at an engine pressure ratio of 16.5 and a maximum combustor exit temperature of 2150°F (1177°C), and falls within current EPA limits (75 ppm).

The design of the combustors was based on the lean premix concept. By mixing fuel and air in lean proportions before combustion, flame temperature and thus $NO_x$ formation are reduced. As reported in AF-1144, all three of the combustors tested met the $NO_x$ requirements, but all exhibited poor turndown characteristics (lower combustion efficiency at part load). On the basis of these findings, Phase 2 of the research (RP985-3) was initiated in 1979 to develop combustors that incorporate fuel staging to burn MHV gas with acceptable combustion efficiencies and $NO_x$ emissions over the entire engine operating range. Another goal is to improve combustor fabricability.

A full-size catalytic combustor for a stationary gas turbine will be designed, fabricated, and tested in a project that began in February 1980 (RP1657). The goal is to achieve very low $NO_x$ emissions without water injection in firing low-FBN petroleum distillate fuels.

### Turbine cooling

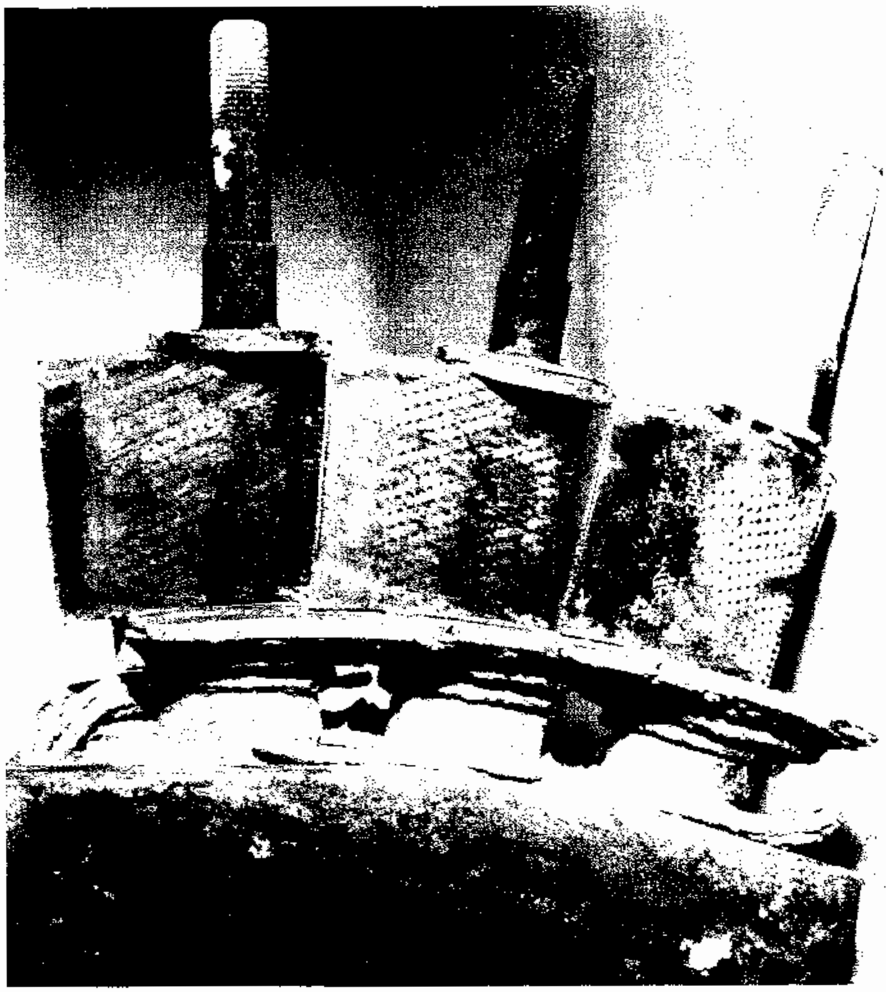
The degree to which hot-gas-path turbine components can function with fuel impurities in high-temperature and high-pressure environments is a key determinant of an engine's fuel flexibility and heat rate (Btu/kWh). Much development work is being focused on technologies that will allow combustion turbines to operate with higher-ash fuels at higher turbine inlet temperatures. This research includes a long-term EPRI project to investigate the practicality of water-cooled gas turbines (RP234) and a DOE–General Electric Co. project on high-temperature turbine technology.

Work under RP234 indicates that below a metal surface temperature of 1000°F (540°C), hot-gas-path corrosion is negligible. Corrosion becomes a consideration above 1100°F (600°C). Ash deposited at metal temperatures of 900–1100°F (480–600°C) was found to be easier to clean than ash deposited at higher temperatures, even though the deposition rate could be higher at the lower metal temperatures. Water cooling does not appear to lead to rotor balance problems. However, designs for water recovery require more work. Water-cooling techniques developed in RP234 are being applied in RP1319-1 to a specific advanced engine design planned for prototype about 1985. The project will study ash deposition rates at low metal temperatures and the cleanability of the resultant deposits in order to quantify the effects on electricity costs and enable a comparison between this engine and a fully air-cooled engine.

Advanced air-cooled designs for turbine blading have been developed (RP1319-2). One configuration used lamilloy pseudotranspiration shells; another was a shell-spar design with impermeable shells and impingement cooling between shell and spar. Figure 1 shows the suction surface of pseudotranspiration-cooled vanes tested for 96 hours in a high-ash fuel. With a reduced cooling-air flow, both configurations produced metal temperatures lower than those in existing engines. Temperatures with the impermeable shell design were 300°F (170°C) lower; those with the lamilloy shell design, 500°F (280°C) lower. Deposition tests showed that the lamilloy shells are vulnerable to hole blockage and tend to have a higher resistance to cooling-air flow. A new engine is being planned that will use this technology to run at gas temperatures that are 200°F (110°C) higher than current operating temperatures but with metal temperatures that are 200°F (110°C) lower. A prototype is projected for 1984–1985. Figure 2 shows the effect of advanced cooling techniques on heat rate and specific power.

Another advanced air-cooling technique being investigated involves wafer construction of turbine blades and vanes and uses convection impingement cooling (RP1319-3). Wafer blades have been built and are awaiting test. A new multipiece casting technique for blade fabrication shows greater economic and reliability potential than the wafer design and has been selected for further development.

Figure 1 Pseudotranspiration-cooled blades exhibit a low degree of deposition on the suction surface after 96 hours of testing with a high-ash fuel.



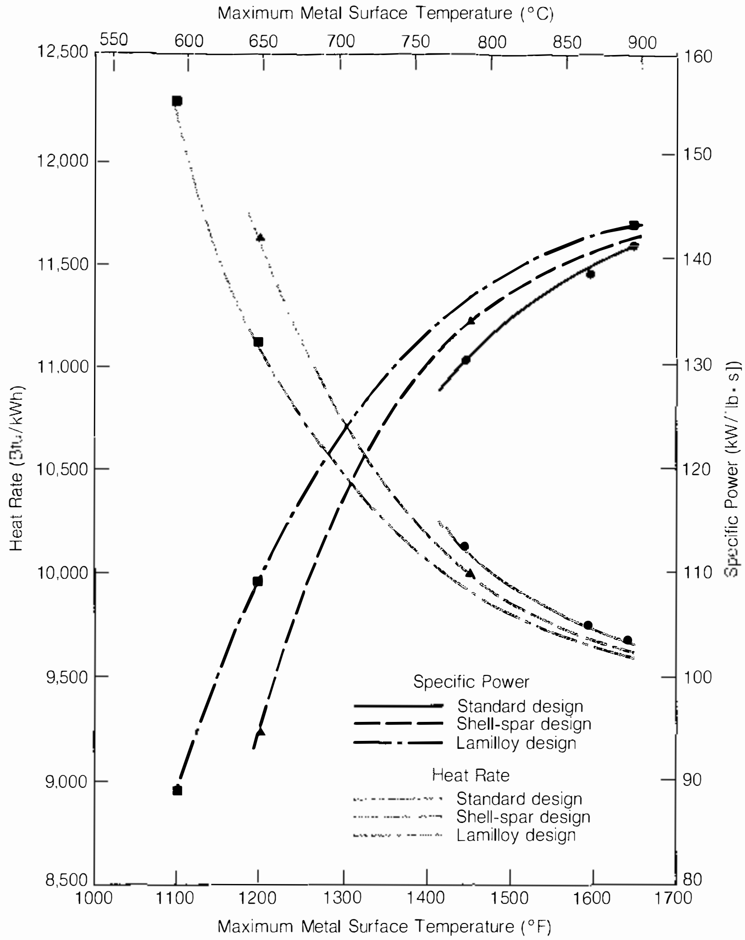
### High-temperature materials technology

Another approach to high-temperature operations involves the evaluation of ceramic thermal barrier coatings for hot-gas-path turbine components exposed to No. 2 distillate and heavy (ashy) fuel combustion products (RP1039). Although ceramic coatings that showed promise in aviation applications have proved to be sensitive to impurities in utility-type gas turbine fuels (RP421), new coating configurations—zirconia stabilized with 8% yttria or calcium silicate with a Ni-Cr-Al-Y undercoating—have been shown to be viable. In a clean fuel test of ceramic coatings at a gas temperature of 2100°F (1150°C) and a metal temperature of 1475°F (800°C), the new coatings worked well for 500 hours. However, at a metal temperature of 1650°F (900°C), all the coatings tested failed. (Calcium silicate was not tested.)

Ashy fuels have a more severe effect on ceramic coatings than clean fuels. It appears that coatings whose composition is graded from the outer surface to the undercoating are more resistant to ashy fuels than duplex coatings, which have a discrete boundary between the surface coating and the undercoating. After initial testing at 4 atm (405 kPa) with ashy and clean fuels, it is planned to test successful coatings at 16 atm (1.62 MPa). This will be followed by a multithousand-hour endurance test at 4 atm.

Work under RP1345 is attempting to quantify the corrosion and deposition effects of real residual oil (rather than doped No. 2 oil, often used in testing to simulate residual) on air-cooled cylinders in the hot gas path under current and projected turbine pressure

**Figure 2** Advanced blade-cooling techniques will allow turbines to operate at higher gas temperatures but with lower metal temperatures than at present. The advanced lamilloy and shell-spar blade designs show a significant improvement over conventional designs in terms of heat rate and specific power at a burner outlet temperature of 2200°F (1200°C).




and temperature conditions. Preliminary results show that water-washed and magnesium-treated residual fuel does not cause immediate corrosion below a metal temperature of 1600°F (870°C). Unwashed, untreated fuel causes corrosion at metal temperatures above 1100°F (600°C); no corrosion has been seen below this temperature. A comparison between real residual oil and doped No. 2 oil has been undertaken. Future investigations in this series will emphasize the corrosive effects of CDLs under high-temperature conditions.

Another effort aimed at reducing problems associated with hot corrosion is a two-part project to optimize corrosion-resistant metal coatings for utility turbine components (RP1344). In the first part the Co-Cr-Al-Y coatings used on aircraft engines are being modified (by increasing the proportion of Cr and decreasing the Al) to resist the more corrosive combustion products of utility turbines. The first screening tests are being performed on a rig. An investigation to evaluate different methods of applying the selected coatings (electron beam, physical vapor deposition, plasma spray) may also be undertaken. Then the optimized coatings will be applied to 36 vanes in a utility gas turbine (aircraft derivative), and tests will be run to compare the performance of the candidate coatings with that of state-of-the-art coatings. The second part of this project will involve rig testing of experimental coatings containing silicon. Plans for testing these coatings on utility turbine blades are currently being made.

Hot-corrosion-resistant metal cladding applied to turbine blades as a 30-mil (0.75-mm) film by hot isostatic pressing is also being investigated in a project just under way (RP1460). The objective is to develop this technique for large stationary utility turbines. Work on optimizing cladding composition is also planned. One typical cladding is 50% Ni and 50% Cr; another, GE2541, is an iron-based alloy (Fe-25Cr-4Al-1Y). It is projected that optimized cladding will at least double blade life in applications with low-grade fuels; effects are not as great (but still significant) in applications with higher-grade fuels. *Project Manager: Henry Schreiber*

# R&D Status Report
# COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

## SOLIDS BY-PRODUCT AND HAZARDOUS WASTE DISPOSAL

*This is the second status report on the activities of the solids by-product and hazardous waste disposal subprogram. Since the first (*EPRI Journal, *June 1979, p. 38), a number of project reports have been published, which are described below. The objectives of this research and related work at EPRI are to define the physical and chemical nature of solid waste; to develop an economic and environmentally sensitive method for assessing the hazard potential of utility wastes; to develop resource recovery processes and utilization systems; to develop safe solid-waste disposal systems; and to respond to the industry's socioeconomic concerns. Utility designers still face the uncertainty discussed in last year's report because final EPA regulations for the disposal of hazardous and special wastes have not been promulgated.*

### PCB disposal

Three handbooks (FP-1207, Vols. 1–3) were published in December 1979 to aid utilities in handling and disposing of polychlorinated biphenyls (PCBs), a hazardous material regulated under the Toxic Substances Control Act of 1976. Prepared by SCS Engineers, the handbooks contain information on PCB production and use, PCB disposal regulations, projected demand for regional disposal sites, available incineration technology and proposed commercial facilities, and PCB landfill facilities. Volumes 2 and 3 present guidelines on the development of spill prevention and countermeasure control plans to ensure that the risks associated with PCB activities are minimal. These guidelines are also useful in preparing plans for other hazardous materials that are expected to be regulated under Section 311 of the Clean Water Act.

The fourth volume (soon to be published) documents the October 1979 test incineration of PCB solids and liquids in an integrated commercial incinerator in El Dorado, Arkansas, owned and operated by Energy Systems Co. The report, prepared by Acurex Corp., concludes that the facility does destroy PCBs with the required levels of efficiency. It also discusses problems associated with an EPA method of PCB analysis, the perchlorination process; results from this method indicated the presence of PCBs in samples that were known not to contain them. The EPRI results were verified by more elaborate and precise analytic techniques.

Originally, EPRI intended to fund a test burn of PCB-contaminated mineral oil in an oil-fired utility boiler. Plans were dropped when no satisfactory host site could be identified. Subsequently, after giving EPA the required 30 days' notice, one utility has begun to incinerate its own PCB-contaminated mineral oil in a coal-fired plant. Thus an EPRI-sponsored test is no longer needed. The funds saved will be used to develop a field device for measuring PCBs in liquid form or in soils. The ability to measure PCBs in the soil will be particularly useful after a spill.

### Artificial reefs for coal wastes

As coal will be the major energy resource in the United States during the next decade for replacing oil-fired capacity and for new generation, large quantities of coal ash and flue gas desulfurization (FGD) scrubber sludge will be produced. In the highly urbanized regions of the country, land for the disposal of coal wastes will be extremely difficult to find. Thus EPRI, together with several government agencies, is funding a project to assess the feasibility of disposing of these wastes in artificial ocean reefs (RP1341).

During 1979, under Phase 1 of the project, building blocks of various sizes and waste compositions were manufactured and tested. Originally it was thought that blocks 1 yd (0.91 m) on a side would be the most suitable, considering the amount of coal wastes requiring disposal. These large blocks were difficult to handle, however, and required a long curing time to develop the necessary strength. Consequently, $8 \times 8 \times 16$-in ($20 \times 20 \times 40$-cm) blocks, which could be manufactured with machinery from a commercial concrete block construction plant, have been made experimentally with good results. The blocks can be steam-cured, and after one day they have a compressive strength greater than those produced by some other curing methods in one month. A summary report on this phase of the project is now available (FP-1252).

In mid-1980, 500 tons of the smaller blocks will be used to form a reef off Long Island, New York. Two different mixtures of fly ash and scrubber sludge will be used, both within the range of what a conventional coal-fired power plant might produce. Research scientists at the State University of New York at Stony Brook will study the blocks' durability and their effects on the marine ecosystem.

### Sludge and ash disposal manuals

An early product of EPRI's solid-waste disposal research was the *Flue Gas Desulfurization Sludge Disposal Manual* (FP-977), published in January 1979. Since that time there have been significant changes in the requirements and techniques for FGD and for waste treatment. Thus a completely revised edition of the manual has been developed under RP1685-1 and will be published this summer.

