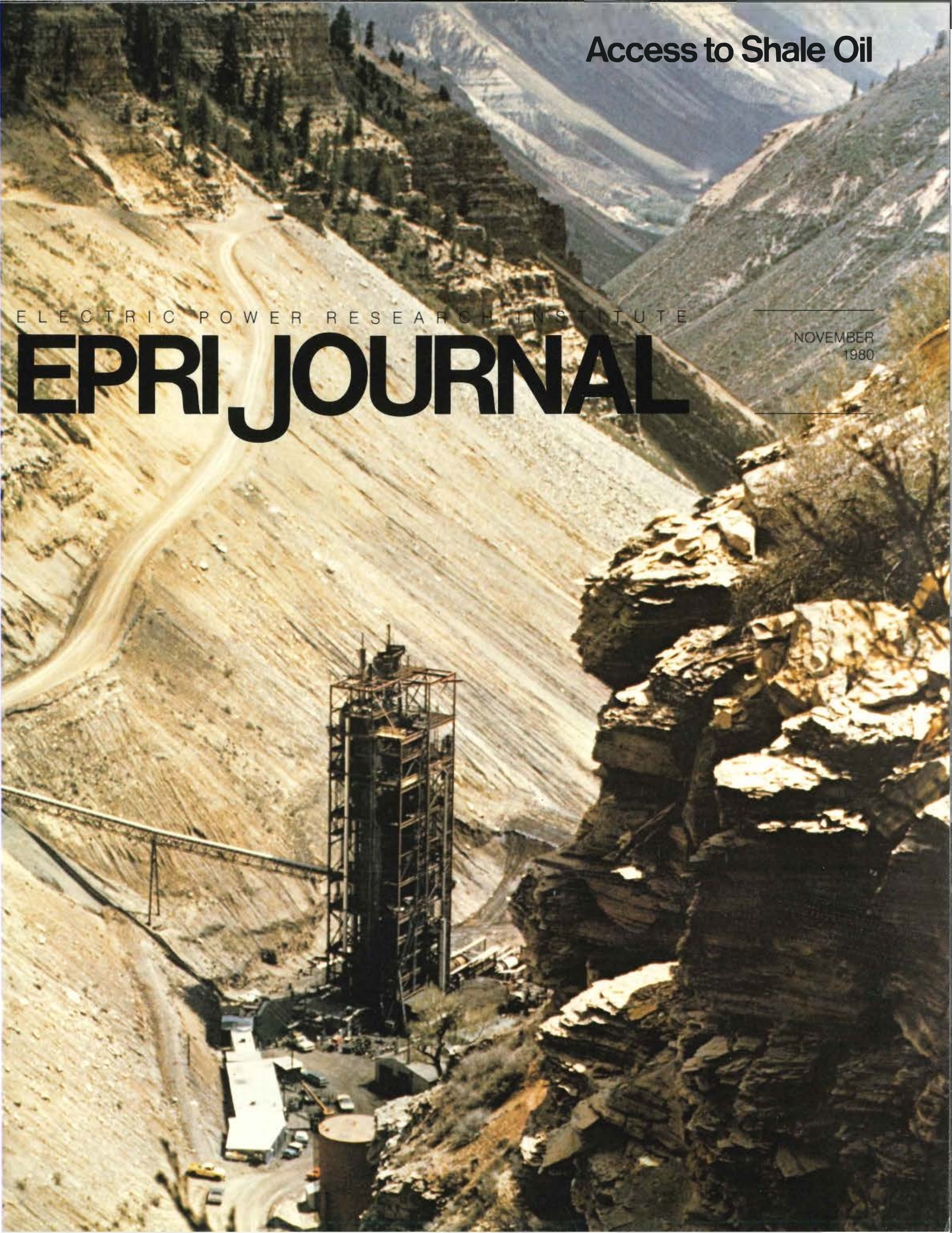

Access to Shale Oil

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Cover: The Colony shale oil Semi-works retort and pilot mine near Parachute, Colorado. The shale moves down from minemouth to crusher to storage to retort. Colony is a joint venture of Exxon Corp. and The Oil Shale Co.

EPRI JOURNAL

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Technical Review

Shale Oil: First of the Synthetic Fuels?

Recent events in the Middle East serve as a sharp warning that production of liquid fuels from oil shale is overdue and should be accelerated. For some 50 years the shale deposits of Utah, Colorado, and Wyoming—as well as others east of the Mississippi River—have been known as a potential fuel resource. Now, based on extensive R&D during the past 10 years especially, an aggressive shale oil industry is ready to undertake modular demonstration projects and build pioneer plants. These will provide the technologic and environmental data base for fuel production that can fill at least a portion of U.S. energy needs. Increasing prices for imported oil are independently contributing to the economic feasibility of shale oil technology. For example, if 500,000 barrels a day could be produced, the nationwide expenditures for imported oil (at its present price) could be lowered by $6.4 billion annually.

Progress toward such a goal is not controlled, however, by technologic, environmental, economic, or even marketing problems, although they are real and must be resolved. The major issues are institutional controversies, and political leadership has yet to make the decisions that will remove these barriers to shale oil commercialization. Firm policies are required to reduce the uncertainties of corporate investments and, by so doing, to commit demonstration and scale-up schedules to a real-time calendar. Only then, as fixed charges fall into place, can economic projections be made that will place an upper bound on shale oil cost.

Shale oil, like synthetic liquids from coal, will indirectly benefit the utility industry by its incremental effect on the national volume and cost of imported oil. It will directly benefit utilities as a fuel for boilers and combustion turbines that with only minor modifications can substitute refined shale oil products for oil or natural gas. Toward this objective, EPRI-sponsored research has included projects to establish a shale oil combustion data base. As examples, Southern California Edison Co. has operated an oil-fired boiler on shale oil and Long Island Lighting Co. recently completed burn tests in a combustion turbine. Both these tests were successful; in particular, the techniques used to deal with special properties of the fuel, such as its nitrogen content, were adequate for maintaining air quality standards.

More extensive tests to confirm where and how utilities can use shale oil await the larger production that will flow from demonstration and pioneer plants in the West. It is clear that the electricity industry represents a significant market for what may be the first U.S. synthetic fuel.

Seymour B. Alpert
Technical Director
Advanced Power Systems Division

Authors and Articles

Westward emigrants crossing the Rocky Mountains learned from Indians about "the rock that burns." They made use of it too, lubricating their wagonwheels with residues liberated from those burning rocks. The extraction and use of shale oil in the United States thus began some 140 years ago. Its technology has taken a little longer to get started.

Today, several variants of that technology are front runners in the synthetic fuel marathon, and they are backed by what is now seen to be an unmatched resource base. **Cracking the Shale Resource** (page 6), written by Mary Wayne, surveys the resource, the technology of shale oil extraction, and the problems that must be resolved if today's attractive cost estimates are to be confirmed in the experience of electric utilities and other prospective users. For background material and guidance, Wayne worked with two staff members of EPRI's Advanced Power Systems Division.

Bert Louks has monitored the economics of energy resource developments since 1966, when he was supervising engineer for market research and planning for the refinery and chemical division of Bechtel Corp. Later an engineer-economist for six years with SRI International, Louks first came to EPRI in October 1973 to guide research in fossil fuel economics. He returned to SRI briefly as director of industrial and utility energy systems, then rejoined EPRI in November 1977 as project manager for novel power cycles. Louks' earlier experience includes eight years with Union Oil Co. of California and four years with Pacific Delta Gas, Inc., where he had responsibilities in process R&D, petroleum and gas production planning and marketing, and venture analysis. Louks holds a BS in chemical engineering from the University of Missouri.

William Reveal, project manager for engineering and economic evaluation since June 1978, was previously with Shell Development Co. for 26 years. As a senior staff research engineer, he undertook development, economic evaluation, and engineering guidance of oil and coal conversion processes in the R&D stage. His earlier experience includes 3 years in pilot plant research and operation with Union Oil Co. of California and 4 years on the engineering faculty of Montana State University. Reveal holds BS and PhD degrees in chemical engineering from Purdue University and the University of Minnesota.

■

Cleaning house is not an exercise in efficiency for most of us, except to get it over with quickly. We rely on a vacuum cleaner for that. And if we're methodical, we put in a new filter sack before we attack the shag rugs and deep-pile carpets so there is lots of airflow without taxing the motor. **Upsurge in Baghouse Development** (page 14) elevates the vacuum cleaner to a new level for filtering the ash out of exhaust gases from a coal-fired power plant.

Carr

Once-a-week housework is now a 24-h routine, and the efficiency of dust collection must be 99.99%. At 500-MW scale, the familiar disposable paper sack becomes a carefully designed array of 10,000 or more 35-ft-long (11-m) fiberglass bags. What's more, according to writer William Nesbit, even though pressure drop through the filter fabric must be minimized, research shows that the filter cake itself (up to a point) is an important contributor to dust collection efficiency.

To trace the path of R&D that is rapidly bringing baghouses up to the scale and reliability needed by electric utilities, Nesbit conferred with Robert Carr, project manager for particulates and combustion in the Air Quality Control Program of EPRI's Coal Combustion Sys-

Louks

Reveal

tems Division. Carr joined the Institute staff in May 1974, and he has guided much of its sponsored research in fabric filtration since then. Previously, with KVB, Inc., he consulted with utilities on boiler emissions; still earlier, he was a University of California research assistant on the measurement and analysis of combustion emissions. Carr has a BS and an MS in mechanical engineering from the University of California at Berkeley.

■

Developments in synthetic fuels can easily be seen as a head-on competition between the coal conversion processes that yield liquids and those that yield gases, with perhaps just a nod to the ones that yield solids. This would be a mistake. **Directions in Synfuel Development** (page 21) reviews the reasoning of major electric utilities in their call for both forms of fuel and in their support of technologic and institutional moves that will bring coal-derived fuels, as well as shale oil, to commercial reality.

The *Journal*'s feature editor, Ralph Whitaker, drew this report from speeches delivered at a recent conference of U.S. and German synfuel process developers. Cosponsored by EPRI and the Federal Republic of Germany's Ministry for Research and Technology, the conference owed much of its organization to Seymour Alpert, technical director of EPRI's Advanced Power Systems Division during most of his 7 years with the Institute. Previously with SRI International and Chem Systems Inc. in the 1970s, Alpert earlier was with Hydrocarbon Research, Inc., for 15 years, becoming manager of its experimental R&D program for processes to desulfurize and hydrocrack heavy petroleum feedstocks.

■

Elie Abel: Keeping the Lines Open (page 26) sketches some insights of a professional communicator who is on EPRI's Advisory Council. This profile was drawn by Jenny Hopkinson, *Journal* feature writer, from her interview with Abel at his office in the Department of Communication at Stanford University.

Technology transfer, for example, is a time-consuming communication process at best, even when there is essential agreement to begin with at both ends of the line from laboratory to user. From his own work, Abel shows how the process can be stalled if it becomes politicized, even inadvertently, or by someone who is only listening in on the line.

Shale oil deposits in the western United States, totaling an estimated 1800 billion (10^9) barrels, far surpass the petroleum reserves of the entire Arab world. What's more, the technology already exists for turning out domestic shale oil that can do virtually everything imported petroleum can do. Until June 1980 all that was lacking was a large enough economic incentive to spur private developers into commercial production.

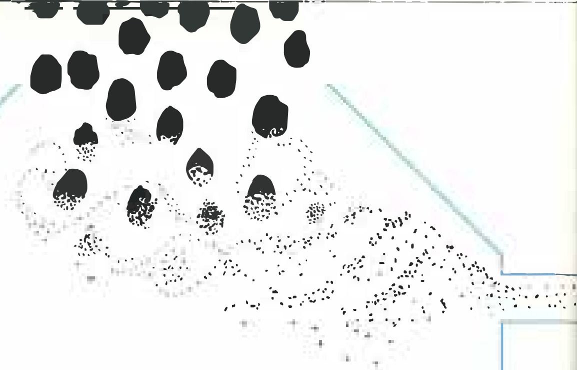
Now that the federal synfuels bill has provided the necessary boost, the infant shale oil industry is rapidly finding its feet. How far can we expect it to go, and how fast? Optimistic production estimates range as high as 3 million (10^6) bbl/d by the year 2000. Probably by that time, a daily yield of about half a million barrels is more likely.

Compared with the 7–8 million barrels of foreign oil we are now consuming daily, half a million by the century's end may seem like a mere trickle. But it's a beginning, and one that holds promise for expanded flow of affordable liquid fuels if developers can overcome present constraints: a shortage of trained and qualified personnel and environmental concerns over land use, water use, water quality, and air quality.

What is shale oil?

Shale oil comes from a solid fossil substance called kerogen. By weight, a typical kerogen sample may contain about 80% carbon, 10% hydrogen, 6% oxygen, 3% nitrogen, and 1% sulfur. Kerogen is found embedded in a sedimentary rock known as oil shale—a fine-grained, thinly layered mixture of dolomite, calcite, quartz, and clays.

How the kerogen got into the rock is a story that began some 50 million years ago when decaying plant and animal remains settled to the bottom of vast prehistoric lakes and were covered with layers of lake bed sediments. Over the ages, the organic matter became the kerogen and the sediments hardened to become the host rock. Any kerogen-



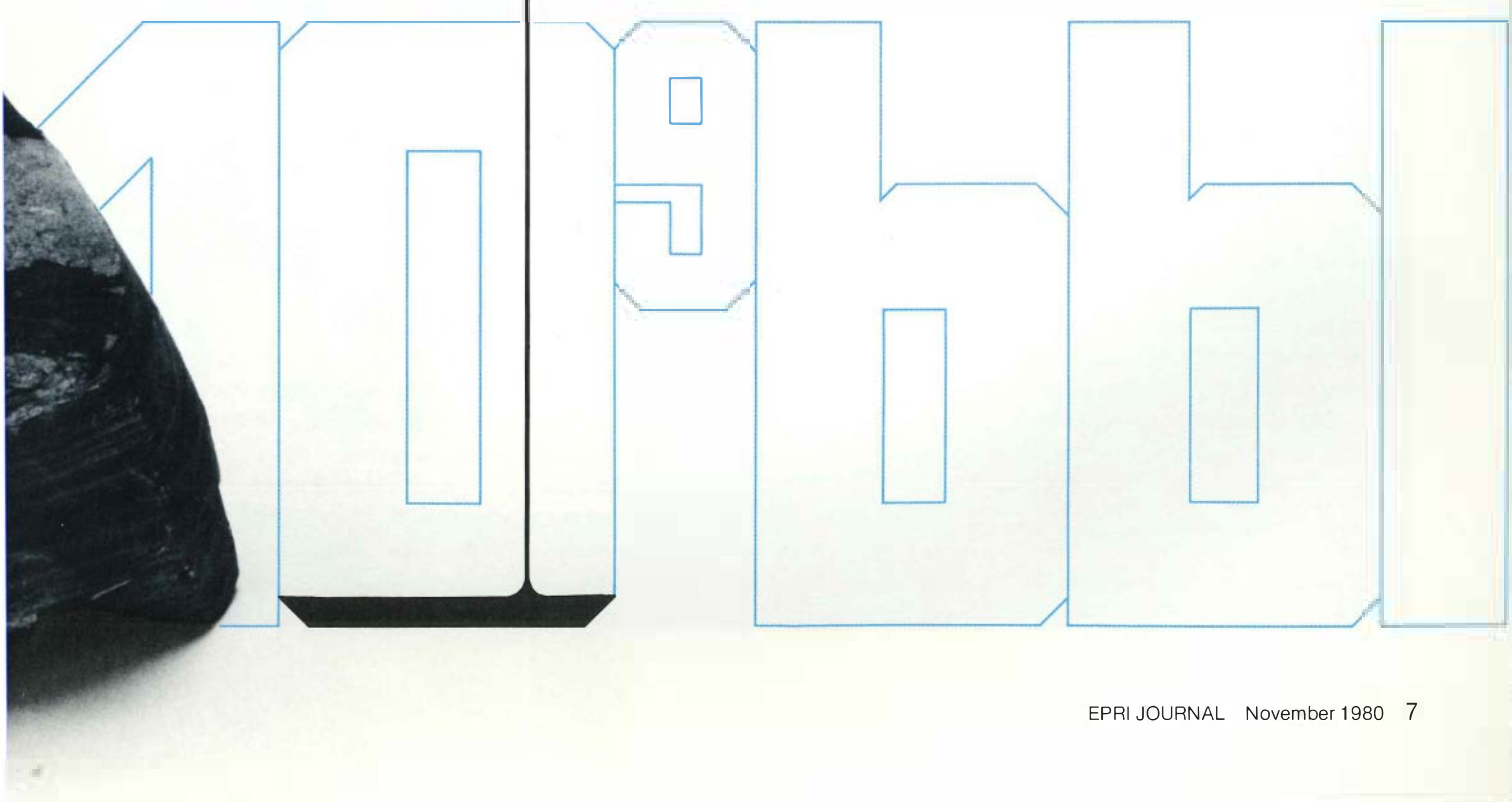
Extraction of shale oil requires the use of a retort, a chimney-like vessel in which fragments (0.25–3 in) are heated to over 900°F. Vapors are released and then condensed for recovery. Hydrotreatment is subsequently used to upgrade the fluids and create a lighter, more manageable product.

Traditionally, the rock is mined, crushed, and heated in freestanding retorts. The alternative in situ method uses the earth itself as a retort; a columnar receptacle is blasted out underground and the shale rubble is heated in place.

After surface retorting operations, the spent shale must be disposed of in an environmentally acceptable manner

Cracking the Shale Resource

Entrapped in the oil-bearing shales of the Rockies is a fuel resource of staggering proportions, but one that will not willingly flow at ordinary temperatures. The host rock must be fractured and heated, requirements that portend the development of an immense mining and materials processing infrastructure. Pioneer plants are being built on the expectation that shale oil prices will be competitive with petroleum before the decade is out. Nevertheless, only a relative trickle of this vast pool of immobile oil will be tapped by century's end.



bearing rock qualifies as oil shale, regardless of the particular combination of sediments that may make up a given sample.

Kerogen is a heavy hydrocarbon that will not willingly flow out of its rock at ordinary temperatures, nor can it be extracted with solvents. It must be driven out by a process known as retorting. At high temperatures, around 900°F (482°C), kerogen breaks down into shale oil, combustible hydrocarbon gases, and a black carbon residue.

The difference between kerogen and petroleum, which is also composed of fossilized organic matter, is that the rockbound resource was never subjected to the intense natural heat and pressure that created petroleum. Oil shale is usually found at surface level or only a few hundred feet below, whereas petroleum deposits are often buried beneath the pressure of some 10,000 ft (3048 m) of overlying earth. Retorting oil shale subjects it to intense heat, but there is no attempt to replicate the pressure that created petroleum. Oil from kerogen is equally as good a fuel as petroleum—in fact, it is in some ways superior because shale oil is naturally lower in sulfur than many petroleum oils and releases fewer sulfurous air pollutants when burned.