The revised manual will reflect the final requirements of the New Source Performance Standards; the impact of the Resource Conservation and Recovery Act (RCRA); the evolution of sludge disposal practices; the growing interest in forced oxidation; and the interest of utilities in the practices and experiences of others. It will not be a state-of-the-art report, although it will use case histories to illustrate waste disposal problems and recommended practices and procedures. The information it provides is especially important at this time, when more and more companies are becoming involved with designing and installing FGD systems.

Although the manual will discuss the disposal of fly ash as it relates to sludge disposal and will cover cases where the ash is collected in the scrubber, it will not address the collection and disposal of fly ash as a separate by-product. In March 1980 the *Coal Ash Disposal Manual* (FP-1257) was published to provide utilities with detailed information on the technical and economic factors that govern the selection of optimal ash disposal systems and locations at new plants.

The ash disposal manual assesses current practices to determine possible deficiencies and discusses the design and construction of new facilities. It covers site selection, including physical, engineering, regulatory, environmental, and economic considerations; the physical, chemical, and engineering properties of ash and its leachate; the prediction of waste quantity, waste characteristics, and system costs; equipment selection; licensing; monitoring-well systems; and reclamation procedures for ash disposal areas. It also presents cost curves and tables for making preliminary general cost estimates.

Under RP1685-3, GAI Consultants, Inc., has already begun work on a revised edition of the ash disposal manual, scheduled for publication in spring 1981. A questionnaire was included in the first edition to provide a channel for feedback so that revisions will reflect the needs of utilities.

The sludge and ash disposal manuals both emphasize the construction of new facilities and have only limited usefulness for retrofitting existing waste disposal sites. A design manual to assist utilities in upgrading disposal facilities is being prepared by SCS Engineers (RP1685-2). Scheduled for completion in March 1981, the manual will assess current disposal systems in terms of EPA criteria, describe the remedial measures necessary to bring them up to these standards, and present retrofit cost estimates. It will cover site closure procedures; the conversion of wet disposal systems to dry systems; alternative retrofit procedures; liner design; the installation of liners and leachate control systems; the recovery of by-products for reuse; and cost analysis techniques. An engineering evaluation of alternative retrofit systems will be presented, along with selected case studies.

### Sludge disposal demonstration

A major effort of the by-product disposal subprogram is a sludge disposal demonstration at a 20-MW (e) limestone dual-alkali scrubber (RP1405). This project is being conducted at Gulf Power Co. in conjunction with an EPA process evaluation demonstration. The monitoring of sludge disposal at this experimental facility will provide a technical basis for the design of full-scale disposal facilities. The project provides an opportunity to identify and solve the potential engineering, operational, and environmental problems associated with the disposal of high-sodium, high-sulfur sludges. The 20-MW (e) size is sufficient for scale-up to a full-size facility.

During the demonstration, particular attention will be given to the following: the effects, if any, of the mixing of sludge and ash on dewatering, handling, stability, and leachability; fixation and stabilization techniques and costs; site preparation requirements; the composition of leachate, supernatant, and runoff; the rate of containment leaching; potential problems associated with recycling runoff and drainage water from the landfill to the scrubber (as makeup water); the problems, if any, resulting from the high-sodium, high-sulfate composition that is characteristic of these sludges; and long-term maintenance and site reclamation requirements.

The project, which began in April 1979, was originally scheduled for completion in 31 months, but it may run a year longer. Start-up of the demonstration is planned for June 1980. Each of three landfill disposal areas will be filled with a different mixture of fly ash, FGD waste, and lime, and the chemical and physical fate of the waste materials will be evaluated.

### Monitoring and modeling

Monitoring and model development are the tasks of a three-year project at Columbus and Southern Ohio Electric Co.'s Conesville station, the first full-scale facility to use the proprietary fixation process of IU Conversion Systems, Inc., to treat sludge (RP1406). A monitoring study is being conducted to determine whether full-scale application of this process reflects the laboratory and test-pond results claimed by the proprietor, provides an environmentally acceptable disposal method, creates no new operating problems for the utility, and meets criteria established by regulatory agencies. A report on the first phase of the monitoring effort (FP-1172), prepared by Michael Baker Jr., Inc., under RP1406-2, was published in December 1979. Additional monitoring wells have been installed in the second phase, and reports will be issued annually.

In related work Battelle, Pacific Northwest Laboratories has developed a model for predicting the quality and quantity of leachate and its migration path in the disposal area (RP1406-1). A data base was compiled and laboratory studies were conducted to determine saturated and partially saturated permeabilities of sludge and ash materials and to describe the composition and distribution of the sludge and ash leachate. The data base and laboratory results were used to develop, calibrate, and verify a two-dimensional, finite difference hydrologic flow model for the study area. The model uses a technique of graphing contaminant arrival distribution to predict the distribution in time and space of contaminants traveling with the groundwater. The flow model was calibrated against water surfaces characteristic of both high and low river stages. In each case the model prediction was in good agreement with the field-measured potential surface, the root-mean-square difference being about 16 cm (6 in). A report on this first phase of modeling was published this month (CS-1355). Further model development and verification work is under way.

### Waste containment research

Most utility solid-waste disposal sites are lined with native soils rather than synthetic membranes. This may change in view of proposed stringent federal regulations (RCRA, Section 4004). Soil-lined containment may remain the prevalent design for utility waste disposal, but admixed materials and synthetic membranes may increasingly be used as a leachate-control technique. In environmentally sensitive areas, such as floodplains and wetlands (where most power plants are located), the use of these lining materials may become the rule.

An EPRI project was initiated in March 1979 to evaluate the effects on 14 liner materials of exposure to nine types of potentially hazardous utility waste over an extended period (RP1457). The objectives of this laboratory study are to determine the cost-effectiveness of using synthetic membranes, admixed materials, and natural soils as liners for waste storage and disposal areas; to estimate the effective life of liner materials exposed to different utility wastes under conditions like those in holding ponds, lagoons, and landfills; and to develop a method of assessing the relative merits of various liner materials for specific applications. Figure 1 shows an unassembled exposure cell used to test membrane liners.

In another part of this project, a state-of-the-art investigation is being made of groundwater monitoring systems to provide guidelines for proper design, location, construction, and maintenance. A report on this work will be published this summer.

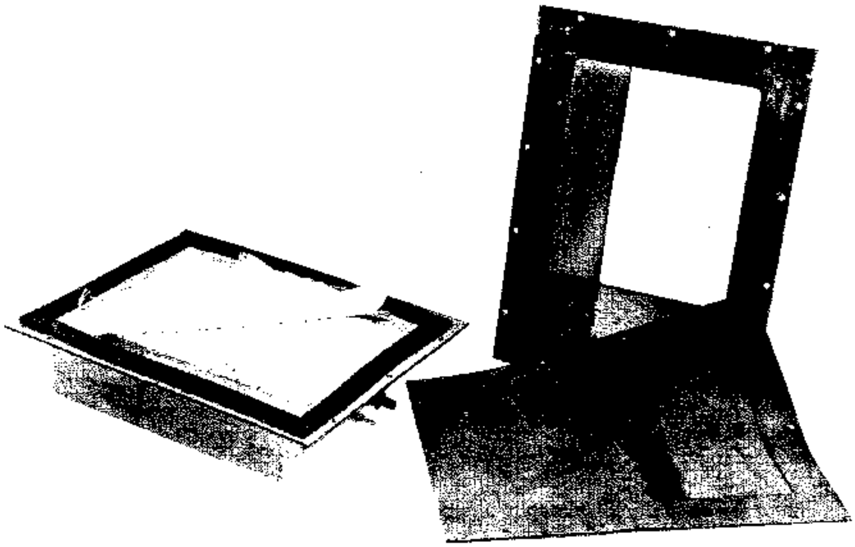


Figure 1 Unassembled exposure cell used to evaluate the effect of different types of potentially hazardous utility waste on membrane liners. The cell consists of a tank, a base filled with silica gravel, and a membrane specimen.

### Regulatory impact assessment research

Occasionally a law has such a cost impact on utility operations that extensive research studies are justified. RCRA is an example, and as part of its solid-waste disposal program, EPRI published a study in 1978 entitled *The Impact of RCRA (PL94-580) on Utility Solid Wastes* (FP-878). Another project is making a detailed engineering evaluation of representative solid-waste disposal sites and disposal alternatives under different regulatory assumptions (RP1728). It will develop cost data that will be useful for the EPRI disposal manuals and in estimating the economic impact of the RCRA regulations. A report will be published in late 1980.

EPRI was one of several sponsors of the American Society for Testing and Materials (ASTM) Collaborative Test Program, in which two ASTM-developed leachate extraction procedures were compared with each other and with the EPA extraction procedure. A number of utility wastes were included in the test program. Results varied from laboratory to laboratory for each test procedure, in some cases by as much as 100%. A modified version of the EPA extraction procedure was proposed in the EPA regulations of April 30, 1980. An EPRI report on the procedure evaluation (FP-1183) was published in November 1979. Its conclusions are important because one of the major questions the utility industry faces is which power plant wastes will be classified as hazardous under the screening-test procedures established by EPA.

Pursuant to RCRA, EPA has proposed regulations that prohibit disposing of hazardous wastes in a 500-year floodplain and nonhazardous wastes in a 100-year floodplain. These floodplains are located near rivers and lakes in low-lying areas subject to flooding after rainfall events of such a magnitude that they occur only once in 100 or once in 500 years. The potential impact of these regulations is significant because disposal facilities located in floodplains or other environmentally sensitive areas can cost from two to five times more than facilities in areas not considered sensitive. EPRI funded a study to determine the location of all existing and many proposed coal-fired power plants; of the 551 plants studied, only 109 were definitely outside a 100-year floodplain and only 33 were outside a 500-year floodplain. These findings are presented in *Evaluation of Flood Levels for Solid-Waste Disposal Areas* (FP-1205), which was published in December 1979.

This report also reviews the Federal Insurance Administration methods of flood mapping, which are to be used to enforce the EPA solid-waste regulations. Major concerns regarding the use of these methods are discussed, and preliminary guidelines are given for estimating flood levels and responding to EPA regulations.

Another report, CS-1376 (forthcoming), summarizes the state of the art of disposing of utility fly ash and FGD wastes in active and abandoned mines. Funded under RP1260-14, this report presents six examples of full-scale mine disposal operations, examines the regulations promulgated under the Surface Mining Control and Reclamation Act of 1977, and discusses the potential effects of these regulations on disposal operations.

### By-product utilization research

A two-year project begun in December 1978 is studying three methods of extracting the trace metals in fly ash (RP1404-2). Because trace metals can cause an ash to be categorized as hazardous, their removal before disposal may have important environmental and economic advantages. Also, many of the metals recovered have a significant commodity value. The project will identify the most promising removal process and will present process flow sheets, detailed designs for a demonstration plant, cost estimates, and expected benefits from the recovered resources.

The contractor, Oak Ridge National Laboratory, reports that the processes produce various soluble materials in addition to alumina ($Al_2O_3$), some of them in substantial quantities. For example, for each ton of alumina produced (worth $155), the Calsinter process would yield titanium dioxide, iron, and manganese dioxide in amounts worth $28.20, $16.50, and $1.10, respectively. This process's estimated annual operating costs are $200/t, so it is very close to the break-even point. Of the three processes being evaluated, the Calsinter process has the lowest capital cost per unit on alumina production. No credit was taken for reduction in disposal costs. A report is scheduled to be published in late 1980.

### Waste disposal for emerging coal technologies

Now is the time for industry to address the potential environmental impacts of emerging coal technologies. These impacts can be minimized if industry acts to redesign systems and subsystems and to adjust operating parameters before construction of advanced facilities. Proper methods for disposal or resource recovery must be developed for the new process wastes that will be produced.

To begin an effort in this area, EPRI funded a workshop in April 1979 on solid-waste R&D needs for emerging coal technologies. (The proceedings are now available through the American Society of Civil Engineers.) The workshop brought together experts in such areas as liquefaction, gasification, fluidized-bed combustion, and coal cleaning and preparation. A list of R&D needs was drawn up at the end of the workshop; during 1980 the priority of these needs will be determined and research projects developed for approval by the EPRI advisory committees. *Subprogram Manager: Dean Golden*

# R&D Status Report
# ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

## UNDERGROUND TRANSMISSION

### Thermomechanical bending of pipe-type cables

The excellent, long-time service record of oil-impregnated paper-insulated cables is a result of the uniformly high dielectric strength of their laminar paper-and-oil insulation structure. This insulation, built up of many individual paper tapes precisely applied in a designed overlay pattern, provides multiple radial barriers in series with the oil-filled butt spaces. When, for any reason, this overlay pattern is distorted significantly, an area of reduced dielectric strength can result. The distortion shows up in the form of wider-than-normal butt spaces and a higher-than-normal number of coincident or nearly coincident tapes.

Such an area, termed a soft spot because it yields under pressure, is an anomaly that detracts, both mechanically and electrically, from the geometric precision of the insulation. Soft spots can result either from deficient taping design or tape application or from uncontrolled bending during manufacture, testing, or installation. Most of the earlier problems related to these operations have been effectively eliminated by application of computerized design techniques that incorporate advanced taping theory and by use of special manufacturing equipment, including air-conditioned low-humidity taping enclosures.

In recent years, another mechanism of soft-spot formation has been identified in some commercial 345-kV cables and experimental 550-kV cables with insulation wall thicknesses over 1 in. In this mechanism, the soft spots appear to develop in service because of irreversible cumulative displacement of the paper tapes at cable bends. The bends result from thermomechanical expansion and contraction of the cables within the pipe as the cables heat up and expand under electrical loading.

The commercial problems to date have been confined to 345-kV cables in the joint casings. Here the cables are bent to permit splicing, and the much larger casing allows greater lateral movement. Concentration or accumulation of cable movement at these locations has caused soft spots and has required removal of some cables to prevent failure. Although it has not been established that soft spots within the line pipe are caused by this mechanism, there is an evident need to fully understand thermomechanical bending (TMB) to ensure long-time service continuity of EHV pipe-type cables. EPRI has funded a five-year project with Power Technologies, Inc., as the contractor; Empire State Electric Energy Research Corp. is jointly sponsoring the work and providing one-third of the funding (RP7873).

The project includes extensive testing, both by bench-scale mechanical flexure and by actual thermal expansion in longer-length cable pipe. Theoretical analysis after preliminary testing of the best current cable designs should lead to design improvements.

Since tests on full-scale samples are time-consuming and expensive, considerable planning and evaluation of the experimental program is being conducted before testing is fully launched. Various test matrices have been designed to separate the effects of the many interrelated variables in the complex conductor-insulation interplay as the cable is subjected to repetitive bending, expansion, and contraction during each loading cycle.

For example, mathematical analysis and model simulation of thermomechanically stressed cable as an axially compressed beam is one approach that has been helpful; however, the TMB effects resulting from repetitive bending are far too complicated to be completely explained in terms of the small elastic deflections associated with beam theory. *Project Manager: Stephen Kozak*

## TRANSMISSION SUBSTATIONS

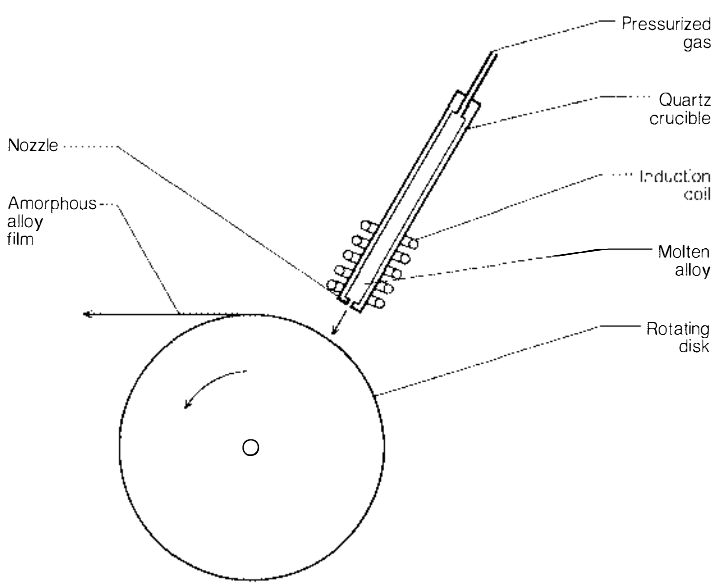
### Magnetic amorphous alloys

Amorphous alloys, or glassy metals, make up a new class of materials formed by very rapid quenching of a liquid metal on a moving metal surface (Figure 1). Because of the high cooling rates required ($10^6$ °C/s), only thin strips or ribbons have been made. These alloys typically are very hard and exhibit high electrical resistivity and mechanical strength. Many alloys are strongly ferromagnetic and because of their high chemical and physical homogeneity, low anisotropy, and high electrical resistivity, have excellent soft magnetic properties. In addition, because the production process is relatively simple and very fast, it should be inexpensive when operated on a large scale.