The nation's largest known oil shale deposits were left behind in the western United States by a long-vanished freshwater lake that once covered most of Colorado, Utah, and Wyoming. This lake bed geologic area, the Green River formation, embraces some of the richest deposits of oil shale in the world—up to 1500 ft (457 m) in thickness. The eastern United States also contains oil shale in a wide triangle between Michigan, Pennsylvania, and Mississippi, particularly in the rocky bed of what was once the Chattanooga Sea. But these deposits yield less oil by ordinary retorting methods.

Quality of shale oil deposits is determined by the Fischer assay. In this test, a sample of the oil-bearing rock is crushed, dried, and heated according to procedures laid down by the U.S. Bureau of Mines. The amount of oil it yields gives an assay value in gallons of oil per ton of rock. Western shales yield between 25 and 40 gal/t, whereas eastern shales average less than 15 gal/t. Generally, deposits that yield fewer than 20 gal/t are considered poor candidates for commercial development.

A history of false starts

The first shale oil patent was granted in England in 1694 for distilling "oyle from a kind of stone," but wringing fuel from a rock was not attempted commercially until the 1800s. American pioneers crossing the Rockies learned from the local Indians of "the rock that burns," put it in their campfires, and greased their wagonwheels with the waxy exudation. A fledgling industry soon took root, with the shale oil output used mostly for the production of kerosene. Soon after the nation's first petroleum gusher burst forth in Pennsylvania in 1859, however, cheap petroleum inundated the shale oil industry.

The invention of the internal combustion engine sparked increased demand for liquid fuels during the 1920s, and again the nation turned to shale oil for a fuel boost. But once again a new oil find, this time in Texas, supplied petroleum that was cheaper than shale oil laboriously drawn from rock.

Even today's federal program for synfuel development is not a new idea. The first such scheme, embodied in the Synthetic Liquid Fuels Act of 1944, was conceived during the Roosevelt administration in the last years of World War II. It came too late to secure fuel reserves for the war effort, but federal support did enable the U.S. Bureau of Mines to set up operations in 1945 at Anvil Points, Colorado, which led to the development of modern methods for large-scale shale oil production. Although little used since the 1950s, the technology and the experience gained at Anvil Points provided a jumping-off point for the full-scale commercial shale oil industry that now appears imminent.

Surface versus underground recovery

Recovering shale oil from kerogen-bearing rock is basically a simple technology, although controversy remains as to which of its many variations is the most reliable, the most economic, and the most sound from an environmental viewpoint. Some developers plan to use the tried-and-true method of shale oil recovery, surface retorting. Others are pioneering the riskier process of underground retorting, also known as in situ retorting.

A retort is a chimneylike vessel in which shale fragments with a diameter from 0.25 to 3 in are heated to release the oil as a vapor, which is then cooled and condensed for recovery. The principles of heating and condensation are the same in all retorting operations. What distinguishes surface from in situ processing is the location of the retort. Traditionally, the rock is mined, brought to the surface, crushed, and heated in free-standing retorts. The in situ method uses the earth itself as a retort by blasting out a columnar receptacle underground and heating the shale rubble where it lies.

Experiments with pure in situ techniques have shown that it is very difficult to get the proper heat into the formation or the products out: solidly packed rock resists heat injection, and the impermeable shale, if not sufficiently fractured, will refuse to give up its oil and gas.

In the Occidental Petroleum Corp.–Tenneco, Inc., project now being launched in Colorado, the recovery technology is modified in situ—modified because some actual mining is necessary before the explosive charges are set in order to provide void volume (space) for the subsequent rubblization of the remaining rock.

The Occidental process, vertical modified in situ, carves a retort by first mining out 20–25% of the rock at an underground site and then blasting the rest to rubble. The underground chimneys thus created are approximately 30 stories deep, extending to a base about the area of a football field. Occidental hopes to recover a total of 50,000 barrels of oil from each retort. To this end, the company is still experimenting with ways to achieve more uniform fragmentation of the rock for maximum yield.

This type of retorting begins when fuel and air are introduced to the rubble at the top of the chimney and ignited. When a predetermined amount of rubble has been processed, leaving residual carbon on the spent shale, the fuel is turned off. The continuing flow of air allows a self-sustaining combustion process, using the residual carbon as the major fuel. Part of the off-gas is typically recycled to control the oxygen concentration of the inlet gas.

The combustion front moves slowly down the vertical retort at a rate of about 1–2 ft/d. For simplicity, four zones can be identified in the retort: the burned-out zone at the top; the combustion zone, where the actual burning takes place; the retorting zone, where the kerogen decomposes to a vapor; and the cooling zone, where the vapor is condensed to liquid shale oil. The oil then flows by gravity to the bottom of the retort where it is collected in a sump and pumped to storage. The off-gas not recycled in the retorting process can fuel a gas turbine for on-site electric power generation.

The product: raw and thick

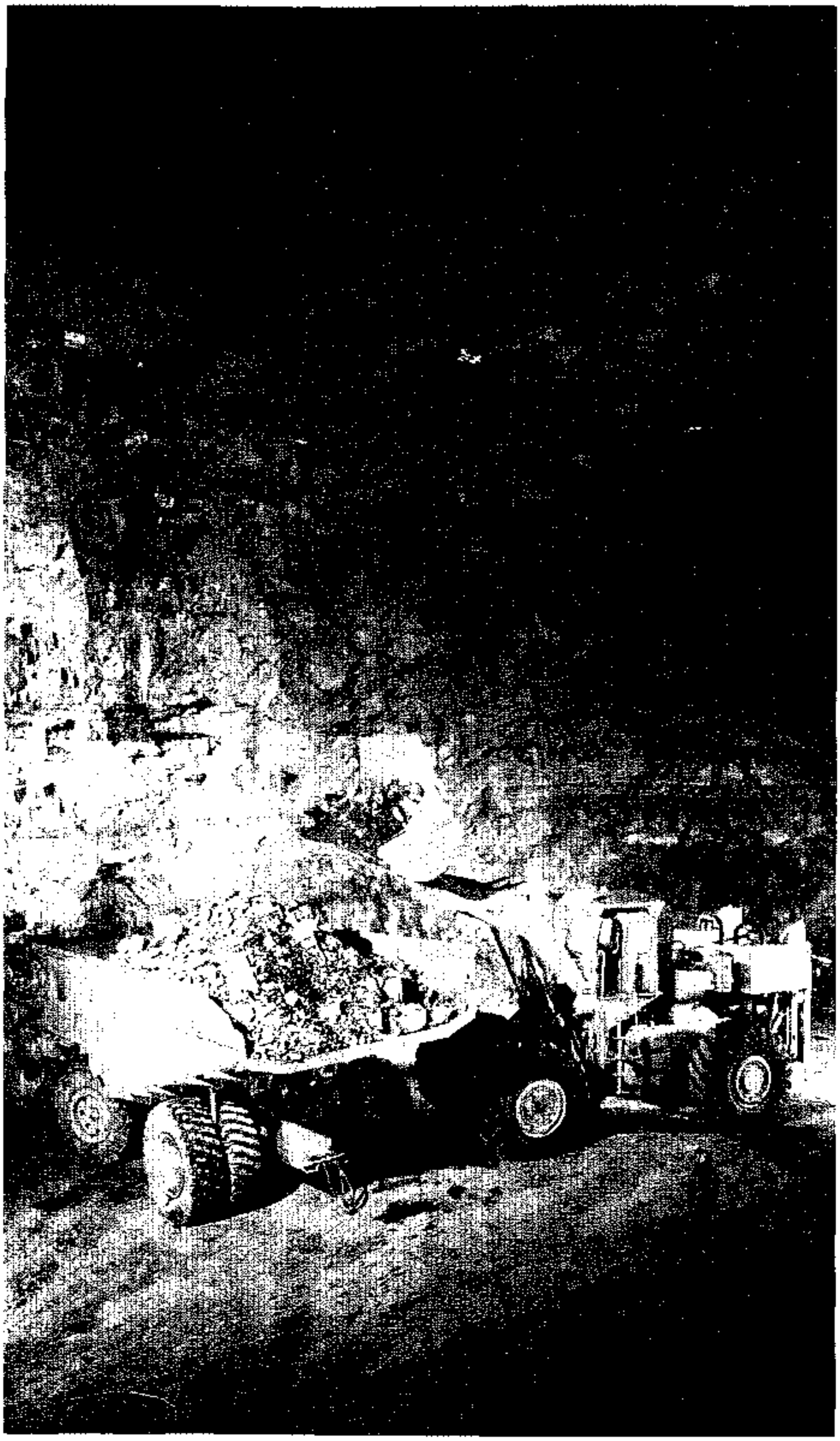
The raw shale oil collected from a retort is too heavy and thick to flow through a pipeline to a refinery. The solution is to upgrade it, usually right at the site, to create a lighter, more manageable product.

Hydrotreatment, the main upgrading step, consists of passing the raw shale oil over a catalyst in the presence of hydrogen. The oil becomes lighter and gives up some of its sulfur and nitrogen in the process. These two contaminants are eventually recovered as sulfur and ammonia; refining them out of the oil is desirable because it produces a cleaner-burning fuel.

Even when raw, shale oil has a sub-

The nation's oil shale deposits were left behind after large inland lakes vanished. The richest deposits are found in the Green River formation of the Rockies, where an estimated 1800 billion (10^9) barrels lie. The darkest shadings are known high-grade deposits of oil shale (30 gal/t). Lighter shadings denote lower-grade deposits.

Shale oil production on a large scale would entail one of the largest mining operations ever conceived. For example, producing two million barrels a day of shale oil would very roughly require the equivalent mining output of today's U.S. coal industry. This poses one of the principal constraints on rapid development. Shown is the interior of Colony's pilot mine at Parachute, Colorado.



stantially lower sulfur content than many petroleums, a feature that makes it viable for use as a boiler fuel fresh from the retort. In 1976 Consumers Power Co. of Michigan burned 5000 barrels of raw shale oil retorted by the Occidental process and found that it met all environmental standards, including those for the emission of sulfur and nitrogen oxides. But for most applications, upgrading and refining are necessary. Topping the list of products that refined shale oil is expected to supply for the United States are diesel fuels, jet aircraft fuel, and high-octane gasoline.

Scope of development

Commercial shale oil prospects cluster in the rich Piceance Creek basin of Colorado, the heart of the Green River formation and the home of an estimated 640 billion (10^9) barrels of oil. Here the Occidental-Tenneco project hopes to reach a production goal of 57,000 bbl/d by 1986. To reach this goal, it will have to have about 40 of its giant retorts burning simultaneously beneath the arid, sagebrush-covered soil.

Rio Blanco Oil Shale Co., a partnership of Gulf Oil Corp. and Standard Oil Co. (Indiana), is also exploring the modified in situ technique. Rio Blanco has over $100 million slated to build and operate three underground test retorts near Rangely, Colorado. They will be deeper than the Occidental chambers and have a greater void volume, perhaps as much as 40%, mined out before blasting. If these retorts, which are scheduled for operation by the end of 1981, yield satisfactory results, Rio Blanco plans to scale up to commercial size. Other alternatives are still being evaluated. Commercial size generally means a plant that can produce at least 50,000 bbl/d, and the current price tag on a plant of that scale runs from $1.2 to $1.5 billion.

Sticking to more traditional methods, both Union Oil Co. and the Colony Development Operation have surface retorting projects planned. The Union Oil effort near Grand Valley, Colorado, calls for a 9000-bbl/d prototype facility that will cost about $100 million and use externally heated gases to extract the kerogen from the shale in free-standing retorts. Colony, a joint venture of Exxon Corp. and The Oil Shale Co. (Tosco), plans a different type of indirect heat application in its surface retorting. Relying on the principle of solids-to-solids heat exchange already tested at its Parachute Creek pilot plant, Colony will use the patented Tosco-II process to cook the shale by constantly circulating hot ceramic balls through the retort. This process operates most efficiently on rather rich shale, that having a Fischer assay value of 35 gal/t or better.

Other surface retorts include one by Paraho Corp., operated by Standard Oil of Ohio. The Paraho process is an improved version of the vertical kiln surface retorting technology developed by the Bureau of Mines at Anvil Points. During demonstration at Anvil Points 100,000 barrels of shale oil were produced for Navy testing as diesel and jet aircraft fuel. It is estimated that a commercial Paraho plant with 24 full-scale retorts could eventually produce 100,000 bbl/d.

Superior Oil Co., also active in western Colorado, has plans that embrace a broader scope. Besides producing oil from the shale deposits, the Superior process is designed to recover nahcolite, dawsonite, and soda ash from spent shale. Nahcolite works very well in power plant stack gas scrubbing; dawsonite is an aluminum precursor; and soda ash is used in manufacturing, photography, and water softeners. Superior proposes to build several $350 million modules, each capable of producing 12,000 bbl/d of shale oil, 4900 tons of nahcolite, 600 tons of alumina from the dawsonite, and 1000 tons of soda ash—all from about 26,000 tons of raw shale.

Other companies active in the western states include Equity Oil Co., which has been working on the injection of superheated steam at 1500 psi (10.3 MPa) and 1000°F (538°C) to release the oil, and Texaco, Inc., which is experimenting with retorting the shale in place by radio waves. Geokinetics, Inc., and DOE's Laramie Energy Technology Center are exploring the use of a horizontal in situ technology to exploit the thin, shallow shale seams of eastern Utah, the same method that the Ute Indians will probably use in developing their own deposits in that area. Multi Mineral Corp., a subsidiary of Charter Oil Co., is developing an integrated in situ process to produce shale oil, nahcolite, and dawsonite. Shale Oil Science and Systems, Inc., has adapted charcoal kiln technology to oil shale retorting, using indirect heat in a closed-loop recycle system with a steam cycle to recover residual carbon. The company plans to demonstrate this technology with 3 million (10^6) tons of shale from Anvil Points.

Tapping eastern shale

Meanwhile, on the other side of the Mississippi, the Institute of Gas Technology (IGT) has come up with a surprise for all those who assumed that the Devonian shales of the eastern United States were too low in grade to be commercial. As most eastern shale falls below the Fischer assay commercial cutoff level of 20 gal/t, eastern deposits have usually been ignored in discussion of the nation's shale oil resources. But now IGT researchers believe that a new method, hydroretorting, could change the outlook for eastern shale development.

Hydroretorting introduces hydrogen during the actual retorting process so that a higher fraction of the total carbon in the shale can be recovered. In effect, hydroretorting digs deeper into the eastern oil shale than do conventional retorting techniques, thus boosting the hydrocarbon yield. With this process, even low-grade shales may be able to provide oil in quantities competitive with the yields from higher-grade western deposits.

U.S. Geological Survey estimates the known resources of Devonian shale oil in the eastern United States to be 400 billion (10^9) barrels, with another 2600 billion probable. IGT believes hydroretorting could multiply this yield, extracting 2.5 times the amount of oil the Fischer assay would predict. This means that the actual yield from known resources alone (400 billion $\times$ 2.5) could zoom to about 1 trillion (10^{12}) barrels, more than all the oil in Saudi Arabia.

Digging into deposits on both sides of the Mississippi can bring rich rewards, although the first thrust of development will probably be in the West. And as today's pilot and demonstration plants scale up toward full commercial output, the environmental constraints that developers can already feel may begin to bind more tightly.

Environmental snags

Disposing of resource-bearing rock after the resource itself has been extracted is a problem for all kinds of mining operations. Broken rock simply won't fit neatly back into a mineshaft that has been carved out of compact, solid rock. In the case of oil shale, the problem is magnified by the shale's tendency to expand during processing. This tendency has been colorfully labeled the popcorn effect, a substantial exaggeration because shale can only expand to about half again its original volume, whereas a kernel of corn expands to several times its original volume when popped.

Assuming a shale grade of 35 gal/t, a surface retorting operation must use 60,000 tons of rock a day to produce 50,000 barrels of oil. This leaves the operators with some 51,000 tons of spent shale on their hands, day after day. If the same operation uses a lower grade of shale, there is an even greater volume of spent shale for disposal.

Interest in underground retorting is in part a response to this surface disposal problem. Some regard in situ retorting as the wave of the future not only because it can tap lower-grade deposits than surface methods and requires fewer trained people but also because of its hoped-for environmental advantages: less use of land and water, less air pollution, and, proponents say, less danger of water supply contamination.

To produce a single barrel of oil, a surface retorting operation must mine from one to two tons of rock. Since modified in situ techniques mine out less rock, the disposal problem is proportionately smaller. About 60–75% of the shale does remain in the ground, and part of the mined-out balance can probably be returned as backfill, whether retorted or not. Whatever remains on the surface can then be handled in the same way that surface retorters plan to handle their waste shale—revegetation with native grasses and flowers, or even with food crops, such as wheat and barley.

Water use is a related issue. In the arid western land where the shale oil industry is trying to establish a foothold, water is a precious resource, and any major new use is viewed as competitive with existing agriculture.

About 40–50% of the water consumed by shale oil production is used for waste disposal following surface retorting. It is used to wet down the hot, dusty spent shale so it can be moved and/or prepared for revegetation. In situ retorting is expected to take only one barrel of water for every barrel of oil produced. Estimates of the water requirement for large-scale surface retorting range from two to nearly four barrels for every barrel of oil, although water use will probably become more efficient as the industry matures.

Recent studies of the Colorado situation suggest that water availability will not really be a serious constraint, at least not during this century. The Colorado Department of Natural Resources has completed a study for DOE and the U.S. Water Resources Council in the Upper Colorado River region and found that sufficient water will be available to support production of at least 1.5 million (10^6) bbl/d—three times the probable production level for the year 2000—without any displacement of agriculture.

A more optimistic study by the Colorado Energy Institute projects enough water to operate a 2-million-bbl/d shale oil industry. And the federal Office of Technology Assessment (OTA) envisions sufficient water to support oil shale operations until at least 2025. By the time the industry reaches a production level sufficient to run up against real water constraints, it is reasonable to assume that advances in dry-cooling techniques will help alleviate the water-use issue.

Water quality is also a concern. The fear is that spent shale fragments, besides taking up space, offer a great deal of exposed surface area that invites leaching—rainfall could leach soluble salts out of the shale and into groundwater supplies. This is a potential problem with both aboveground disposal piles and spent shale returned to mine shafts. Backfilling mine shafts will work only if the permeability of the spent shale is sufficiently low to prevent salt release or if the mobile salts can be permanently bonded to the host rock.