EPRI has recently completed a project with the University of Pennsylvania to develop an appropriate alloy for use in power transformers (RP932). Such an alloy must contain fairly large proportions of nonmagnetic elements in order to be amorphous. At the beginning of this project, the best available magnetic alloy was $Fe_{80}B_{20}$ (an alloy composition consisting of 80% iron and 20% boron by atomic weight), with a saturation induction at room temperature of 16 kG (1.6 T). This compares with 20.5 kG (2.05 T) for 3% silicon transformer steel, and with a working flux density in power transformers of about 17 kG (1.7 T). The major goal of this project was to explore alternative alloy compositions in an attempt to find materials that have higher saturation induction values and that would retain the advantages of high resistivity, high permeability, and low magnetic losses.

About 150 different compositions were prepared and the saturation magnetization measured. Various other magnetic and physical properties were measured on compositions of particular interest. The principal finding was that the addition of carbon or carbon plus silicon to an iron-boron

Figure 1 Splat-cooling equipment used to produce magnetic amorphous alloys. On striking the rotating disk, the molten metal solidifies into a continuous, narrow strip of film.




amorphous alloy can substantially increase saturation induction. The introduction of carbon has several beneficial effects: It changes the shape of the magnetization-versus-temperature curve so the alloy at room temperature retains a larger fraction of its full (absolute zero) magnetic moment; it also increases the physical density so more iron atoms are contained in each unit volume, enabling the magnetic flux per unit area to be increased. The combination of these effects raises the saturation induction to about 17.5 kG (1.75 T) at the optimal composition of about $Fe_{86}B_8C_6$. This can be increased further, to about 17.8 kG (1.78 T), by a low-temperature annealing treatment. As a result, the saturation induction was increased about 10%. The only amorphous alloys known to have higher values contain about 10 at% cobalt and are too expensive for large-scale use. Carbon has the further advantage of decreasing the cost of raw materials because carbon is normally present in pig iron and scrap steel and is expensive to remove.

The other magnetic properties of the carbon-containing amorphous alloys are similar to those of $Fe_{80}B_{20}$: coercive fields are less than 0.1 Oe (8 A/m) and losses are well under 1 W/kg at 15 kG (1.5 T) and 60 Hz (all measured after a low-temperature anneal). Extrapolations from measured behavior on annealing at 250–350°C suggest that the stability of these alloys at normal transformer operating temperatures is satisfactory. These findings will be used to advantage in a parallel project now under way with Allied Chemical Corp. to produce these materials experimentally (RP1290). The increased attainable width of 6.7 in (170 mm) should be suitable for the testing of amorphous steels in transformers. A final report will be issued by mid-1980. *Project Manager: Edward Norton*

## Analyses of transmission line transients

Development of better surge arresters has resulted in an industry trend toward reduced insulation requirements for transmission facilities. Now the new zinc oxide arresters offer an opportunity for further reduction of insulation levels. In another area, protective relaying, there are demands for faster operation of the protective relays and for relays that will work with fewer incidents of unwanted operation. Both of these areas require a good understanding of the nature and frequency of switching and fault-related surges. The EPRI-sponsored development of a system for recording transmission line transients is expected to provide data that will support engineers working on such insulation and relay problems (RP751). Two recording systems have been built by Westinghouse Electric Corp. and are now installed in Florida Power & Light Co. substations (Figure 2).

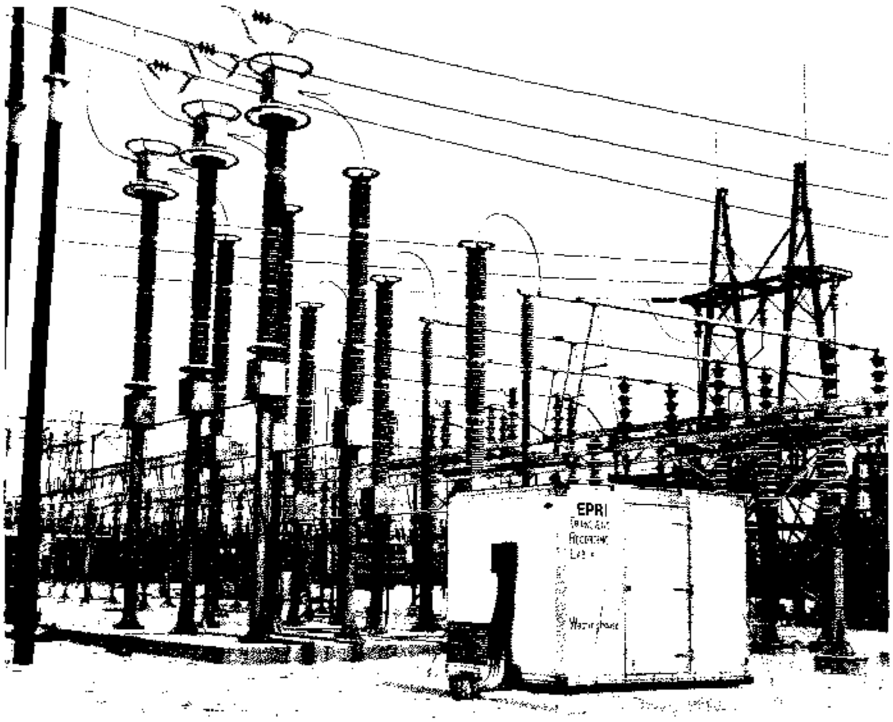
The systems are built for automatic, unattended operation. Because the primary interest is in fault and switching surges, the system was specified to have a useful recording range in a passband of 2 Hz to 100 kHz, within which the ratio of input signal to output signal has a deviation of less than 1 dB (maximum error of about 10%). Since the last report on this research (*EPRI Journal,* July-August 1978, p. 55) two new contracts have been let: one with the University of Pittsburgh (RP1422-1) and the other with Rensselaer Polytechnic Institute (RP1422-2). Researchers at UP will evaluate the performance of proposed digital relaying algorithms. The study will include performance characteristics of both current transformers and potential transformers. The RPI researchers will evaluate the performance of different ultrahigh-speed relay designs. The study will include fault-current-limiter control devices. In accordance with its contractual obligations, Westinghouse will look at the transients from a dielectric designer's point of view. So Westinghouse engineers are primarily interested in the frequency of occurrence, the magnitude, and the rate-of-rise characteristics of overvoltages.

Each system has the following major components.

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

The operating principles of the recording system are relatively simple. A surge automatically triggers the recorder, which stores 8192 samples per channel during each recording interval. At the fastest sampling rate (2 μs between samples), it can record about one full cycle (60 Hz) each time it is triggered. To conserve memory space, however, the recorder will automatically

Figure 2 Instrumentation system installed at Florida Power & Light Co.'s Lauderdale substation for detection and recording of switching surges.



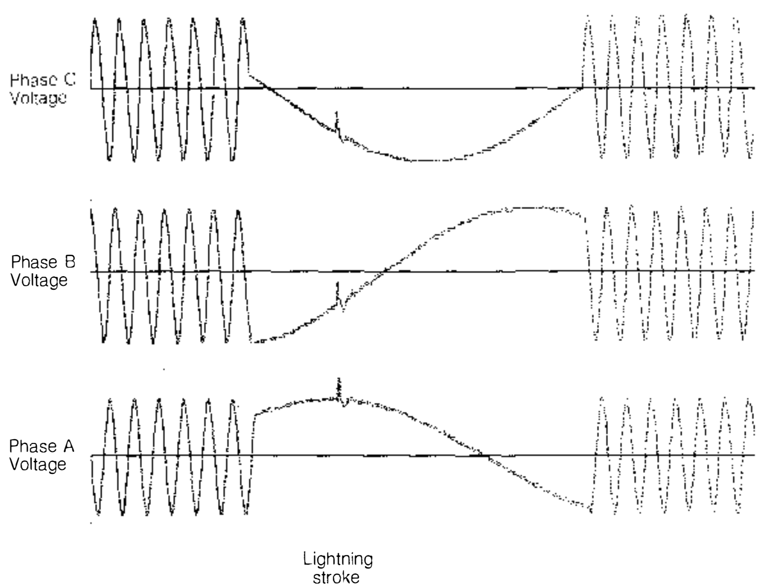



Figure 3 A lightning stroke that appeared on a trace of the Westinghouse transient recorder illustrates the memory storage capabilities of the machine. Note that just one-half cycle has been expanded to 25 times its normal width and that the memory function has retained, expanded, and printed out the wave shape before, during, and after the disturbance.

switch between two selectable sampling rates, which could extend the recording interval to 1 s or more if little high-frequency content is present in the transient.

Prior to the delivery of the system to the field, one of the two systems underwent extensive checkout in the Westinghouse High-Voltage Laboratory at Trafford, Pennsylvania. In spite of this, a number of electromagnetic interference problems were discovered when the first system was installed in Florida Power & Light Co.'s 138-kV Lauderdale substation. It has been concluded that the high-voltage laboratory's environment is too benign to predict problems that could occur at substation sites. Although correction of these problems has taken time, some useful and interesting recordings have been made. Figure 3 shows what is believed to be a lightning stroke about 8–10 mi (13–16 km) from the substation. It must be stated, however, that the recording system is not built to record lightning surges (or other transients) that have a rise time of less than about 3 $\mu$s. The rise time of the recorded lightning surge is on the order of 12 $\mu$s and thus well within the capacity of the recording system.

Eventually a library of transients will be built from data recorded by the system. In addition to supporting researchers who are working with dielectric or relaying performance problems, this data base could be used for testing and validation of low-energy protective relays. *Project Manager: Stig Nilsson*

## POWER SYSTEM PLANNING AND OPERATIONS

### Power plant performance scoping study

Rising fuel costs and uncertainty of fuel supplies have prompted utility management to place increasing emphasis on performance, both of the system and of individual generating units. In the next two decades, most of the customer load will be served by generating facilities that are already in operation, under construction, or for which the design is nearly complete. But because of rapidly escalating fuel costs, the cost of running fossil-fired boilers is 10 times what it was 3–5 years ago.

EPRI is currently investigating the establishment of a demonstration test facility that uses an advanced computer-based instrumentation package installed in an existing fossil-fueled power plant. This instrumentation will provide more accurate and timely plant performance data for power system operation. In addition, the package can be used to determine generation component, subsystem, and overall unit performance. Experience gained from the test facility would be disseminated on a regular basis during and following the tests and evaluation.

Improvements in operating performance can be achieved by work in three areas: design of both control equipment and major plant equipment, system and operational planning, and operating procedures. For the most part, only the last two are applicable to existing power plants. The initial effort is focused on operating procedures, and modifications in this area will eventually affect planning and design. The overall objective of this research is to develop the project definition, scope, and detailed work statement for a future research project that will provide an advanced, computer-based instrumentation package for installation in an existing fossil-fueled power plant (RP1737). This package will include descriptions of the data to be collected, the computations to be made, the tests to be run, and the quantity and format of the results obtained. The costs associated with design, installation, operation, and maintenance are also included.

The six phases of the present scoping study cover the following tasks.

- Determine the state of the art for the advanced, computer-based instrumentation package and for the associate analysis
- Develop a plan for the test facility and its operations, including cost estimates
- Produce a report defining the state of the art for performance data gathering, analysis, and evaluation
- Produce a work statement for a future RFP and specify the anticipated cost of developing and operating the test facility
- Provide a description of the anticipated benefits to the power industry
- Provide estimated costs for each phase of the future project

In addition to determining the state of the art in the United States, information is being gathered from England, Germany, and Japan, which are ahead of the United States in several areas identified in this project.

The present project concentrates on analyses of both thermodynamic and component performance to determine realistic requirements for a demonstration test facility. Only through improved measurements, analysis and evaluation, operating procedures, and control can improved performance be achieved. It is most important to obtain accurate thermodynamic performance data, such as data on heat rate and incremental costs. Component performance data (e.g., on unit system and subsystem performance as they relate to availability and maintenance) should have high resolution and repeatability.

FPA Corp. of Avon, Connecticut, has put together a team of consultants to conduct this scoping study. The project began in September 1979 and will be completed in mid-1980. *Project Manager: John Lamont*

### Bulk transmission system reliability

Evaluation of bulk power system reliability is an important part in the planning, design, and operation of electric power systems because the reliability level has a major effect on the requirement for new facilities and on system operating security. Because system reliability has a direct impact on the quality of service customers receive and the rates they pay, electric utilities are under pressure to make more precise evaluations of system reliability and associate cost benefits.

Evaluation of bulk transmission system reliability involves consideration of both system adequacy and system security. System adequacy is a system's ability to meet system demand within major component ratings and design voltage limits in the presence of scheduled and unscheduled outages of generation and transmission facilities. Adequacy thus encompasses evaluation of steady-state reliability. System security relates to the ability of the system to withstand disturbances without the occurrence of cascading outages.

Currently, the evaluation of steady-state system reliability in transmission system planning is based on deterministic criteria. Recently there have been attempts to apply quantitative or probabilistic approaches to bulk power system reliability evaluations on an exploratory basis. A method of computing reliability indexes is needed to quantify the reliability of a system before regulatory commissions and to translate the need for facility additions in terms of quality of service to customers.

A research project with Power Technologies, Inc., focuses on the enhancement of probabilistic methods to evaluate bulk transmission system reliability (RP1530). The contractor will develop advanced mathematical models for computing reliability indexes that express the frequency and duration of power interruptions and the amount of load not served. As part of this project, the contractor will develop a prototype computer program capable of analyzing systems having up to 150 buses; the program should be suitable for comparative testing and demonstration of alternative approaches and models for maintaining transmission adequacy. The practicality of using these methods for large-scale systems will be assessed, and a methodology for applying probabilistic results to the system planning process will be proposed.

The computation of reliability indexes will encompass the development of models and solution methods; these will include system load representation, network analysis to detect system problems, system response and operator actions, different types of outages, appropriate selection of outages to reduce computation burden, and a reliability evaluation to compute reliability indexes. Different system problems, such as circuit overloads, abnormal voltages, and system separation and voltage collapse, will be addressed in the development of these models and solution methods.

The prototype computer program to be delivered at the completion of this project by the end of 1981 should be suitable for the evaluation of future transmission system reliability. *Project Manager: Neal Balu*

## DISTRIBUTION

### Distribution system reliability

With the continued pressure to minimize capital additions to the distribution system, it becomes necessary to evaluate distribution system performance as a normal part of the planning process. The development of reliability and risk models will add another dimension to the distribution planner's repertoire of planning tools. Such models will enable the planner to evaluate the performance of the various alternatives being considered and calculate risks associated with postponing system reinforcements.

EPRI is funding a project in which Westinghouse will develop distribution system reliability and risk analysis models (RP1356). The two-year project has five objectives.

- Evaluate the state of the art of reliability assessment procedures used by the utility industry
- Recommend a uniform system of reliability indexes that can be used by most utilities for reporting outages
- Develop computer programs to calculate these system reliability indexes and to perform risk analysis
- Prepare an easily understood reliability handbook
- Incorporate the reliability and risk analysis

model into the feeder model of a distribution load forecasting and planning project also being funded by EPRI (RP570)

The state-of-the-art report on assessment procedures has been completed and includes a literature search and a utility survey. Of the 70 utilities surveyed, 5 were chosen for on-site visits to study their outage-reporting schemes in greater detail. From this survey came the basic design for the historical reliability assessment model (HISRAM), a multilevel program that charts the historical performance of the distribution system.

The first of HISRAM's four levels is simply an incident log that would limit the utility to system reliability indexes. Level two allows greater resolution than level one, inasmuch as the reliability indexes are calculated for subdivisions and emphasis is placed on the factors that contribute to unreliability. Level three includes the collection of component outage data in sufficient detail to produce a realistic risk model. Level four adds the modeling of improper operation of protective devices. This multilevel approach allows a utility to start out with a basic reporting scheme and advance to the more sophisticated schemes by simply increasing the data input to the program.

The second model to be developed in this project was the predictive reliability assessment model (PRAM), used for risk analysis. PRAM employs component reliability indexes calculated by HISRAM to predict system indexes for a proposed distribution system configuration.

The two models, HISRAM and PRAM, have been programmed and are now undergoing field tests by the two subcontractors, Public Service Electric & Gas Co. (New Jersey) and Duquesne Light Co. The final report is scheduled to be completed in the fall of 1980. *Project Manager: Richard Lambeth*

### Maximum safe pulling lengths for solid dielectric cables

Parameters employed to compute the maximum safe pulling lengths of extruded dielectric cable in underground ducts were established more than 30 years ago. At that time, maximum permissible values for tensile stress, sidewall bearing pressure, and coefficient of friction were not well documented because of inadequate test data. In addition, little was known about how the various cable components would react when subjected to pulling forces in straight and curved duct sections. As a consequence, highly conservative parameters were employed in the calculations, resulting in relatively short pulling lengths and quite expensive construction practices.

Although cable construction, types of materials used, and installation practices have all changed considerably in the last 30 years, knowledge of safe pulling tensions has not improved significantly. Maximum allowable pulling tensions and sidewall bearing pressures that these newer designs of extruded dielectric cable can withstand without adverse impact on their overall performance are unknown. Hence, the utility industry must either design new underground duct systems for highly conservative safe pulling tensions or assume less conservative tensions without adequate substantiating data.

The former design approach uses cable section lengths that are less than optimal, necessitating additional manholes and cable joints, which leads to a relatively high cost. The latter approach increases the risk of cable failure because of potentially excessive mechanical stresses that can occur during cable installation. Because neither approach is fully acceptable, there is a need to develop complete and reliable data on which to base cable installation guidelines. These guidelines would then serve as an additional tool to be used by the utility engineer in designing a technically sound and economic underground duct system.

EPRI has funded a two-year project with Pirelli Cable Corp. (assisted by Georgia Power Co. and Georgia Institute of Technology) to determine the maximum safe pulling lengths for extruded dielectric cable (RP1519).

This investigation will determine and quantify the factors that influence the maximum permissible lengths of extruded insulated cables rated 600 V and 15–138 kV that can be pulled through duct enclosures without damaging the cable. The work will be accomplished via the development of an analytic model, with laboratory and field tests performed on full-size cables to verify all model work. Tests will be conducted to determine the physical stresses involved in the cable-pulling operation; the stress distribution among cable components; and the influence of cable materials, design, and installation methods on permissible pulling tension and sidewall bearing pressures. The significance of a number of other variables will also be evaluated, including cable and duct surface, type of pulling compound, conduit fill and jam ratio, configuration of cables, pulling speeds, and temperatures.

Applicable ASTM test methods will be used to determine significant changes in cable components. Full-size cables will be evaluated on the basis of physical dimensions, conductor resistance, and selected electric withstand and dielectric breakdown tests. This investigation will culminate in the development of a utility engineer's handbook for calculating safe pulling lengths of extruded dielectric cables in conduits. The study supplements a cable-pulling investigation involving pipe-type transmission cable (RP7847), which is now nearing completion (*EPRI Journal,* May 1979, p. 58). *Project Manager: Robert J. Stanger*

## OVERHEAD TRANSMISSION

### Wood structure design

In light of the arbitrarily high nominal safety factors used in current wood structure design and the ambiguities involved (*EPRI Journal,* May 1979, p. 51), it is apparent that rational, efficient, and economical procedures for the design of wood transmission structures are rarely possible to attain. Further, the current absence of uniform analytic procedures within the utility industry and the various interpretations of current National Electric Safety Code design provisions result in wide fluctuations in safety and economy. EPRI's recognition of this fact led to a project on probability-based design of wood transmission structures (RP1352). As an early result of this work, a computer program, POLEDA, is presently being formulated, which should prove immediately useful to utilities. This new management tool will be used to accurately evaluate assumptions made in designing single wood pole transmission line structures and will also allow the evaluation of structural systems already in service.

The POLEDA program will give utilities a format for adjusting designs according to site-specific loading conditions, pole species, and design requirements. When coupled with an adequate data base for pole material properties and strengths, the program, which in final form will employ probabilistic methodology, will allow proper consideration of economics. Cost-risk analysis, which has not been possible with previous design procedures, will also be available through use of this methodology, when fully developed.

It should be stressed that this new probability-based design method will be simple to use and designer-oriented. The resultant computer programs for analysis and design of wood pole structures can, in effect, simplify the design process while increasing the level of accuracy. Individual utilities will also be furnished the methodology to evaluate their designs by using a more sophisticated procedure and will be encouraged to incorporate data for their particular location to achieve the maximum cost efficiency. As a result, the ever-increasing need for better cost control and the demand for adequate (but not excessive) safety levels can be addressed. Continued EPRI-sponsored efforts are anticipated to help utilities improve their data base for materials and loading; such work should further enhance the usefulness of this research.

The POLEDA computer program will be available shortly from EPRI's Electric Power Software Center. *Project Manager: Phillip Landers.*

**Line stringing tensioner**

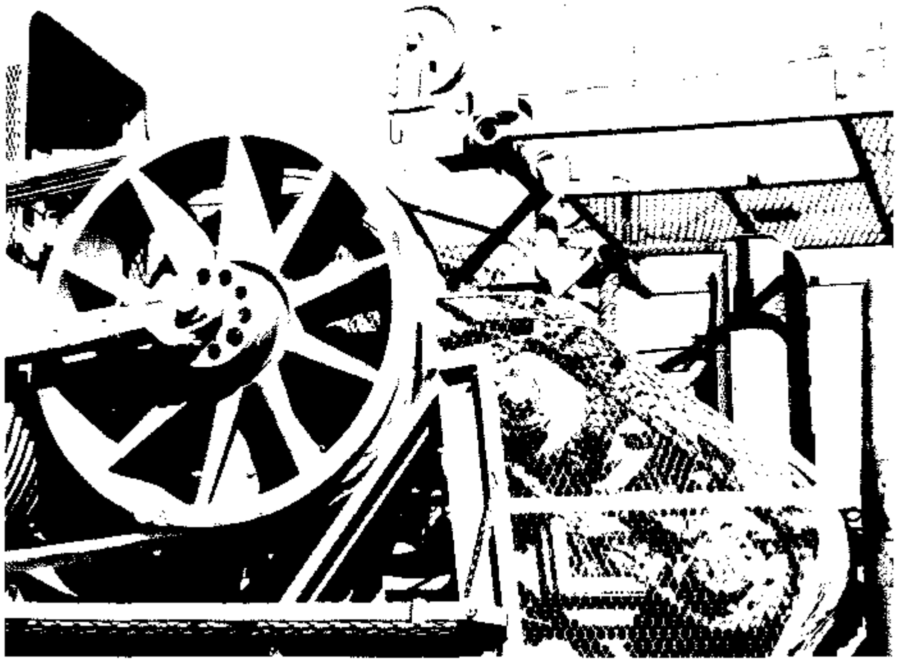
Transmission lines often need to be built in areas so inaccessible that the use of conventional construction equipment and procedures is virtually precluded. One such construction operation is the stringing of single or bundled conductors. Present methods use a large and extremely heavy device, a bull wheel, to apply tension to the conductor (Figure 4). While this device is quite effective in accessible areas, its large size and weight present severe transportation problems for construction in remote, inaccessible areas.

At the request of the electric utility industry, EPRI has initiated a project to develop a lighter tensioner that can be transported into remote areas (RP1279). With minor modifications to the equipment, this tensioner should be capable of stringing multiple subconductors in addition to distribution-size conductors.

Design and testing of a prototype tensioner is presently being carried out by Morgan Power Apparatus Corp. Unlike the bull wheel, which requires the conductor to be wrapped around a large drum, the new line-stringing tensioner uses a system that continuously grips the conductor, thus providing the restraining tension required for the stringing operation (Figure 5). A production tensioner is expected to weigh 4000–5000 lb (1.8–2.3 Mg) and will be capable of applying approximately 5000-lb tension to the conductor. This capability is somewhat lower than that of conventional bull wheels, which weigh 10,000–20,000 lb (4.5–9 Mg) and can apply as much as 20,000-lb tension to the conductor.

The line tensioner being developed by EPRI is not intended to replace the bull wheel for heavy-duty applications, but rather to offer the utility industry a specialized tool for constructing transmission and distribution lines in otherwise inaccessible areas. *Project Manager: Phillip Landers*

Figure 4 At 10,000–20,000 lb (4.5–9 Mg), a bull wheel is large and extremely heavy, but it can apply up to 20,000-lb tension on a conductor during transmission line stringing operations.



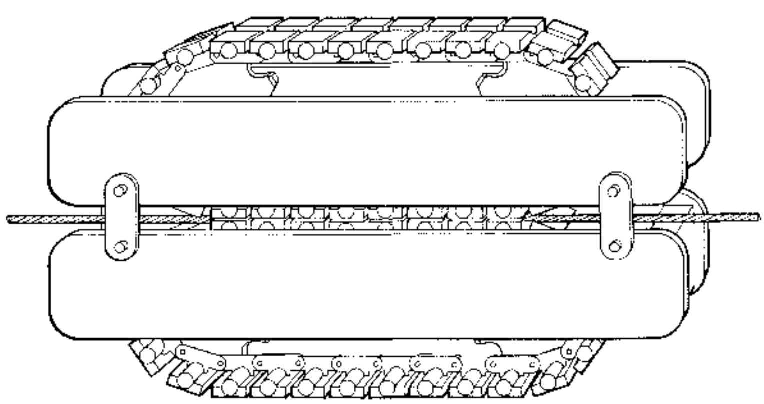


Figure 5 The new line tensioner under development by EPRI is expected to weigh no more than 4000–5000 lb (1.8–2.3 Mg) and is designed to apply about 5000-lb tension.

# R&D Status Report
# ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

## ACID PRECIPITATION MONITORING

*In the summer of 1977 EPRI began its first major regional air quality study: the Sulfate Regional Experiment, or SURE (RP862). This $6 million program focused on the relationship between concentrations of atmospheric sulfates in the northeastern United States and local emissions of the $SO_2$ precursor. Measurements were made both from aircraft and at 54 ground stations—daily for nearly a year and a half at 9 of the stations, and during selected 30-day periods at the other 45. In 1978 EPRI decided to monitor acid precipitation as part of this study, and a collection network was set up at or near the 9 SURE stations where daily air quality measurements were being taken. The program's goals are to define the chemical nature (especially pH) of precipitation falling over the Northeast; to assess how precipitation chemistry varies from one site to another and from one storm to the next; and to identify the relationship, if any, between regional air quality and the acidity of precipitation. Rockwell International Corp. is the contractor.*

Monitoring began in late August 1978 under RP1376 and is expected to continue under RP1630-2 through June 1980. It involves collecting precipitation at each site and measuring its pH, conductivity, and major chemical constituents (sulfate, nitrate, and ammonium, among others). Samples are collected on an event basis (i.e., for individual 24-hour periods) rather than weekly or monthly. Hence the data are believed to be more representative of the chemical state at the time of deposition than weekly or monthly collections and more useful in establishing the relationship of precipitation to ambient air quality and meteorological variables.

Automatic collectors that open only during precipitation are used to minimize contamination from dry deposition during periods of no rainfall. As part of the overall quality control program, duplicate samples are taken at each site from two collectors spaced approximately 3 ft apart and are analyzed in exactly the same way. This provides a backup in the event of mechanical failure or sampler contamination and enables assessment of errors caused by sampler variability.

To minimize changes in sample chemistry between collection and analysis, a preservation procedure was developed. A field technician changes the sampling buckets at a set time each day, measures the pH and conductivity of the samples, and then stores the samples at 4°C. Samples are shipped to a laboratory weekly in insulated containers cooled with artificial ice. At the laboratory, pH and conductivity are measured again, as well as the major chemical constituents. Disagreement between the field measurements and the laboratory measurements of pH and conductivity indicates that a change in sample chemistry has occurred, although the specific nature of this change cannot always be deduced.

Special features of this EPRI project are its quality control and quality assurance components, including blind laboratory analysis, interlaboratory checks, checks of field operator performance (by distributing synthetic samples), and field audits of instrumentation performance and operator procedures. The extensive amount of information developed should enable the investigators to segregate variations observed in the data for each chemical constituent by site, time, and meteorological condition. The high degree of data reliability resulting from this effort will enhance the data's usefulness in future analysis.

Data analysis is not complete, but measurements from the first nine months of operation show some interesting features. Rainfall in the Northeast is generally acid, with the overall weighted average pH being about 4.3. However, the pH can change radically from one storm to the next; in some instances, it changed by as much as 2–2.5 units, which means that the hydrogen ion concentration changed by a factor of more than 100 in a few days. These marked changes from storm to storm represent the most notable finding so far. Their significance and causes are difficult to assess. They do not correlate with day-to-day changes in emissions from anthropogenic sources, including power plants. It is hoped that a thorough analysis of findings from both the acid rain study and the SURE air quality program will shed more light on the variable nature of the chemistry of precipitation in the Northeast. *Project Managers: Charles Hakkarinen and John Jansen*

## REGIONAL CAPACITY PLANNING

*Planning for future electric power generation requires new techniques to deal explicitly with the tremendous uncertainties about demand and supply that prevail today. In a project undertaken with the National Electric Reliability Council (NERC), EPRI has used decision analysis methodology and the Baughman-Joskow regionalized electricity model (REM) to assess the adequacy of bulk power supply plans in the nine NERC regions (RP1153).*

The political and economic environment in which electric utilities operate has changed substantially since the late 1960s. The industry faces increased uncertainty about fuel supply and the growth of electricity demand. Several factors—including the 1974 oil embargo, the rapid fuel cost increases that followed, and the accident at Three Mile Island—have combined to place a heavy burden on industry operation and planning. Since 1974 the trends in electricity peak load and energy demand have broken sharply with the past and appear to be less stable, thus complicating expansions. There are also uncertainties about regulation (environmental and economic) and government energy policy, which tend to increase construction lead times and delay licensing. As a result, the planning process has become more complex than ever before and errors more costly. The development of new techniques is urgently needed to deal with the problems created by uncertainty.

In 1977 EPRI's Systems Program initiated a project to develop a framework for regional utility planning, using existing methodology, models, and information (RP1153). In this study the University of Texas, in cooperation with a subcommittee of NERC's Technical Advisory Committee, analyzed the adequacy of bulk power supply plans under uncertain demand conditions for all nine NERC regions.

On the basis of 1978 NERC reports, total generating capacity of the nine regions is expected to grow at an annual rate of 4.5% during the period 1978–1990, and the peak load at an annual rate of 5.2%. The anticipated planning reserve margins in 1983 vary across regions from 21% to 38%, but by 1990 they drop to between 17% and 31%. What do these statistics imply? Will there be a serious shortage of generating capacity in 1990? Should we plan for a more rapid expansion? The study addressed these questions from a social cost-benefit point of view.

The methodological bases of the study were decision analysis techniques and REM. The NERC capacity projections, which represent the expansion paths utilities expect to take, were used as the base case for the analysis. Alternative capacity scenarios were developed by increasing the base case capacity proportionally or by delaying, en bloc, plants expected to come on-line. The demand forecasts were represented by probability distributions instead of point estimates. Four distributions were considered for each region, ranging from wide to narrow variance, but all having the same mean value given in the NERC projection.