In situ developers hope to avoid this problem, at least with the 60–75% of the shale that never leaves the ground. Occidental reports that its tests of the spent shale in underground retorts show the carbonates have been converted to insoluble silicates as a result of prolonged exposure to the high temperatures—over 1300°F (704°C)—that occur during in situ retorting. If leached, according to Occidental, the spent shale produces not the limey, highly alkaline solution that is feared, but a leachate with a pH comparable to that of the local Colorado groundwater.

Air quality is also an issue in oil shale development, with the major hazard being particulates (*EPRI Journal*, October 1978). Plant construction alone can release millions of these tiny airborne particles, followed by additional dust releases from mining, crushing, retorting, and shale disposal operations. The retorting and hydrotreating processes can also release troublesome gases, among them hydrogen sulfide, sulfur dioxide, nitrogen dioxide, and carbon monoxide. Existing technology can control most of these emissions, but controls are costly. So a move to underground retorting with minimal mining is also seen as a possible relief from air quality problems.

Land, water, air, and other environmental hurdles will probably not be a limiting factor in oil shale development during its early stages. EPA sources have expressed confidence that there will be no insurmountable environmental problems at production rates up to 200,000 bbl/d. And latest EPA estimates suggest an even higher limit—as high as 800,000 bbl/d—before air quality constraints (the first that are expected to become critical) could actually begin to stunt production.

There is no guarantee, however, that a shift toward in situ techniques will be able to contain environmental concerns as the industry grows ever larger. In situ techniques are themselves experimental. It will take time to tell whether in situ operations on a large scale are more environmentally benign than surface methods and whether the new technology, with its potential for unforeseen problems, can be expanded smoothly and economically to commercial scale.

The sheer volume of expanding shale oil operations could magnify a wide range of concerns. Not the least is the boomtown result of explosive socioeconomic growth in pockets of the largely uninhabited western regions. Predictably, there is some strong opposition to the development of these wide open spaces. And since nearly 80% of the nation's oil shale resources rest beneath government lands, federal leasing policy will continue to play a critical role in the rate and level of industry growth.

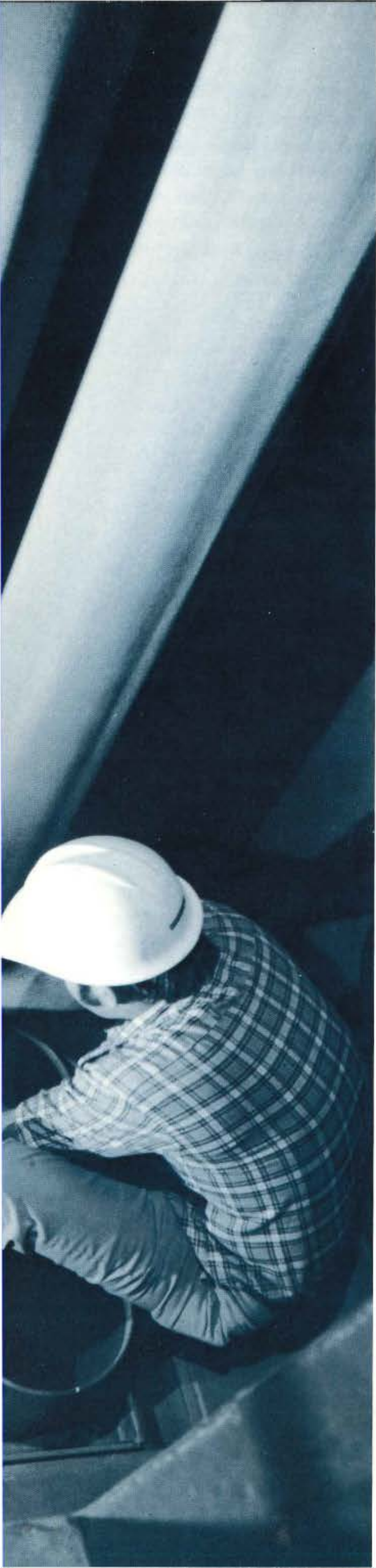
The petroleum factor

Besides the direction of public policy—providing access to shale deposits, offering economic incentives to development, loosening the environmental constraints that could impede development—the other great unknown in the shale oil picture is the petroleum factor.

Shale oil is being touted as an eventual petroleum substitute, so the fortunes of shale still depend on the price and availability of petroleum. B. M. Louks, EPRI project manager for engineering and economic evaluations of advanced fossil power systems, expects shale oil to become price-competitive with petroleum in the very near future—before the decade is out. Economist Milton Searl, technical manager in EPRI's Energy Study Center, supports this judgment with a rough projection that the price curves of OPEC oil and domestic shale oil will cross during the 1980s in the range of $30–$35/bbl (1980 dollars). Shale oil, unlike some more exotic entries in the race for new energy sources, looks like a solid prospect that can pay its own way without the need for long-term subsidies.

If the United States should come upon vast new petroleum deposits in its own backyard or if the world oil situation should suddenly ease with regard to price and supply constraints, the domestic shale oil boom could once again fizzle. But such possibilities appear increasingly remote. The federal government and private developers alike are now backing shale oil, the dark horse that is finally expected to be a winner in the nation's energy sweepstakes. ■

This article was written by Mary Wayne. Technical background information was provided by Bert Louks and William Reveal, Advanced Power Systems Division.



UPSURGE IN BAGHOUSE DEVELOPMENT

Now capable of filtering fly ash at 99.99% efficiency, the ancient baghouse is being adapted to modern utility practice. The research challenge is to find the optimal design that will reduce size and cost and will improve durability and reliability.

Coal must be cleaned if it is to receive broader acceptance as a fuel for electric utilities. A key element for this acceptance is the capture of particulate matter released in the combustion process.

Clearly, the general public has an overwhelmingly negative impression of coal as a dirty fuel; and equally clearly, much could be done to reverse this sentiment if stacks at coal-fired plants are clear and clean of particulates.

For some time electrostatic precipitators have been used successfully by utilities to collect particulate emissions from coal-fired boilers. But in recent years, air quality standards have been stiffened significantly; there has been a shift from high-sulfur to low-sulfur coals; and regulatory attention has begun to focus more and more on emissions of the fine particulates known to be most responsible for both health and visibility problems.

As a result of these factors, new attention is being given to an old, alternative technology: fabric filters, or baghouses. Used by some industries in the late 1800s for product recovery and today broadly adapted for emissions control by a number of industries, baghouses recently have been shown to be capable of filtering fly ash at efficiency rates of up to 99.99% on pulverized-coal-fired utility boilers that burn low-sulfur western coal.

At this level of efficiency, 9999 lb (4.5 Mg) of fly ash would be captured for every 10,000 lb of fly ash produced. And of the 1 lb in 10,000 that did escape, results have shown that only approximately 15% would be in the form of fine particulates. The net result is emissions below EPA's New Source Performance Standards and, most important, no visibility problems.

"Baghouses give utilities what they want the most, a clear stack," says George Green, manager of government licensing and planning for Public Service Co. of Colorado and chairman of EPRI's Fossil Fuel Power Plants Task Force. "That represents 90% of our problems. In every case where we've put a baghouse in service, it has produced a clear stack."

The technology

Fly ash filtration inside a baghouse involves separating the finely divided solids produced in coal combustion from their carrier gas stream. There are two methods of accomplishing this: with an outside or pulse-jet collector or with an inside collector. For reasons of cost and reliability, utility interest and EPRI's attention are focused almost exclusively on inside collectors.

Fabric filtration with inside collectors is basically a simple process that begins when ash-containing flue gas comes off a boiler and is ducted into the lower portion of one of a number of baghouse compartments. Here the gas is directed upward through a cell plate, a sheet of perforated metal with thimbles protruding from each cell; a fabric filter—a tube-shaped bag supported from above—is attached to each cell. The flue gas passes through the bag, where the dust is trapped and deposited on the inside of the bag.

Once through the bag, the cleaned gas is routed to an outlet duct that joins other similar ducts and is carried downstream, ultimately to the stack.

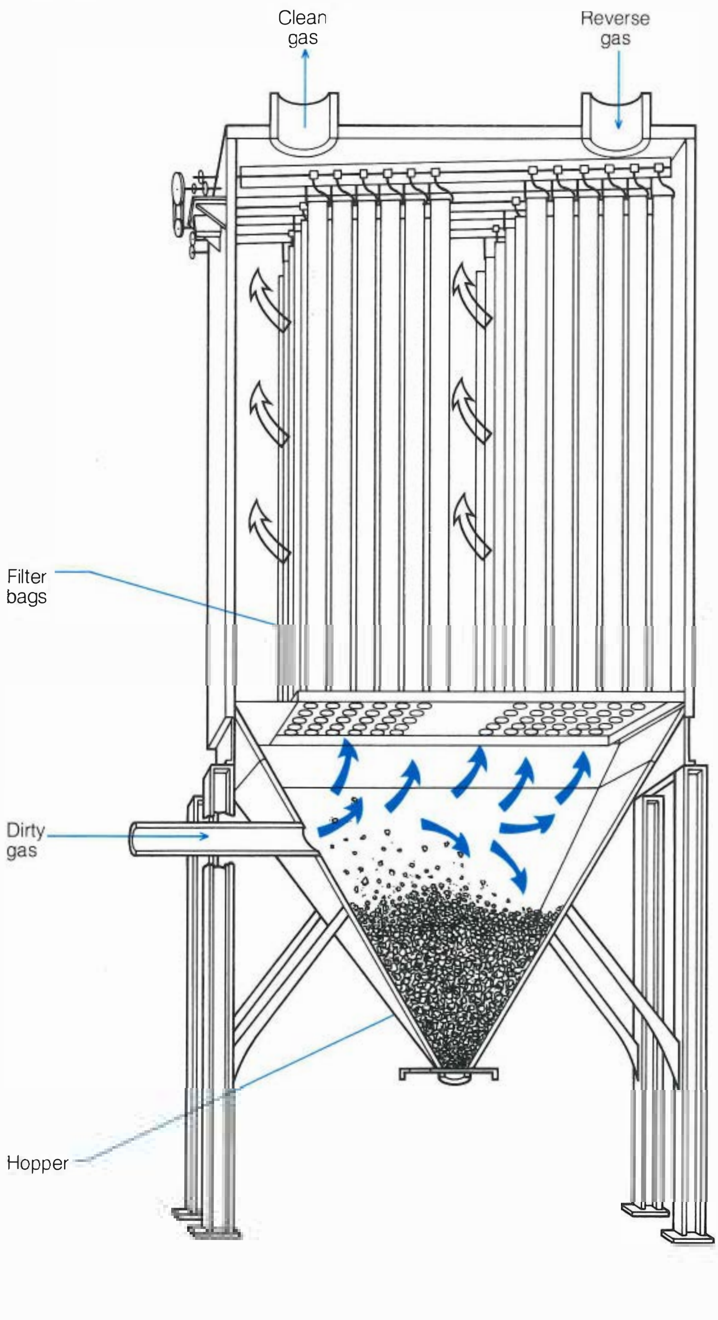
In the filtering, a clean bag is not the most efficient collector. In fact, it is the collected dust on the inside of the bag, called the dust cake or the filter cake, that acts as the filtering medium.