REM is a model that links supply, demand, and regulatory and financial behavior in a single integrated framework. It was assessed favorably in an earlier EPRI-sponsored project (RP1015). With modifications to accommodate NERC load and capacity projections, REM is used in the present study to compute the total cost of shortages and electricity generation under alternative expansion plans and electricity demand growth rates. The objective is to determine the capacity expansion plan that minimizes this cost. The overall approach is similar to that used in an EPRI cost-benefit study of over- and under-capacity planning (RP1107). However, the studies differ in their degree of aggregation: The over- and under-capacity study was designed for individual utilities, whereas this study covers the nine NERC regions.

Based on an assumed cost of $1/kWh for energy undelivered because of shortages, the results indicate that in most regions of the country, even with the narrowest range of demand uncertainty, a more rapid expansion of generating capacity would result in lower total costs in 1990. Table 1 compares actual planned capacity levels with the optimal ranges derived by this study for the years 1983, 1988, and 1990. Note that the range between the optimal capacity level under conditions of least uncertainty and the optimal level under conditions of greatest uncertainty is rather wide for most regions. This confirms the impact of uncertainty and the importance of considering it explicitly in the planning process.

**Table 1**
**PLANNED CAPACITY LEVELS VS OPTIMAL LEVELS**

| | 1983 | | 1988 | | 1990 | |
|---|---|---|---|---|---|---|
| NERC Region* | Planned Capacity (GW) | Optimal Capacity (GW) | Planned Capacity (GW) | Optimal Capacity (GW) | Planned Capacity (GW) | Optimal Capacity (GW) |
| ECAR | 110 | 105/114 | 144 | 144/172 | 160 | 163/207 |
| ERCOT | 50 | 48/50 | 59 | 51/61 | 64 | 61/73 |
| MAAC | 55 | 47/58 | 60 | 65/77 | 62 | 65/92 |
| MAIN | 57 | 56/58 | 69 | 70/82 | 76 | 80/98 |
| MARCA | 31 | 28/30 | 36 | 36/44 | 40 | 41/54 |
| NPCC | 57 | 53/76 | 66 | 69/95 | 72 | 75/103 |
| SERC | 148 | 143/162 | 185 | 202/236 | 204 | 232/278 |
| SPP | 64 | 59/64 | 87 | 80/91 | 98 | 98/108 |
| WSCC | 122 | 114/145 | 150 | 170/175 | 161 | 177/205 |
| Total | 694 | 653/757 | 856 | 887/1033 | 937 | 992/1218 |

Note: Planned capacity levels are based on figures reported to NERC on April 1, 1978. The assumed cost of undelivered energy is $1/kWh. The lower figure for optimal capacity is the level that minimizes the sum of expected generation (fuel, operation and maintenance, and capital) costs and shortage costs under conditions of least uncertainty; the higher figure is the optimal capacity level under conditions of greatest uncertainty.

*ECAR, East Central Area Reliability Coordination Agreement; ERCOT, Electric Reliability Council of Texas; MAAC, Mid-Atlantic Area Council; MAIN, Mid-America Interpool Network; MARCA, Mid-Continent Area Reliability Coordination Agreement; NPCC, Northeast Power Coordinating Council; SERC, Southeastern Electric Reliability Council; SPP, Southwest Power Pool; WSCC, Western Systems Coordinating Council.

Needless to say, the study's conclusions depend on the specific demand projections used and the assumptions made about the value of undelivered energy. A sensitivity analysis has indicated, however, that the results are fairly insensitive to the cost assigned to undelivered energy. The study's conclusions are based on 1978 projections of load growth and capacity. An interim project report was well received by members of the NERC subcommittee, and an EPRI report is being prepared.

Besides demand uncertainty, supply uncertainty (the possibility, for example, of a prolonged oil embargo, a nuclear moratorium, limits on coal use, or a curtailment of the use of natural gas in utility boilers) may well have far-reaching implications for both technology mix and capacity level. In the future, RP1153 will be expanded to quantify the implications of these supply uncertainties. *Project Manager: Hung-po Chao*

# R&D Status Report
# NUCLEAR POWER DIVISION

Milton Levenson, Director

## CABLE FLAMMABILITY RESEARCH

*Cables in power plants carry a wide range of currents and are subjected to rigorous handling, temperature, pressure, and radiation conditions in both normal and accident circumstances. Typically, they are selected on the basis of cost, electrical characteristics, handling ease, and durability. In accidents, plant cables may be exposed to above-normal temperatures, pressures, humidity, and radiation, or to external fires or overheated conductors, so the flammability of insulation and jacket materials is an important factor. Under EPRI contract, Factory Mutual Research Corp. (FMRC) is investigating the flammability characteristics of the cable insulation materials in general use by utilities throughout the country (RP1165). Characteristics being studied include ignition and flame spread, mass loss rate, heat release rate, and mass generation rate of combustion products. A major goal of this research is to determine if laboratory testing produces accurate, reliable data on cable flammability. If so, it will provide a convenient, relatively inexpensive means of obtaining information for use in cable selection.*

The composition of cables is quite varied as a result of the many additives manufacturers use in an attempt to produce satisfactory materials. Common stabilizers used in the plastic industry include $CaCO_3$, $Al_2O_3$, CaO, MgO, and $Na_2CO_3$. Plasticizers include phthalates, sebacates, and phosphates; there are about 500 generic types of plasticizers for polyvinyl chloride cable alone. Fire retardancy can be achieved by the use of such substances as phosphate esters, chlorinated hydrocarbons, antimony oxides, and borates. These additives, together with colorants and lubricants, make cable a very complex material that is not easily categorized. Successful categorization of cable types on the basis of flammability parameters will help utilities weigh the risk of cable fires when choosing cable materials.

In this project cable samples were ignited and burned in a laboratory device developed by FMRC (Figure 1). In the laboratory, testing included both autoignition and piloted ignition, and the cable was exposed to varying radiation heat energies. Flaming fires were produced in all the cables tested, although there was wide variation in burning rates and in releases of radiant and convective energy. There were also significant differences in the density and toxicity of the smoke produced. Some cables burn with little smoke, while others produce dense smoke that contains such toxic materials as chlorides and hydrochloric acid. The results of this laboratory phase of the project are discussed in an interim report (NP-1200).

Full-scale tests are also being conducted in actual cable trays loaded and configured in a nonconservative array (two side-by-side stacks 8 ft long and six tiers high), and the results used to determine the accuracy of the laboratory results. Testing included both free burns and burns extinguished by water after the cable attained its maximum energy release rate. (Since NRC has indicated that it plans a program on gas and dry chemical extinguishment, EPRI has limited its present work to water extinguishment.)

This portion of the project is still in progress, but there is some correlation between results from early full-scale tests and the laboratory results. In line with a series of NRC tests, which established that fires in packed cable trays ignited by an over-capacity conductor current did not propagate seriously, FMRC found that in many cases small external fires did not propagate into major fires. FMRC has determined, however, that some spacings are more conducive to the initiation and spread of fires in cable bundles. This work will be presented in detail in the final report, which will be published on completion of the project this summer.

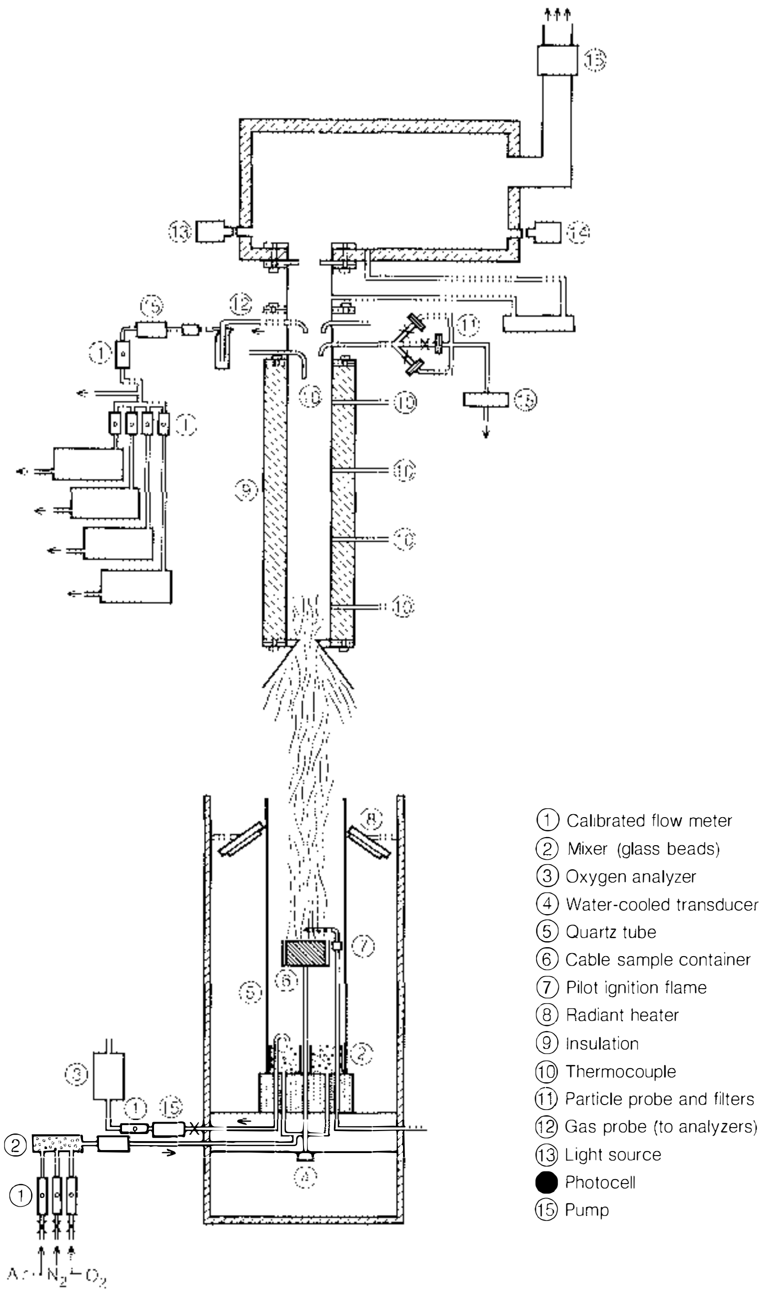
The laboratory and full-scale tests have indicated that it is not practical to attempt to classify burning rates by the generic materials involved. Preliminary results showed very early in the testing that two samples of insulating materials that have relatively low fire hazard may not show a relatively low hazard if combined in a cable insulation because of the interactions between the materials.

There are also variations in the flammability characteristics of cables identified as being made of the same generic material. In tests in which four different cable samples composed of polyethylene–polyvinyl chloride were subjected to an external heat flux of 60 $kW/m^2$, these heat release rates were measured: 589, 395, 359, and 312 $kW/m^2$. (The measurement often used—heat of combustion, kJ/g—is not as descriptive of fire hazard as the heat release rate per unit area, $kW/m^2$. Hence the FMRC study uses heat release rate to classify the fire risk of cable materials.)

These flammability variations appear to be due to binders, surface coatings, colorants, fire retardants, or other differences in insulation materials, as selected by the manufacturer. Wire size and interactions between jacket and insulation materials may also have an effect. The cables were manufacturers' runs obtained directly from the supplier or from utility stocks. Because current ordering procedures do not specifically identify detailed composition of the cable, suppliers do not guarantee specific material compositions in any future order; and because there is no requirement for a repeatable heat release rate, there is no assurance that materials purchased from these suppliers now or in the future would have the same characteristics. Therefore, the FMRC study does not identify the cable samples by manufacturer.

The tests also revealed that the fire hazard of certain materials varies according to the external heat flux applied. For example, cables with cross-linked polyethylene insulation and chlorosulfonated polyethylene jackets demonstrated a low fire hazard

Figure 1 To ascertain the fire behavior of various types of cables, 22 cable samples were subjected to varying magnitudes of heat flux in this laboratory-scale flammability test apparatus.




when exposed to a low (40 kW/m²) heat flux. Both cross-linked polyethylene–neoprene and cross-linked polyethylene–cross-linked polyethylene cables had heat release rates as much as four times as high at this same heat flux exposure. However, when the external heat flux was increased to 90–100 kW/m², the cross-linked polyethylene–chlorosulfonated polyethylene cable had a higher risk than the other two.

Assuming validation of the laboratory results, the testing apparatus and procedures developed by FMRC will enable categorization of cables on the basis of ignition and flame spread values, smoke opacity, and the generation of toxic and corrosive products. Such information will be useful to utilities in selecting cable for specific power plant applications. For example, control rooms require a very high degree of fire resistance and minimum generation of smoke and toxic gas because they must allow occupation and access during a fire. Similar low fire risk is also an important requirement for cables used in cable tunnels and areas of limited access. A Teflon cable, though expensive, might be considered for these applications because its heat release rate is low at all external heat flux values, its ignition–flame spread value is low, and it releases low-density smoke. Silicone cables also show very low fire risk, and they produce lower-density smoke than most other cable samples. Cables for use in open areas with easy access and noncritical circuits must meet much less stringent requirements. *Project Manager: Roy E. Swanson*

## STRESS CORROSION CRACKING OF ZIRCALOY CLADDING

*Pellet-cladding interaction (PCI) leads to the degradation of the Zircaloy tubing used to clad $UO_2$ fuel pellets. Limits on rates of power increases in nuclear fuel rods have been recommended by fuel vendors to minimize failures due to PCI. While these limits have proved effective in reducing fuel rod failure rates, they are costly to utilities because they also reduce plant capacity factors. Earlier work (*EPRI Journal*, December 1976, p. 24, and October 1978, p. 75) showed that the phenomenon responsible for PCI-induced failures is the stress corrosion cracking (SCC) of the Zircaloy cladding. This report highlights results from recently completed laboratory studies on this phenomenon conducted at SRI International and Argonne National Laboratory (ANL). Details are provided in previously issued reports for these projects (NP-717, NP-1155, and NP-1329).*

The goals of these projects were to identify the factors controlling the key steps in the SCC process that ultimately lead to failure of the Zircaloy cladding and to provide data for the modeling of Zircaloy cladding failure being pursued under RP700-3. The response of unirradiated cladding was investigated at SRI (RP455) and that of irradiated cladding at ANL (RP1027). The studies used similar experimental techniques: The susceptibility of Zircaloy to SCC was measured by internally pressurizing short lengths of tubing specimens loaded with iodine, which is known to be aggressive to Zircaloy. The data show the existence of a threshold stress, defined as that hoop (circumferential) stress below which no failures are observed in long-term (≥100 h) tests. The threshold stress was used as a basis for comparing the susceptibility to SCC of different types of Zircaloy.

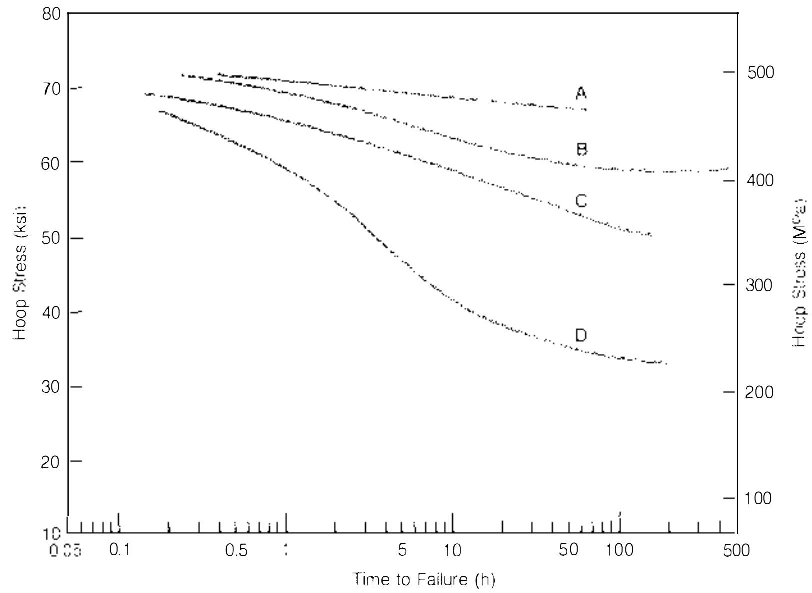
Scanning electron microscopy (SEM) was used to identify fission product deposits and inside-surface features of the Zircaloy tubing that are important to the SCC process. The projects evaluated the role of both manufacturing variables and operating variables on SCC behavior. Manufacturing variables considered were tubing crystallographic texture, inside-surface finish, and local surface chemistry; operating variables considered were irradiation, hoop stress changes, and axial-to-hoop stress ratio.