Throughout the process, baghouses have been shown to be "forgiving," that is, they will accept a range of coals, boiler operating conditions, ash compositions, and the like, with no major upsets.

On a cost basis, a baghouse sized to filter flue gas from a 500-MW boiler burning low-sulfur western coal would require a capital outlay of approximately $25 million. Costs vary widely, however, because there are a host of manufacturers, each with a different philosophy and a range of system designs.

"We know the baghouses will capture particulate matter," asserts EPRI Project Manager Robert C. Carr. "And we know we can comply with existing standards. Despite our limited experience and the reliability concerns associated with baghouses in utilities today, baghouses in some regions of the country are even now considered the best available control technology by EPA. The challenge is to optimize the units to reduce their size and to improve their reliability and durability—to locate and iron out the problems that are bound to occur when you scale up to utility size. For example, design parameters have to be better understood, and monitoring equipment and procedures have to be developed and refined to provide utilities with the tools required to keep the units operating at their optimum."

Baghouse technology is essentially modular. Shown is one baghouse compartment, illustrating hopper tube sheet and bag arrangement. Each compartment can contain several hundred bags up to 35 ft tall and 12 in diam. A commercial-size baghouse may have from 8 to 32 such compartments.



The EPRI program

It was to address these concerns that in 1975 EPRI began its investigations of fabric filters for utility application. The goal was to characterize the technology from the onset so as to avoid expensive and inefficient development work on full-scale units (as had been the problem when many electrostatic precipitators and SO_2 scrubbers were brought on-line) and to produce results directly transferable to utility application. At the time this work began, only two baghouse units were operating in the utility sector: Pennsylvania Power & Light Co.'s Sunbury station and Colorado-Ute Electric Association's Nucla station.

EPRI investigators first turned to Nucla and studied that unit's characteristics—engineering, efficiency, and economics. The resulting report was the first extensive documentation of baghouses in a utility setting. Among a number of striking conclusions were the following.

- Particulate emission control at Nucla represented the highest efficiency of any current technology.

- The station's plume was invisible, and it had a stack output opacity of between 0.02 and 0.06%. (The 0.06% recording represented the equivalent of 13-mile visibility.)

- The baghouse emission control performance was relatively insensitive to the properties of the ash from the boiler. During major boiler upsets caused by variable coal quality, particulates only increased from 0.0035 to 0.005 lb (1.6 to 2.3 g) per million Btu.

- For particulate matter in the 0.02–2 μm size range, fractional collection efficiency did not fall below 99.9%.

- From a power generation standpoint, the baghouses were 100% reliable.

With publication of these results in 1976 and with comparable performance reported at Sunbury, a number of utilities changed their position on the technology. It became clear there was a reasonable chance that many in the industry might install baghouses or that regulatory authorities might mandate such a turn. But despite these promising results, the data base remained modest, and because of the small size of the Nucla and Sunbury units, their firing method, and/or the type of coal used, neither station represented a typical utility application.

To expand the data base, in 1978 EPRI initiated a second study, this of a 25-MW unit at the Nebraska Public Power District's 25-MW Kramer plant, the first baghouse installation to come on-line in the

KEY BAGHOUSE PARAMETERS

In understanding the mechanics of baghouse sizing and operation, there are two key parameters: air-to-cloth ratio and system pressure drop.

In simplest terms, pressure drop represents the energy required by a fan to pull flue gas through the system. Measured with a manometer in inches of water, a pressure drop reading of 4 in or less would typically be desired in a baghouse. Operation in excess of this level is expensive because of the amount of energy required to keep the system running. Indeed, 1 in of pressure drop per 1000 MW of plant capacity can cost about $100,000 a year, or as much as $5 million over the life of the plant. On top of this, pressure drops that exceed the design limits of the fans can require station boilers to operate at less than full load —an extremely costly situation.

Air-to-cloth ratio represents the most fundamental parameter of all because it determines the size (and thereby the cost) of the baghouse. It is calculated by dividing the volume flow of flue gas (ft^3/min; m^3/s) received by a baghouse by the total area (ft^2; m^2) of the filtering cloth. These ratios can and do vary among systems from about 1.6 : 1 upward to 3.4 : 1, a nominal ratio being 2 : 1. In the last instance, the baghouse would be constructed with 1 ft^2 (0.09 m^2) of bag area for every 2 ft^3/min (944 cm^3/s) of flue gas to be filtered.

It is important to note that baghouses can filter efficiently over a range of air-to-cloth ratios. The tradeoff comes in the capital and operating costs involved. The higher the air-to-cloth ratio, the less fabric required and thereby the less structure and capital cost involved. But with the smaller amount of cloth, pressure drop may become more of a problem, forcing energy costs up. And more frequent cleaning may be required, meaning increased compartment downtime, additional flexing of bags, more opening and closing of valves, and the potential for reliability problems. Lower air-to-cloth ratios, on the other hand, produce more fabric area and therefore less resistance to gas flow, resulting in minimum maintenance and—it is hoped—lower pressure drops. Lower ratios, however, involve more equipment and higher capital costs.

Assuming a flow rate of 2 million ft^3/min (944 m^3/s) of flue gas to be filtered—a typical flow for a 500-MW plant—and an air-to-cloth ratio of 1.6 : 1, approximately 1.25 million ft^2 (116,250 m^2) of cloth would be called for. Inasmuch as one bag requires about 100 ft^2 (9.29 m^2) of material and costs about $100 installed, the capital cost for these bags alone would be approximately $1.25 million. Assuming a ratio of 3.4 : 1, the capital cost would be less than half that amount. Most utilities have adopted a conservative position in this regard, opting for a 2 : 1 ratio. □

industry at a plant burning a typical low-sulfur western coal in a pulverized-coal-fired boiler.

According to Carr, the Kramer experience was extremely important. Not only were EPRI investigators and Kramer plant personnel able to improve system performance but the testing confirmed the Nucla results, a significant finding in that the two plants used totally different boilers and had totally different baghouse designs. In addition, the study pointed out the need for adequate instrumentation to understand the technology and pinpointed the cleaning cycle as one area that appeared to require more development work.

"The big thing for us was that the work established an optimal cleaning cycle for the units," comments Robert J. Beaton, Kramer plant superintendent. "With the data EPRI collected, we were able to make improvements to the point we now clean 17 times less frequently. And this prolongs bag life and reduces emissions."

Parallel with the Kramer work, EPRI began preparing to build its own fabric filter pilot plant at Public Service Co.'s Arapahoe station—a 10-MW unit with four compartments, each capable of independent operation. It was commissioned last April and testing is now under way in several areas: hopper and ductwork design; startup and shutdown procedures; cleaning; relationship of air-to-cloth ratios to particulate matter collection and pressure drop; bag size; fabric type and finish; instrumentation and monitoring requirements; and operation in tandem with an upstream SO_2 removal system.

Central to the strategy of developing utility baghouses was the 1979 formation of a 15-member utility advisory committee on fabric filter technology. This group has provided a forum for exchanging experiences and points of view and for transferring technical results in real time. Members are typically drawn from those utilities who have a direct interest in fabric filter technology. At present, approximately 80 utility generating stations, representing some 14 GW of capacity, have full-size baghouses in place or have plans to install such units. Of these, 34 units are 100 MW or larger, with five 350–400 MW, one 250 MW, and one 170 MW. The largest contracts cover ten 175-MW units being installed at TVA's Shawnee station and two 800-MW units going in at the Four Corners station of Arizona Public Service Co.

Scale-up concerns

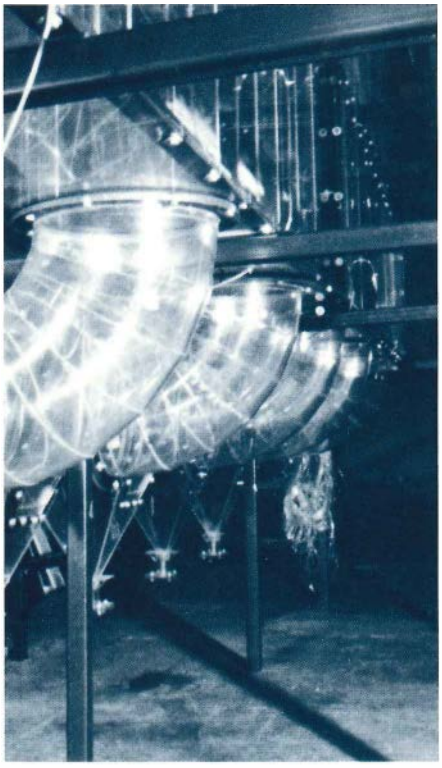
In its work to date, EPRI has identified five areas of primary scale-up concern: gas flow and dust distribution; bag cleaning; bag design and finish; startup and shutdown procedures; and continuous real-time monitoring. At Arapahoe and elsewhere, programs are under way in each of these areas.

Gas flow and dust distribution work focuses on the need to ensure a balanced distribution of particulates among baghouse compartments and among bags within those compartments. Without this balance, one or more bags or compartments could be overloaded, with consequent negative implications for overall system performance. To achieve a balance, dust must be evenly distributed within the gas flow. However, this task is difficult because particulates vary in size and density and an even gas flow does not necessarily mean an even dust distribution. Another difficulty is the tremendous quantities of gas the baghouses handle—as much as several million cubic feet a minute at speeds up to 50–60 ft/s (15–18 m/s).

Unequal dust distribution could occur, for example, because larger dust particles may not be able to negotiate ductwork turns as well as smaller ones, which would cause particles to segregate according to size in different regions of the baghouse. As a result, the whole character of the filter cake in those regions could be influenced. Excessive pressure drop represents yet another potential drawback of poor gas flow and duct design.

To analyze these concerns, EPRI is measuring gas flow and dust distribution

Transparent model (1/8 scale) of a baghouse used to study the flow distribution of gas and fly ash within the ductwork and compartments. Model is located in the research laboratory of Dynatech R/D Co., Cambridge, Massachusetts.



at Arapahoe, as well as monitoring on-line utility systems and performing flow-modeling studies with specially designed, quarter-size scale models. These models, which can duplicate almost any baghouse system, incorporate ductwork and valving innovations designed to improve compartment-to-compartment gas flow and dust distribution.

Investigations are also under way to study gas flow and dust distribution bag-to-bag and to develop guidelines for gas flow on the clean side of the bags, where excessive pressure drop also appears to be of potential concern.

Bag-cleaning technology and the bag-cleaning cycle, according to Carr, represent one area of baghouse operation requiring and receiving immediate and concentrated research attention. There are important reasons for this focus: Experience to date has shown that most emissions from baghouses occur after cleaning; less-frequent cleaning will prolong bag life and reduce maintenance; system pressure drop is intimately connected to how efficiently the bags are cleaned.

Baghouse cleaning is conducted in cycles on a regular, predetermined basis, with each compartment in a system sequentially shut down so that the filter cakes inside the bags can be cracked off. This cracking is accomplished in one of two basic ways, with a reverse gas system or a shaker.

In reverse gas cleaning, a gentle pulse of already filtered gas is turned back into the compartment and through the bags, causing the bags to partially collapse inward. This action knocks off the filter cake, which falls down through the thimble and cell plate into the hopper. The majority of on-line utility baghouses use this method. In the shaker system, the bags are manipulated from the top so as to send a traveling wave down their length to dislodge the filter cake. Quite often a shaker system will also have reverse gas or deflate capabilities to assist in the cleaning.

Practically, each bag might be cleaned every four hours. EPRI research has shown that more frequent cleaning may be unnecessary and can even be detrimental because of excess wear and potential maintenance problems.

In its investigations at Arapahoe, EPRI is looking at virtually every aspect of these cleaning cycles. In reverse gas cleaning, for instance, tests are under way to pinpoint the most efficient frequency and flow rate for the cycle. In shaker systems, investigators are looking at the amplitude and frequency of the shake, its direction of motion, and the equipment used in the process.

Because of temperature constraints in utility baghouse application (250–350°F; 122–177°C), fabric filter bags are typically made of fiberglass. Beyond this, however, there is uncertainty about a number of specifications, including the best type of finish to use, bag length, diameter, weight, and the tension that should be used in hanging the bag.

For its work at Arapahoe, EPRI has selected 35-ft-long, 1-ft-diam (11-m-long; 0.3-m-diam) fiberglass bags with a tricoat (teflon-silicon-graphite) finish, weighing 10 oz/yd^2 (339 g/m^2). Testing will focus on characterizing these variables in terms of bag life, pressure drop, and cleaning efficiency.

"We feel the bag itself is most important, and we're always trying new ones," says Noel Wagner, senior project engineer at Pennsylvania Power & Light and a member of EPRI's advisory committee on fabric filter technology. "At Sunbury we're getting bag lives of up to five years, and we're replacing bags there primarily because of ring cover failure—the rings supporting the bags become exposed and pitted, causing the bag to fail."

Startup and shutdown procedures in baghouse operation are extremely important because of the unknown effects of temperature fluctuations and possible condensation of water and acid in the flue gas. To address this latter concern, work is under way at Arapahoe to better understand condensation excursions and their impact on bag integrity and filter cake dynamics. The degree of the problem and potential solutions are expected to be defined before year-end.

Work to define and establish real-time monitoring procedures for baghouses and to make these procedures available to plant operating personnel is also going on. This information is important to establish and record baghouse performance (down to and including individual compartments) and as an aid in identifying problem areas before they negatively affect plant operation or stack opacity.

Looking ahead

In addition to its work in the above areas, EPRI is looking toward applying baghouse technology to high-sulfur eastern coals and toward a one-operation process for eliminating both particulate and SO_2 emissions from coal-fired boilers.

High-sulfur coal applications are of concern to utilities because on combustion these coals produce large quantities of SO_2 and SO_3, and the latter may give acid dew-point problems. In addition to being extremely corrosive, this acid solution may harden the filter cake to a cementlike consistency. To explore these problems, EPRI is embarking on a cooperative 10-MW pilot plant research effort (similar to the one at Arapahoe) with Southern Co. Services at the Scholz station of Gulf Power Co. in Sneads, Florida. Now in design, the plant will be constructed and in operation next year.

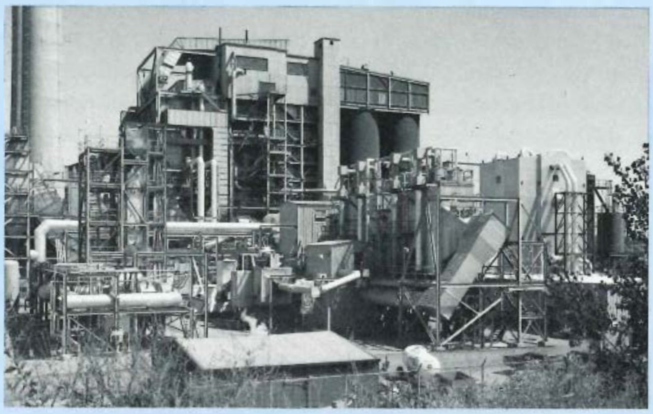
In its work to combine SO_2 and baghouse particulate technologies, EPRI has a spray-drying unit under construction at Arapahoe that is scheduled to begin operations in mid-1981. As flue gas enters the facility, it will be sprayed with an alkaline reagent in a slurry; this will convert the SO_2 into a dry, solid product that can be filtered out with the fly ash particulates in the baghouse.

A second system, capable of performing the same function and favored for its simplicity, was recently evaluated at Public Service Co.'s Cameo station and is now scheduled for diagnosis at Arapahoe. Because chemical reaction with the SO_2 is thought to occur principally in the region of the filter cake inside the bag, a 100% dry sodium-based reagent is injected into the flue gas by sprinkling it in the ductwork upstream of the baghouse. If the system proves to be technically and economically feasible, it would help to solve some of the complex engineering problems associated with wet flue gas scrubbing (particularly for western coals), reduce materials-handling problems associated with wet sludge, and eliminate water consumption in flue gas desulfurization.

"The bottom line," reports Carr, "is that the baghouses work and work well on their own. In combination with other technologies, they are opening the door to alternatives to wet scrubbers for SO_2 removal. If we can optimize the technology and scale it up, it can clearly make a tremendous contribution toward the acceptance of coal." ■

This article was written by William Nesbitt. Technical background information was provided by Robert Carr, Coal Combustion Systems Division.