### Manufacturing variables

The role of vendor-specific fabrication procedures in the susceptibility of tubing to SCC was evaluated by testing standard product-line materials. Extensive testing of Zircaloy-2 tubing manufactured by two different vendors was supplemented by limited testing of Zircaloy-2 tubing provided to SRI by the Fuel Performance Improvement Program (FPIP) sponsored by DOE. These materials met all current ASTM specifications for Zircaloy tubing intended for nuclear service.

The specific effects of crystallographic texture and inside-surface finish were studied by testing stress-relieved tubing fabricated by Sandvik Special Metals Corp. from a single heat of Zircaloy-2. Four different textures were produced by simple modifications to standard tube-processing procedures. This tubing differed from nuclear-grade tubing only in that it was not subjected to tube straightening. The inside surfaces of tubing specimens from each lot were treated to produce three finishes: etched, etched and grit-blasted, and lightly etched and shot-peened. The four textures and three surface finishes provided 12 met-

Figure 2 The effect of manufacturing methods on the susceptibility of Zircaloy-2 to SCC. Each curve shows time-to-failure data as a function of applied hoop stress: A, FPIP tubing tested in inert helium; B, FPIP tubing tested in iodine; C, Vendor 1 tubing tested in iodine; D, Vendor 2 tubing tested in iodine.



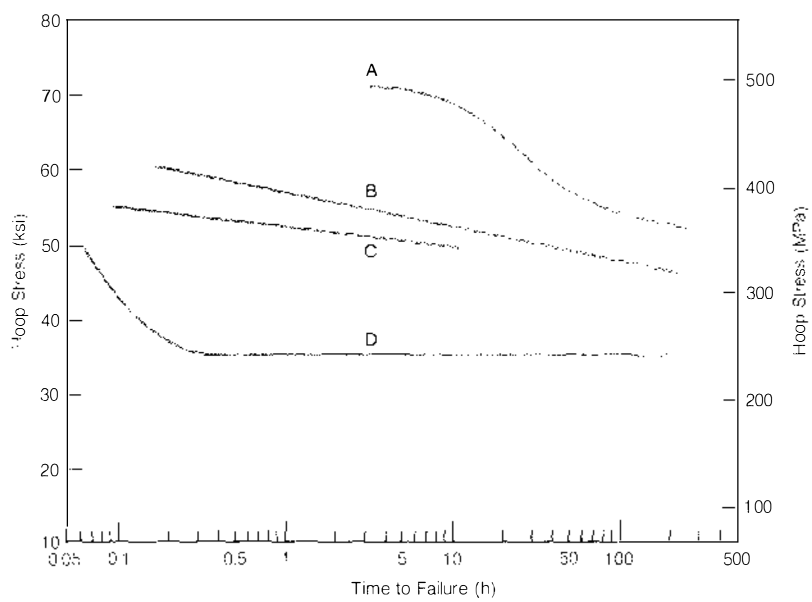




Figure 3 The effect of crystallographic texture on the response of unirradiated Zircaloy-2 tubing with an etched inside surface to testing in iodine. Each curve defines the lower-bound time-to-failure data for a given texture. The resistance to iodine-induced SCC decreases as the texture changes from most radial, A, to most tangential, D.

allurgical conditions for evaluation by SRI.

It was found that differences in the tube fabrication process led to significantly different responses to tube burst testing in iodine even though such tubing met ASTM specifications. Figure 2 shows that tubing provided by Vendor 2 had a lower threshold stress than that of Vendor 1 (by about 17 ksi; ~115 MPa) and failed about 30 times faster under an applied hoop stress of 55 ksi (345 MPa). However, this difference in SCC susceptibility was eliminated if the internal surface was polished prior to testing. Stress-relieving treatments also produced substantial changes in susceptibility to SCC. The FPIP tubing was the most resistant to SCC—there was only about a 7-ksi (50-MPa) difference between the stresses required to produce stress-rupture in the absence of iodine and iodine-induced SCC failure at ~100 h. Differences in the response of these tubing types were attributed to differences in crystallographic texture, surface chemistry, and residual stress.

The effect of texture on the SCC susceptibility of specimens with an etched inside surface is shown in Figure 3. Each curve represents the worst-case response for a given texture. The results clearly indicate that the more radial the texture of unirradiated tubing, the more resistant it is to iodine-induced SCC.

While encouraging, this finding is of limited practical application. It had been hoped that tubing with textures of substantially more radial orientation than currently available could be evaluated. Unfortunately, the most radial texture provided to SRI was comparable to that already available to nuclear fuel vendors. Furthermore, it is necessary to establish whether more radial textures would still be more resistant to SCC after irradiation. Analyses of Zircaloy deformation behavior suggest that the improvement should persist after irradiation, but this conclusion must be considered tentative.

Results from tests to determine the effect of inside-surface finish on resistance to SCC were ambiguous. The lightly etched and shot-peened surface showed the lowest resistance. In terms of lower-bound behavior in tube burst tests, the etched and grit-blasted surface was the most resistant. However, many of the longest times-to-failure were observed for specimens whose surface had been etched only.

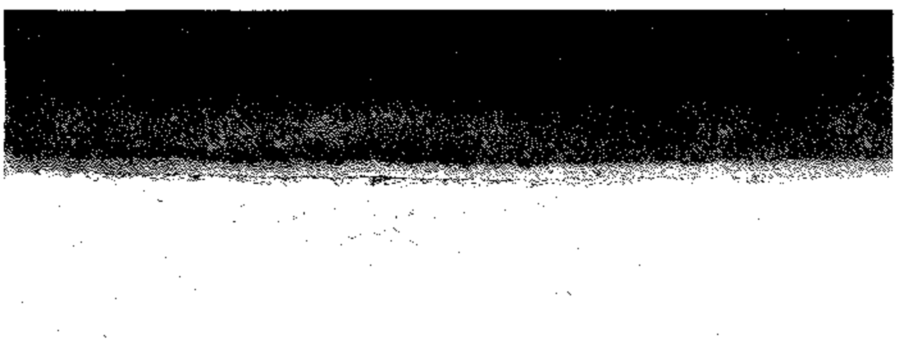
Intensive SEM observations of the inside surface of tubing specimens suggest an association between crack initiation sites and high local concentrations of certain alloying elements (iron and chromium) or of impurities presumably introduced during tube-forming or inside-surface-finishing operations. This association is best illustrated by results from the FPIP specimens. As noted earlier, this tubing proved to be the most SCC-resistant of all the specimens SRI tested. However, SEM fractography showed that high local concentrations of iron (~10%) were associated with the crack initiation sites.

Additional data pointing to the role of impurities in crack initiation are provided by SRI studies of the thermodynamics of gaseous and solid iodides of zirconium. This work, supported by DOE, suggests that $ZrI_4$ plays a crucial role in the SCC of Zircaloy. At 500 K it was found that $ZrI_4$ reacts most rapidly with surface sites that contain a few percent of iron.

### Operating variables

The results discussed above have proved helpful in defining the as-fabricated features of Zircaloy tubing that affect its resistance to SCC. It is equally important to evaluate the effects of irradiation on SCC response. Earlier work by ANL showed that irradiation is the most important single factor in reducing the threshold stress. While threshold stresses of 40–50 ksi (275–345 MPa) were measured for both unirradiated specimens and specimens irradiated to burnups of ≲10 GWd/t, the threshold stresses for specimens irradiated to 20–30 GWd/t were only 25–30 ksi (170–205 MPa).

The EPRI-sponsored project at ANL has identified the key factors responsible for the degradation of the more highly irradiated Zircaloy. Tests were run on specimens obtained from two fuel rods that had been irradiated for one cycle in the Big Rock Point reactor to about the same burnup under comparable operating conditions. The tube burst test data showed a significant difference (~9 ksi; 60 MPa) between the threshold stresses of the rods, which appeared to be related to the breakdown of a protective oxide film on the inside tubing surface. In the more resistant tubing the oxide film was intact and uniformly thick, with no evidence of cesium deposits. In the less resistant tubing the film was no longer intact, and cesium deposits were visible on the tubing surface. Figure 4 shows the difference in appearance between the two inside surfaces. A simple measure of the dif-



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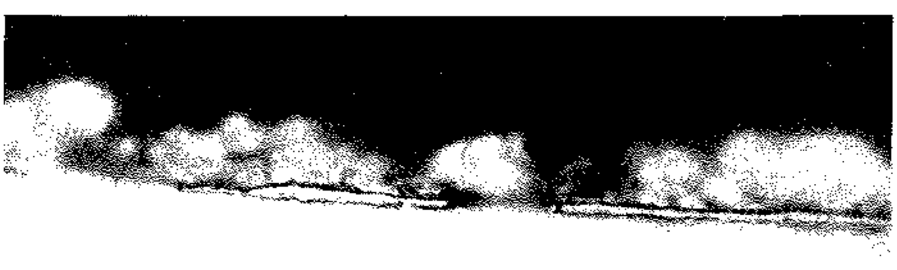

b

Figure 4 Oxide films on the inside surface of two Zircaloy-2 tubing specimens irradiated to the same burnup. An intact, adherent oxide film is observed in the specimen with high resistance to SCC (**a**), which was obtained from a fuel rod with low fission gas release and low cesium release. A cracked, thin film is observed in the specimen with low resistance to SCC (**b**), which was obtained from a fuel rod with high fission gas release and high cesium release. (Magnification: 500×)

ference in cesium release is suggested by the fission gas release values for the two rods, which differed by a factor of 70. These experiments provide strong evidence that the release of aggressive fission product species reduces the resistance of irradiated Zircaloy to SCC.

The results discussed above have been obtained under test conditions in which a constant hoop stress was applied to the specimen until it failed. To model actual operating conditions, in which the fuel rod is subjected to varying stresses during irradiation, it is necessary to determine the response of specimens to changes in loading conditions. Consequently, tests were performed to provide information on the way previous loading at one stress affects the time-to-failure at a second stress.

Data obtained from both unirradiated and irradiated specimens do not support a simple linear damage accumulation law, which holds that each increment of damage depends only on currently imposed external stress and not on the state of internal damage. Instead, these data suggest that explicit representation of crack initiation and growth rates under different imposed stresses are required to predict times-to-failure of cladding specimens subjected to changing stresses. Therefore, the remaining-life concept used to analyze data from creep rupture experiments under changing stress conditions is being employed in analysis of these data.

Also, the data discussed earlier have been obtained from specimens subjected only to stresses produced by internal pressurization. In this loading state the axial-to-hoop stress ratio is 0.5. To address the response of Zircaloy under loading conditions more like those that occur at pellet interfaces, where the cladding tends to ridge, the SCC susceptibility of tubing specimens under combined internal pressure and axial loading was measured. It was found that the SCC susceptibility was dependent on the axial-to-hoop stress ratio and that the effect of the stress ratio was dependent on the absolute stress level. At all stress levels, however, the maximum susceptibility to SCC was observed when the axial-to-hoop stress ratio was 0 (a pure hoop stress).

The stress ratio results are consistent with the interpretation that at high stresses SCC occurs by a process controlled by hoop strain, such as cleavage and fluting, while at low stresses SCC occurs by a process that is more dependent on effective strain, such as intergranular corrosion. These results also accord with the observation that the ridged regions of the fuel rod at pellet interfaces are favored sites for SCC failures. In these regions, released fission products can most readily accumulate at the inside surface of the cladding, and the overall stress level and state of stress (as measured by the axial-to-hoop stress ratio) render the cladding most susceptible to attack by the aggressive chemical environment.

### Using the research

The data summarized here have been used in two key areas: developing a model that provides a description of Zircaloy cladding failure caused by SCC, and suggesting changes to present tubing fabrication procedures that might improve the resistance of Zircaloy to SCC.

Current fuel performance computer codes do not explicitly model processes leading to failure of the cladding. The information generated by these two projects has served to identify the critical factors that affect the response of Zircaloy tubing to aggressive environments during in-reactor exposure. The data have been used as the basis of the cladding failure model that will be incorporated into the SPEAR code, which is being developed to predict fuel rod failure probabilities under arbitrary duty cycle conditions (RP971).

Programs to provide more PCI-resistant fuel rod designs are being sponsored by EPRI and DOE. The focus in these programs is to reduce the amount of aggressive fission products that can reach the inside surface of the Zircaloy cladding. Some emphasis is also being placed in DOE programs on reducing PCI-induced cladding stresses by using coatings on the inside cladding surface that serve as lubricants. The results reported here suggest secondary approaches to improve the resistance of Zircaloy tubing to SCC. These improvements could be realized through development of procedures for fabricating tubing with more radial textures; development of ways to facilitate the formation of an adherent oxide film on the inside cladding surface; and better control of the presence and distribution of impurities and alloying elements on the inside surface. *Project Manager: Howard Ocken*

# New Contracts

| Number | Title | Duration | Funding ($000) | Contractor/ EPRI Project Manager |
|---|---|---|---|---|
| RP422-8 | Advanced Dry Cooling Demonstration: Acid Injection for Evaporative Cooling Towers | 6 months | 21.2 | Pacific Gas and Electric Co. *J. Bartz* |
| RP434-40 | Electric Utility Rate Design Study | 2 months | 15.0 | Resource Planning Associates, Inc. *R. Malko* |
| RP891-3 | Feasibility Study of Plantwide Disturbance Analysis Surveillance System | 8 months | 212.2 | Westinghouse Electric Corp. *A. Long* |
| RP982-21 | Limestone Survey | 6 months | 57.6 | Dravo Lime Co. *D. Stewart* |
| RP1129-4 | Arapahoe Fine-Particulate Characterization | 4 months | 70.2 | Meteorology Research, Inc. *R. Carr* |
| RP1162-4 | Velocity and Void Distribution in Steam Separators | 10 months | 52.5 | University of Toronto *S. Kalra* |
| RP1191-7 | Performance Monitoring of Hybrid Passive-Active Solar Systems | 14 months | 65.0 | University of Arizona *G. Purcell* |
| RP1201-9 | Heat Pump Study | 15 months | 8.9 | Resource Conservation Office, City of Palo Alto *R. Mauro* |
| RP1260-16 | Recovery, Utilization, and Disposal of Solid By-Products of Dry Flue Gas Desulfurization Systems | 6 months | 36.4 | SCS Engineers *R. Komai* |
| RP1265-9 | State of the Art of Handling Coal in Freezing Weather | 7 months | 58.1 | Ford, Bacon & Davis *D. Teixeira* |
| RP1267-7 | Coking Properties of Coal Under Pressure and Their Influence on Moving-Bed Gasification | 15 months | 80.0 | Conoco Coal Development Co. *J. McDaniel* |
| RP1455-5 | Performance Analysis of a Utility Boiler Firing a Coal-Oil Mixture Fuel | 18 months | 303.2 | Babcock & Wilcox Co. *S. Drenker* |
| RP1475-1 | Substitution Between Energy and Other Factors of Production in Manufacturing | 2 years | 297.6 | Resources for the Future, Inc. *S. Braithwait* |
| RP1480-2 | Review and Evaluation of Energy Supply Projects: Coal | 23 months | 30.0 | Pennsylvania State University *J. Eyssell* |
| RP1502-1 | Field Evaluation of 800-kV Gas-Insulated Substation | 8 months | 93.5 | Gould–Brown Boveri, Inc. *V. Tahiliani* |
| RP1534-1 | Modeling of Unit Operating Considerations in Generating Capacity Reliability Evaluation | 2 years | 280.1 | Associated Power Analysts *N. Balu* |
| RP1550-1 | Nonlinear Finite Element Dynamic Computer Code Development | 1 year | 96.5 | Hibbitt & Karlsson, Inc. *H. T. Tang* |
| RP1562-2 | Stress Corrosion Cracking Test Methods | 15 months | 84.9 | University of Delaware *J. Danko* |
| RP1565-2 | Low-Temperature Solute Segregation | 1 year | 76.8 | Rockwell International Corp. *M. Fox* |
| RP1616-8 | Plume Model Validation | 19 months | 5251.4 | Rockwell International Corp. *G. Hilst* |
| RP1631-1 | Effects of Selenium on Fish Reproduction | 27 months | 412.0 | Carolina Power & Light Co. *M. Kiyono* |
| RP1717-2 | Transmission Line Mechanical Research Facility | 5 months | 31.3 | Synergistic Technology Inc. *R. Kennon* |
| RP1743-1 | Sport Fishery Potential of Power Plant Cooling Reservoirs | 3 years | 360.0 | Southern Illinois University *I. Murarka* |
| RP1754-1 | Development of a BWR Core Flow Analysis Capability | 11 months | 94.0 | Yankee Atomic Electric Co. *B. Zolotar* |
| RP1773-1 | Energy Conservation and Hypothermia | 11 months | 53.0 | University of Washington *R. Wyzga* |
| RP1778-1 | Update of Steam Plant Surface Condenser Leakage Study | 9 months | 141.3 | Bechtel National, Inc. *T. Law* |

# 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.

**Requests for copies of specific reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 961-9043. There is no charge for reports requested by EPRI member utilities, government agencies (federal, state, local), or foreign organizations with which EPRI has an agreement for exchange of information. Others pay the listed price. Research Reports Center will send a catalog and price list on request.**

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Microfiche copies are available from National Technical Information Service, P.O. Box 1553, Springfield, Virginia 22151.

## ADVANCED POWER SYSTEMS

### Preliminary Engineering Evaluation of Promising Coal Liquefaction Concepts

AF-884 Final Report (RP832-2); $8.25

Six coal liquefaction process concepts were evaluated: flash hydrogenation; supercritical extraction; solvent-refined coal (SRC) production with critical solvent de-ashing; SRC production with two thermal stages; SRC production by short-residence-time liquefaction and hydrotreating; and conventional SRC production with filtration. Uniform design bases and evaluative procedures were established to provide comparable technical and economic analyses of the processes. Each concept was developed into a fully integrated design, self-sufficient in fuel and power, processing 10,000 t/d of coal in the liquefaction section. The contractor is Catalytic, Inc. *EPRI Project Managers: Howard Lebowitz and Nicolas Korens*

### Design Properties of Steels for Coal Conversion Vessels

AF-1242 Interim Report (RP627-1); $2.75

This report describes in detail the development of equipment for conducting fracture mechanics tests in simulated coal conversion environments. It presents initial design concepts and the subsequent modifications required to produce a viable working test system. The contractor is Westinghouse Electric Corp. *EPRI Project Managers: Ramaswany Viswanathan and Roger Richman*

### Worldwide Survey of Current Experience in Burning Residual and Crude Oils in Gas Turbines

AF-1243 Final Report (TPS78-833); $4.50

The results of a survey (conducted by personal interviews and by questionnaire) to determine the main problems and successes experienced in burning residual and crude oils in gas turbine installations are given. Burning these lower-grade fuels requires additional equipment and certain operational changes, but most problems have been overcome and users consider the fuels practical. The major unresolved problem is buildup of deposits in the turbine. The contractor is Encotech, Inc. *EPRI Project Manager: Richard Duncan*

### Upgrading of Coal Liquids for Use as Power Generation Fuels

AF-1255 Final Report (RP361-2); $9.50

Residual coal liquids were hydroprocessed in a fixed-bed unit to upgrade them to power generation fuels. These ranged from short-contact time (SCT) solvent-refined coal (SRC) to conventional critical solvent de-ashed SRC. A series of catalysts were evaluated for the desulfurization of SCT SRC. Constant-temperature aging runs were conducted with both regular SRC and SCT SRC. A kinetic aging model was developed to estimate process conditions and yields in either a fixed-bed or a fluidized-bed reactor. The contractor is Mobil Research and Development Corp. *EPRI Project Manager: W. C. Rovesti*

### Thermophotovoltaic Conversion From Conventional Heat Sources

ER-1262 Final Report (RP1348-3); $5.25

This study assessed the feasibility of using conventional (nonsolar) heat sources in generating electricity by thermophotovoltaic (TPV) conversion. It concluded that TPV conversion from conventional heat sources is not competitive with existing power generation options. The reasons are discussed, as well as conditions under which the prospects of this type of conversion should be reexamined. The primary factors limiting performance are not ex pected to apply to solar TPV systems. The contractor is Black & Veatch Consulting Engineers. *EPRI Project Manager: E. A. DeMeo*

### Silicon Photovoltaic Cells in TPV Conversion

ER-1272 Interim Report (RP790-2); $5.75

An experimental and theoretical investigation of thermophotovoltaic (TPV) energy conversion, using silicon photovoltaic cells, was performed. Experiments relating to key cell parameters, parasitic absorption, series resistance, and charge carrier recombination are presented. TPV cell development and energy conversion measurements are described, as well as plans for a new processing facility. The measured energy conversion efficiencies were increased from 14% to 26% during the report period. The contractor is Stanford University. *EPRI Project Manager: E. A. DeMeo*

### Solvent-Refined Coal Process: Operation of SRC Pilot Plant at Wilsonville, Alabama

AF-1287 Annual Report (RP1234-1-2); $8.75

This report presents results from tests conducted at the SRC pilot plant at Wilsonville, Alabama, during the fourth quarter of 1978. (Plant activities for the entire year are also summarized.) Two coals were processed, Indiana V and Kentucky 6/11, and the effects of process variables on SRC yield and solvent quality were investigated. Tests confirmed the high rate of coal conversion at short residence time. Several methods of de-ashing the reaction product were studied, as well as the effects of SRC process conditions and critical solvent de-ashing conditions on SRC recovery. The contractor is Catalytic, Inc. *EPRI Project Manager: Howard Lebowitz*

### Conversion of Oil-Fired Boilers to Coal-Derived Liquid Fuels

AF-1295 Final Report (RP779-20); $4.50

The technical problems involved in converting from oil to coal-derived liquid fuels in utility plants are examined. Five types of Exxon Donor Solvent (EDS) liquid fuel were compared with a typical No. 6 fuel oil, and three existing oil-fired power plants were studied to determine the modifications required for handling, storing, pumping, and burning each type of EDS fuel. An engineering order-of-magnitude estimate was prepared for each plant. The contractor is Stone & Webster Engineering Corp. *EPRI Project Manager: J. V. Fox*

## COAL COMBUSTION SYSTEMS

### Mixing and Kinetic Processes in Pulverized Coal Combustors

FP-1199 Final Report (RP364-1-3); Vol. 1, $10.50; Vol. 2, $8.75

In this project, mixing and kinetic processes in pulverized-coal combustors were investigated through four series of laboratory combustor tests and two series of cold-flow mixing tests. The development of computer models for use in correlating experimental measurements and predicting local combustion behavior was also undertaken. A one-dimensional model describing pulverized-coal combustion and gasification processes (1-DICOG) was completed and is available for industrial use. Volume 2 of this report is a user's manual for that code. A two-dimensional model was developed for gaseous systems, and methods for extending it to coal systems were outlined. The contractor is Brigham Young University. *EPRI Project Manager: John Dimmer*

### Summary of Equilibrium and Process Model Data Acquisition: Treatment of Recirculated Cooling Water

FP-1251 Interim Report (RP1261-1); $4.50

This report contains the results of a comprehensive literature search and evaluation in the area of cooling-water chemistry. Special emphasis was placed on silica species, phosphate species, softening operations, and chemical cooling-water treatments. The data documented in this report will be used in the development of (1) a computer program capable of describing closed-loop cooling systems; (2) an effective field test program for a portable test facility; and (3) a laboratory test program to generate chemical and operational data not found in the literature. The contractor is Stearns-Roger, Inc. *EPRI Project Manager: Winston Chow*

### Coal Waste Artificial Reef Program, Phase 1

FP-1252 Final Report (RP1341-1); $4.50

As part of a program to explore the feasibility of disposing of fly ash and scrubber sludge in artificial ocean reefs, this project investigated the specific waste materials considered most promising for reef construction. Experiments were conducted both in the laboratory and at the proposed reef site. Prototype reef block development was pursued, and the physical and chemical properties of the blocks were studied to determine their stability and environmental effects. The economic feasibility of the concept was also assessed. The contractor is New York State Energy Research & Development Authority. *EPRI Project Manager: D. M. Golden*

**Coal Ash Disposal Manual**

FP-1257 Final Report (RP1404-1); $13.50

This manual presents detailed information for use by utilities in selecting optimal methods and facilities for storing and/or disposing of coal ash waste products. It discusses site selection and reclamation, chemical and physical properties of coal ash, types of ash disposal systems, cost estimation, federal regulations, environmental monitoring, and current disposal philosophies. Case studies of existing disposal sites are also given. The contractor is GAI Consultants, Inc. *EPRI Project Manager: D. M. Golden*

**Development of Advanced Rotor-Bearing Systems for Feedwater Pumps**

FP-1274 Final Report (RP1266-7); $3.50

This report summarizes the first phase of a four-phase project to develop new rotor bearing and interstage seal configurations that reduce pump vibration and related failures. Analytic methods suitable for evaluating feedwater pump vibration were developed by upgrading and enhancing general-purpose machinery vibration computer codes. These methods were then used to analyze 12-stage boiler feed pumps, and the results were correlated with field measurements. The contractors are Maurice L. Adams, Jr., et al. *EPRI Project Manager: J. P. Dimmer*

## ELECTRICAL SYSTEMS

**Contamination Effects on HVDC Insulator Flashover**

EL-1203 Interim Report (RP848-1); $7.25

An integrated field and laboratory study was conducted to investigate the mechanism of flashover on contaminated insulators under high-voltage dc conditions. Salient factors identified in the field studies were reproduced under simulated conditions in the laboratory, and the effects of each factor were studied. Theories were formulated to explain the mechanisms involved in various observed phenomena—for example, the formation of clean zones and the deleterious effect of nitrates on insulating materials. The contractor is University of Southern California. *EPRI Project Manager: John Dunlap*

**Development of a Current Limiter Using Vacuum Arc Current Commutation, Phase 2**

EL-1221 Final Report (RP564-3); $9.50

Work in this phase succeeded in increasing the current commutation level of a single 72-kV vacuum arc device to 14.5 kA, while reducing the required parallel capacitance to 50 $\mu$f. Fourteen prototype vacuum devices were designed, built, and evaluated. Major parameters varied were device geometry, characteristics of the parallel circuit, electrode actuation speed, waveshape of the applied transverse magnetic field, point on wave of electrode separation, and use of series-connected vacuum interrupters. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: J. W. Porter*

**Development and Testing of a 242-kV, 4-kA Heat-Pipe-Cooled Apparatus Bushing**

EL-1246 Final Report (RP565-1); $6.50

This report describes design, development, and testing of a heat-pipe-cooled, epoxy-insulated bushing rated 242 kV (900 kV basic insulation level), 4 kA. The bushing is unique in that it provides this rating within a below-the-flange diameter of 292 mm. Heat-pipe cooling of the central conductor permits operation at twice the normal current density, while suppressing the development of hot spots to provide an isothermal, steady-state operating mode. The report explains the mathematics involved in designing the capacitively graded core and describes the modeling of the heat pipe and epoxy system. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: E. T. Norton*

**Development and Testing of a Prototype Current-Limiting Protector**

EL-1250 Final Report (RP1142-1); $5.25

A prototype chemically actuated current-limiting protector and a compatible high-speed level-sensing and trigger circuit were developed and tested. This report reviews current-limiting devices and describes the design, performance (in both ac and dc circuits), applications, and economics of the prototype. The contractor is Phoenix Electric Corp. *EPRI Project Manager: J. W. Porter*

**System Studies for HVDC Circuit Breakers**

EL-1260 Final Report (RP326-1); $12.50

Five developments that promise to improve the flexibility and reliability of HVDC systems were studied: metallic return transfer breakers, parallel operation of lines, parallel tapping of HVDC lines, HVDC ring systems, and diode rectifier systems. The role and specifications of HVDC circuit breakers for these applications were investigated by means of a powerful HVDC transmission simulator. The contractor is Institut de Recherche de l'Hydro-Québec. *EPRI Project Manager: Stig Nilsson*

**Flammability of Solid Polymer Cable Dielectrics**

EL-1263 Final Report (TPS77-738); $8.75

This report presents proceedings of a workshop held in October 1977 on the flammability of solid polymer cable dielectrics. It includes the papers presented at the workshop, discussion reports, an overview, and recommendations for future research. The contractor is the National Research Council. *EPRI Project Manager: Felipe Garcia*

**Particle-Initiated Breakdown in Gas Dielectric Cable Insulation: Expanded-Scope Program**

EL-1264 Final Report (RP7802); $5.75

The adverse influence of particle contaminants in gas-insulated power apparatus was investigated in a series of experiments that employed coaxial configurations and dc voltages to 1500 kV. Particle dynamics was shown to be an important factor in the initiation of gas breakdown. Effects in the gas gap as well as along surfaces of solid insulators were studied. Fundamental forces and processes influenced by particle contamination were identified and found to be the same for dc and ac voltage stresses. The contractor is Massachusetts Institute of Technology. *EPRI Project Manager: Ralph Samm*

**Laser Detection of Voids and Contaminants in Polyethylene-Insulated Power Cables**

EL-1266 Final Report (RP794-2); $4.50

This report describes the characteristics and performance of a breadboard model of a cable inspection system that uses a far-infrared laser beam. The scattering of signals from the laser beam, which scans the insulation at a rate determined by the cable extrusion speed, indicates the presence of voids and contaminants. In tests of the model, reliable inspection was achieved in real time; defects as small 63 $\mu$m (2.5 mils) were detected in a 25-kV cable. The system was also able to detect irregularities in the cable conductor shield. The contractor is United Technologies Research Center. *EPRI Project Manager: J. W. Porter*

## ENERGY ANALYSIS AND ENVIRONMENT

**Evaluating Energy and Capacity Shortages: The 1976–1977 Natural Gas Shortage**

EA 1215 Final Report, Vol. 1 (RP1104-1); $6.50

This report summarizes the development of general methodologies to assess the economic and social costs of energy and capacity shortages and presents cost estimates for the 1976–1977 winter shortfall in natural gas supply as a case study. Cost estimation submodels were developed for annual production shortages, winter energy shortages, and peak-day capacity shortages. Data collected from gas suppliers, state agencies, and consumers were used to develop the methodologies and the summary estimates. A comprehensive estimate of the willingness to pay to avoid shortages was developed for producers, employees, consumers, and the general public. The contractor is Jack Faucett Associates, Inc. *EPRI Project Manager: A. N. Halter*

**Initial Study of the Effects of Transformer and Transmission Line Noise on People**

EA-1240 Final Report (RP852); Vol. 1, $5.75; Vol. 2, $4.50; Vol. 3, $3.50

This project is part of an interdivision research program aimed at evaluating and mitigating noise produced by electric utility operations and is an initial attempt to evaluate the effects of transformer and transmission line noise. Volume 1 presents a summary of the entire project and the results of a laboratory study that compared the annoyance value of transformer- and transmission-induced noise with that of shaped noise and other environmental noises. Volume 2 presents the results of a study of sleep disturbance carried out in the homes of volunteer families, and Volume 3, the results of an attitudinal survey of residents living near utility equipment. Although the current findings should be considered preliminary, they do provide some useful estimates of approximate noise levels that are likely to awaken people. The contractor is Bolt Beranek & Newman, Inc. *EPRI Project Manager: L. A. Sagan*

**Characterization of the EPRI Differential Absorption Lidar (Dial) System**

EA-1267 Final Report (RP862-14); $5.25

This report traces testing of the differential absorption lidar (Dial) system, a ground-based device for mapping concentration distributions of such pollutants as $SO_2$, $NO_3$, and $O_3$ in power plant plumes. Data from the tests, which used $NO_2$ sample chambers, are illustrated and tabulated. Also illustrated are the laser transmitter, receiver, and digital data collection subsystems. Recommendations for improvements to increase the device's accuracy and reliability are presented. The contractor is SRI International. *EPRI Project Manager: G. R. Hilst*

**Proceedings: Review and Planning for Aquatic Cooling Systems Effects Subprogram**

WS-78-151 Workshop Proceedings; $12.00

This report presents the conclusions of an EPRI-sponsored advisory workshop held in June 1979 that reviewed work on the effects of thermal power plant cooling systems on aquatic environments, reappraised technical issues in light of the research results, and suggested new approaches and emphases to better address these issues. The workshop delineated the role of ecosystem analysis in program integration and developed three examples of a five-year research program. Appendixes include a summary of the workshop's structure, a list of participants, and a review of current projects. The contractor is Sigma Research, Inc. *EPRI Project Manager: J. Z. Reynolds*

**Ecological Effects of Acid Precipitation**

EA-79-6-LD Workshop Proceedings (SOA77-403); $9.50

This EPRI-sponsored workshop, held in the United Kingdom in September 1978, reviewed existing information on the ecological effects of acid deposition and identified major areas of uncertainty. Subjects covered included precipitation chemistry and deposition, effects on vegetation, effects on soil, surface water and aquatic ecology, fish and fisheries, and modeling of the lake acidification process. The contractor is Central Electricity Research Laboratories (UK). *EPRI Project Manager: R. A. Goldstein*

## ENERGY MANAGEMENT AND UTILIZATION

**Monitoring the Performance of Solar-Heated and -Cooled Buildings**

ER-1239 Final Report (TPS78-834); Vol. 1, $4.50; Vol. 2, $8.75

Volume 1 reviews utility projects monitoring the performance of solar-heated and -cooled buildings. It discusses the range and nature of the systems monitored, the variables measured, and the monitoring equipment employed, as well as the experiences and views of project personnel. Five means of data acquisition are described: manual readings, digital pulse recorders, microprocessor digital pulse recorders, packaged data acquisition units, and combined data acquisition and data reduction units. Volume 2 is concerned with the measurements needed to assess the thermal performance of these buildings. It discusses the selection, calibration, and installation of measuring instruments. The contractor is Altas Corp. *EPRI Project Manager: G. G. Purcell*

**EPRI–SCE Testing and Evaluation of Electric Work Vehicles**

EM-1245 Annual Report (RP1136-1); $4.50

Four electric vehicles were tested and evaluated: a Jet Industries Electra-Van Model 500, a Volkswagen Type 2 Electrotransporter, a Volkswagen Type GM2 Transporter with Daug electric drive, and a Battronic Minivan. Data on the physical characteristics, range, acceleration, payload capabilities, and field reliability of each vehicle were obtained from road tests. Component failures that occurred are described briefly, and expected field reliability is assessed. The contractor is Southern California Edison Co. *EPRI Project Manager: R. J. Ferraro*

**State-of-the-Art Assessment of Hybrid Heat Pumps**

EM-1261 Final Report (RP1201-6); $7.25

This study was conducted to define the characteristics of hybrid heat pumps and to determine energy costs for consumers using commercially available models. Utility benefits from peak load shaving and improved load factors were also determined for various areas in the United States. The potential market penetration of hybrid heat pumps was estimated on the basis of life-cycle cost calculations, potential utility benefits, and institutional barriers to adoption. The contractor is Science Applications, Inc. *EPRI Project Manager: Robert Mauro*

## NUCLEAR POWER

**Optimization of Radially Heterogeneous 1000-MW (e) LMFBR Core Configurations**

NP-1000 Interim Report (RP620-25); Vol. 1, $6.50; Vol. 2, $4.50; Vol. 3, $7.25; Vol. 4, $4.50

The goal of this work is to optimize large LMFBR core design in order to minimize the impact of a hypothetical core disruptive accident. These parameters were studied: tightness of fuel region coupling, number of fuel regions, core height, number and arrangement of internal blanket subassemblies, and number and size of fuel pins in a subassembly. The influence of these parameters on sodium void reactivity, Doppler effects, incoherence, breeding gain, and thermal-hydraulics was of prime interest. Volume 1 describes the design and performance of reference cores. Volume 2 outlines design assumptions and constraints and describes the selection of six basic core configurations. Volume 3 presents the results of core height and pin diameter optimization. Volume 4 describes the final steps of configuration optimization and the results of generic hardware design activities. The contractor is Argonne National Laboratory. *EPRI Project Manager: E. L. Fuller*

**Human Factors Methods for Nuclear Control Room Design: Human Factors Survey of Control Room Design Practices**

NP-1118 Final Report, Vol. 2 (RP501-3); $3.50

This report presents the results of a survey on existing control board design practices and constraints. The survey, conducted by interviews with board designers, covered the establishment of a control room concept, the design process, and design review and evaluation. Issues related to the improvement of human factors engineering are briefly discussed in the report summary. The contractor is Lockheed Missiles & Space Co., Inc. *EPRI Project Managers: R. W. Pack and H. L. Parris*

**Reactor Core Physics Design and Operating Data for Cycles 1 and 2 of the Zion Unit 2 PWR Power Plant**

NP-1232 Final Report (RP519-6); $19.00

Design and operating data for cycles 1 and 2 of the Zion-2 PWR are given in this report. The design data included are limited to the nuclear aspects of the core; thermal, hydraulic, and structural properties are summarized only insofar as they are required for a nuclear analysis. The operating data consist of core physics parameters measured during the startups of cycles 1 and 2 and data from the unit's four years of operation. Measurements related to core power distribution and core responses during certain maneuvers are included. The contractor is Carnegie-Mellon University. *EPRI Project Manager: W. J. Eich*

**Optical Technique for Internal Diametrical Measurement of Steam Generator Tubes**

NP-1244 Final Report (RP1172-3); $2.75

The design and construction of a proof-of-principle prototype of a noncontacting optical probe for measuring the internal diameter of steam generator tubes is documented. Based on a novel combination of a lens and a polygonal mirror, the device makes it possible to amplify variations in diameter while maintaining the image within the tube circumference. It was demonstrated to be capable of measuring internal diameters ranging from 0.64 to 0.80 in with an absolute accuracy of $\pm 0.002$ in. The contractor is Sigma Research, Inc. *EPRI Project Manager: Gary Dau*

**RETRAN Analysis of Semiscale Test S-06-3 (NRC Standard Problem 8)**

NP-1247 Key Phase Report (RP695-1-3); $8.75

This report documents a prediction of Standard Problem 8 for submittal to NRC. The RETRAN computer code and state-of-the-art models were used to analyze the problem, which was designed to simulate one of the first loss-of-fluid nuclear tests. The analysis was made and submitted before NRC released the test data; the data were subsequently added to this report in the form of overlay plots that allow comparison with the RETRAN prediction parameters. The contractor is Energy Incorporated. *EPRI Project Manager: L. J. Agee*

**Sensitivity and Uncertainty Analysis for the Mixed-Oxide Thermal Lattice U-L212**

NP-1248 Key Phase Report (RP975-3); $5.75

A two-dimensional diffusion theory analysis that was performed for the mixed-oxide thermal lattice experiment U-L212 is described. The sensitivity of the eigenvalue $k$ and the four reaction rate ratios to changes in nuclear data were determined. The sensitivity analysis capability was extended to include upscattering and multidimensional ability. A covariance matrix was developed for $^{239}Pu$, and the uncertainty associated with calculated performance parameters as a result of uncertainties in nuclear data was obtained. The contractor is Oak Ridge National Laboratory. *EPRI Project Manager: Odelli Ozer*

**Review of In-Reactor Zircaloy Corrosion and Crud Deposition Experience at AECL**

NP-1254 Final Report (RP1250-2); $8.25

This is a summary of the Canadian experience with fuel cladding irradiation in commercial pressurized heavy water reactors, as well as results from experiments conducted in research reactors at the Chalk River Nuclear Laboratories. The main parameters studied were coolant chemistry, mode of heat transfer, radiation effects, heat flux, temperature, and crud concentration. The contractor is Atomic Energy of Canada Ltd. *EPRI Project Manager: Howard Ocken*

**Status of the Quest for $^{252}Cf\ \bar{\nu}$**

NP-1258 Interim Report (RP707-4); $3.50

This report reviews various measurements of the Californium-252 $\bar{\nu}$ value (the average total number of neutrons produced in a fission event) in order to identify possible reasons for the discrepancies among them and to suggest approaches that may improve the accuracy of this parameter. Measurements by liquid scintillator, $\bar{\nu}$ ratio, and manganese bath are discussed, as well as theoretical and experimental investigations under way to establish the magnitude of a possible foil thickness effect in $\bar{\nu}$ ratio measurements. The contractor is EG&G Idaho, Inc. *EPRI Project Manager: Odelli Ozer*

**Electromagnetic Pumps for Large-Pool Concept LMFBR**

NP-1265 Final Report (RP620-28); $5.25

The application of linear induction electromagnetic sodium pumps to the heat transport systems of a 1000-MW (e) pool-type sodium-cooled fast breeder reactor is evaluated. Three pumps were studied to determine their potential advantages in mitigating scram temperature transients and their impact on plant efficiency and the arrangement of the primary heat transport system. Estimates of the size and performance parameters of the candidate pumps were made on the basis of conceptual designs. The contractor is General Electric Co. *EPRI Project Manager: J. G. Duffy*

**Iodine Species in Reactor Effluents and in the Environment**

NP-1269 Final Report (RP600-1); $8.25

This study measured iodine-131 in effluents from two BWRs and in the air and vegetation near the reactor sites; measured stable iodine at three locations, two near the reactor sites; and evaluated published information on the sources and behavior of iodine in the environment. The appendixes present detailed procedures and measurements. The contractor is Science Applications, Inc. *EPRI Project Manager: Henry Till*

**Nuclear Power Plant–Related Iodine Partition Coefficients**

NP-1271 Final Report (RP962-1); $4.50

An experimental study of the partition coefficient between liquid- and gas-phase iodine is described. Coefficients were measured as a function of the iodine concentration, temperature, and pH of the aqueous solutions. Results indicate that iodine evolution from a pool of water can be controlled by the water's pH and temperature. The contractor is Science Applications, Inc. *EPRI Project Manager: Henry Till*

**Probabilistic Safety Analysis V**

NP-1275 Interim Report (RP1233-1); $6.50

The development of probabilistic risk assessment methods and their application to the nuclear power industry are considered. Two risk assessment workshops are described, and the status of EPRI fuel-cycle risk assessment is summarized. Also included are a comparison of the EPRI and Lewis Committee reviews of the *Reactor Safety Study* (WASH-1400), a summary of fault tree methodology and code development, two analyses of anticipated transients without scram, a seismic hazard analysis, and a report on the rapid response efforts following the Three Mile Island accident. The contractor is Science Applications, Inc. *EPRI Project Manager: G. S. Lellouche*

**Deformation in Type-304 Austenitic Stainless Steel**

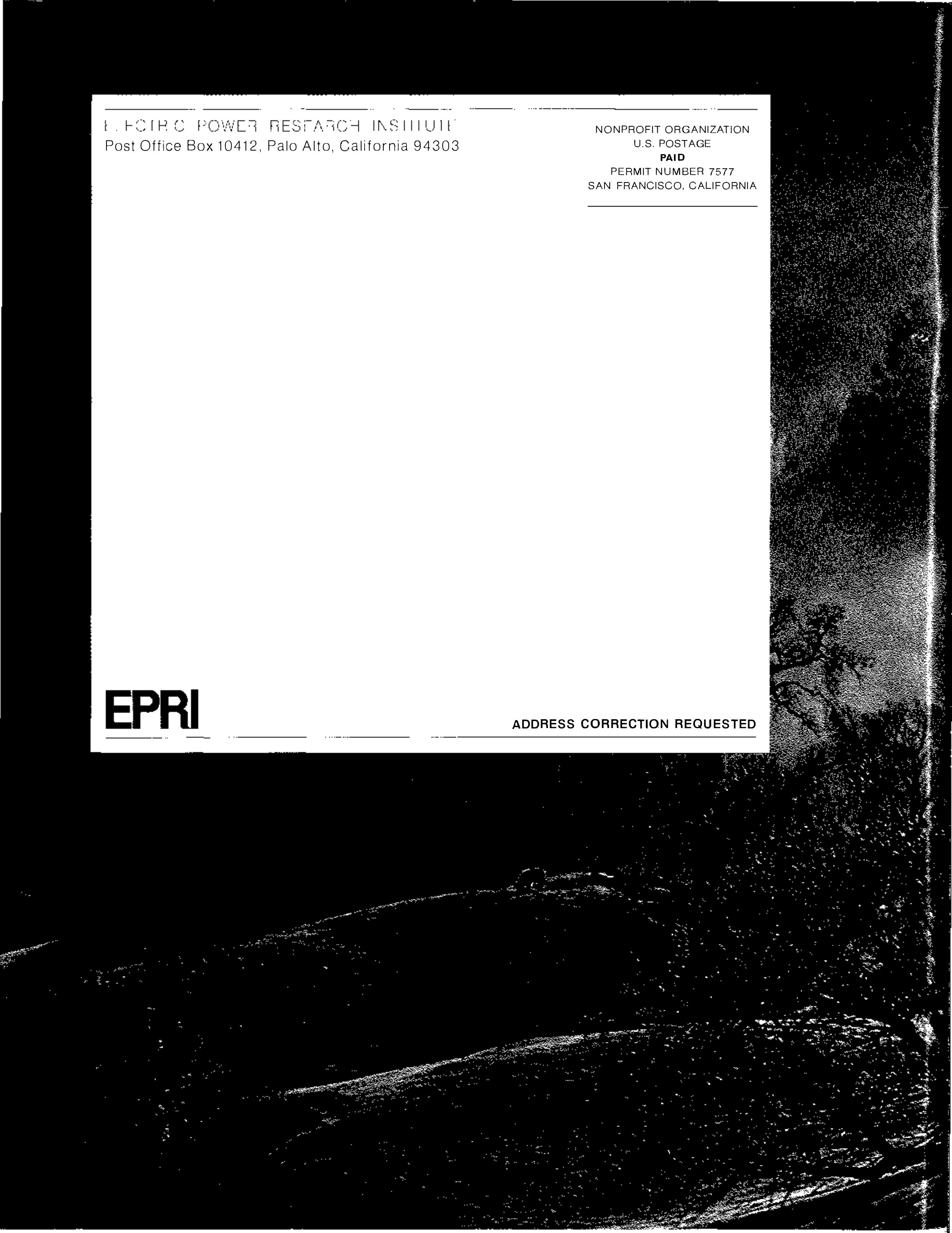
NP-1276 Final Report (RP697-1); $8.25

This report describes the development of a plastic deformation model for type-304 stainless steel. The model relates strain rate to stress, temperature, and several internal material state variables by means of a set of first-order differential equations. Cost advantages of this method of characterizing mechanical properties are discussed, as well as problems in applying the model to practical stress analysis tasks. The contractor is Cornell University. *EPRI Project Manager: S. T. Oldberg*

**Reflood Experiments With a 4-Rod Bundle**

NP-1277 Interim Report (RP1118-1); $7.25

Reflood experiments conducted in a new radio-frequency heating facility are described. Three 4-rod bundles were tested: one with stainless-steel-clad rods, one with Zircaloy-clad rods, and one with two steel-clad rods and two Zircaloy-clad rods. The appendixes include tabulations of all the data, a graphic presentation of quench front locations and velocity, and a thermophysical comparison of $Al_2O_3$ fillers with $UO_2$. Results from the tests were analyzed and reduced, and a correlation is given. The contractor is the University of California at Los Angeles. *EPRI Project Manager: R. B. Duffey*



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