ARAPAHOE

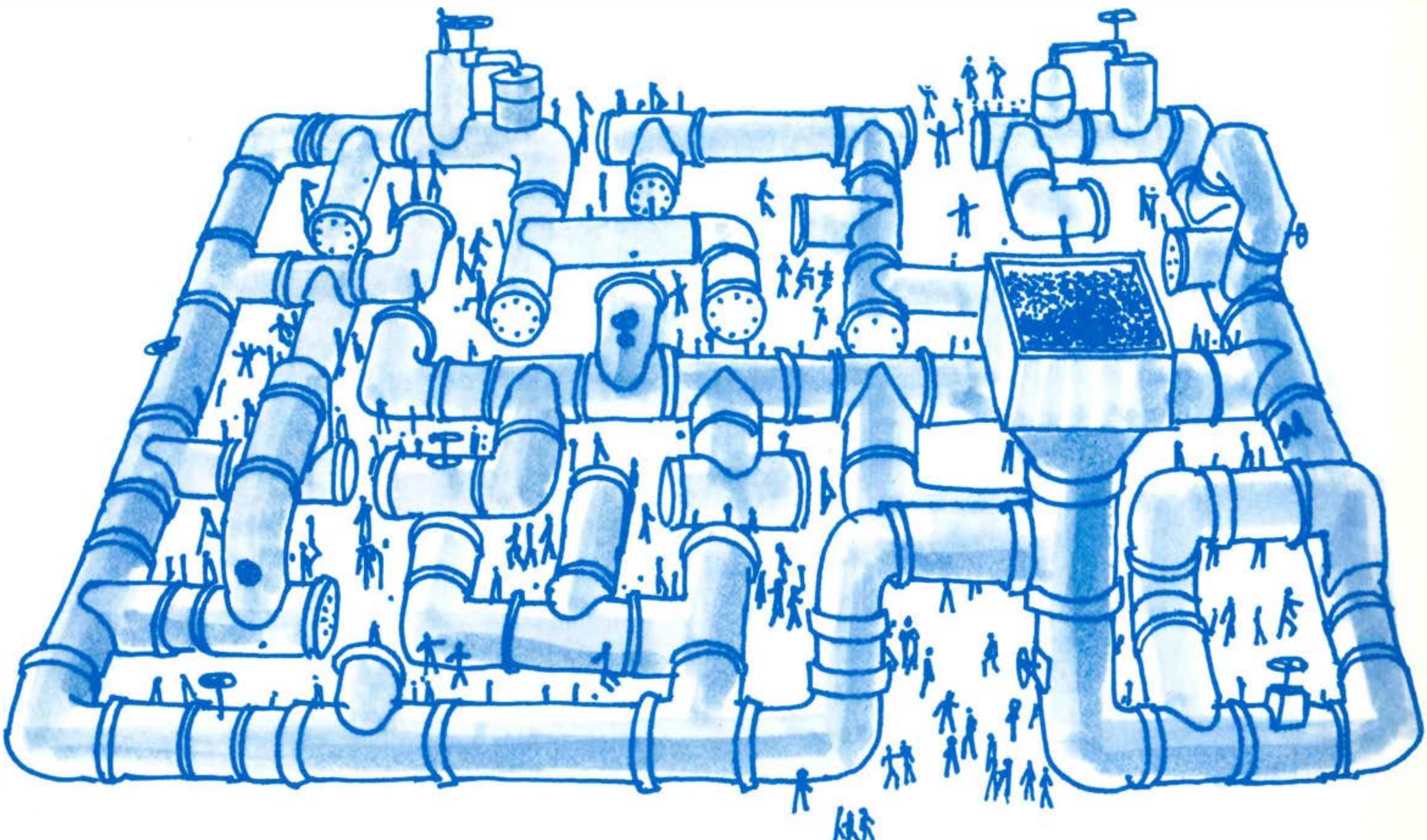


EPRI's work to better understand and improve baghouse technology is centered at the Public Service Co.'s Arapahoe station. EPRI has constructed an advanced emissions control pilot plant to evaluate and develop particulate and gaseous emissions control equipment with the intent of improving the technology and reducing system costs. Arapahoe offers the unique advantage of sophisticated research flexibility at a size representative of large commercial systems; thus it will help prevent premature large-scale utility commitment to unproven environmental control technology.

The Arapahoe facility encompasses five independent pilot plants and operates on slipstreams from a 110-MW pulverized-coal-fired boiler. In addition to a 10-MW fabric filter pilot plant, there are two electrostatic precipitators (one 2-MW unit used as a technology screening tool, another 10-MW for prototype evaluation), a 2-MW plant for evaluating granular bed filtration, electrically augmented fabric filters, and a hot gas cleanup system, plus a 3-MW integrated emissions control plant to optimize the combined air, water, and solid-waste control technology that can represent 50% of the cost of a new coal-fired power plant.

Knowledge gained at Arapahoe should go a long way in making coal more acceptable in utility boiler applications. □

The occasion was a conference of process developers; its keynote speakers underscored the roles of utilities and government in setting the requirements for liquid and gaseous synfuels, sharpening the competition between technologies and, with financial and regulatory commitments and incentives, quickening the pace toward commercialization.



DIRECTIONS IN SYNFUEL DEVELOPMENT

Spokesmen of two electric utilities from opposite sides of the United States were keynote speakers at a mid-October conference on synthetic fuels in San Francisco. Their emphases on liquid and gaseous fuels were two of the many contrasts heard in a program that sharpened the distinctions among two dozen processes for coal conversion and shale oil extraction.

The speakers were Bertram Schwartz and Lawrence Papay, vice presidents of Consolidated Edison Co. of New York, Inc., and Southern California Edison Co. (SCE). The occasion was a four-day meeting titled "Synthetic Fuels: Status and Directions" that brought together most of the major process developers in the United States and the Federal Republic of Germany. Sponsorship of the con-

SCHWARTZ

PAPAY

FUMICH

ference was shared by EPRI and the West German Ministry for Research and Technology. That established a noncommercial setting that drew 30 papers from companies with the most varied and mature synfuels R&D in the world. The conference was the first of its kind for the 450 delegates, including representatives from some two dozen electric utilities.

The motivation of utilities to be a large segment of the eventual synfuels market was thoroughly documented by the keynote speakers. They also pointed out logical and necessary roles for utilities beforehand: defining synfuel performance criteria by R&D support and funding synfuel industry development by advance fuel purchase contracts and equity participation in production facilities.

Between them, Schwartz and Papay presented the case for synfuels as seen by many utilities. It was as if the two men were standing on promontories of the U.S. east and west coasts, counting the tankers of oil imports.

New York: liquids needed

Emphasizing that transportation fuels and petrochemical feedstocks are the major national dependencies that influence the value of oil, Schwartz summarized the economic consequences of rising Middle East oil prices on the Con Edison system. "In 1979, 36 million barrels of oil were needed to generate our electricity and steam. Last year that oil, required to be very low in sulfur content (0.3%), cost $700 million. At current prices the same amount would cost $1.2 billion."

At that, Schwartz noted, "1979 was a good year" because a temporary surplus of natural gas replaced some 10 million barrels of oil, and power purchased from hydroelectric and coal-fired generation sources reduced the Con Edison oil burn by another 13 million barrels.

Including the Canadian hydro facilities with which Con Edison has long-term purchase agreements, system capacity is about 12,000 MW, about 76% (9200 MW) of it oil-fired. Without short-term gas purchases, Schwartz said that the company needs about 45 million barrels of oil annually. "As our load grows, we will be obliged to use our oil-fired capacity more fully," he added. "So unless we can effect some fundamental changes, we will face the 1990s with a potential oil burn of 50 million barrels a year."

If Con Edison is able to convert three 1800-MW units to coal, as it seeks to do, its oil-fired capacity would fall from 76% to 40% by 1985. And a little further off, power from a pair of plants (if built by the Power Authority of the State of New York) could reduce system oil-dependent capacity to 31%. "But these efforts, if entirely successful, would still leave us in OPEC's grip with a 1990 oil burn of 28 million barrels. In the long term," according to Schwartz, "we have no alternative but to count on synfuels for that."

To underscore the point, Schwartz offered three reasons why Con Edison expects to retain at least 7000 MW of liquid-fueled capacity in 1990 and why 5900 MW of it will be in New York City alone. Reliability was his first point.

"It is now evident that a contributing factor to the 1977 blackout was our heavy reliance on power generated outside the city. Our in-city generation then was 3000 MW; the remaining 2900 MW was being brought in from plants elsewhere. Lightning short-circuited four high-voltage ties to the north, and a damaged relay opened a fifth circuit. With more local capacity on-line or readily available," he went on, "it might have been possible to stabilize the system after the initial transmission losses and prevent—or at least defer—the tripping of the sixth and last circuit to the north and, with it, the interties to the east and west.

"Another imperative for city siting is our steam system, the largest cogeneration facility in the free world. We deliver 30 billion pounds [13.6×10^9 kg] of steam annually to 2000 Manhattan customers, and 60% of it is first used to generate electricity."

Schwartz's third reason for retaining significant liquid-fueled capacity is the cost of replacing it, which would be economically premature even in 1990. "Assuming our unlikely ability to find enough sites, a new alternative plant in New York City would cost $15 billion," he said.

For Schwartz and Con Edison, these considerations also suggest the tolerable cost for synthetic fuels. "The break-even in our existing capacity, compared with coal for direct firing in new replacement plants, is five times the cost of mine-mouth coal. That is our challenge to the synfuels industry, and from every cost estimate I have seen, it is a challenge the industry is confident it can meet."

> **If a synfuel costs 25% more than imported oil at plant startup in 1990, its average cost over the following 10 years would be less than that of oil.**

Backing up this expectation, Schwartz reported that Con Edison leadership of an ad hoc utility industry task force since 1978 has gained commitments from 16 East Coast utilities to buy about one-half the output of DOE's SRC-II demonstration unit when it begins production at Morgantown, West Virginia. The goal is to commit all the SRC-II output that becomes available for utilities at a price $2 a barrel higher than equivalent fuel oil (0.3% sulfur) at the time of delivery.

Schwartz urged his case beyond SRC-II alone by pointing out that fixed charges for a synfuel plant will probably account for at least half of a synfuel's cost. The other half, largely labor and coal feedstock, should escalate with the domestic economy. "Thus," he said, "if a synfuel costs 25% more than imported oil at plant startup in 1990, its average cost over the following 10 years would be less than that of oil, even assuming conservatively that oil prices escalated only 3 percentage points faster than the coal feedstock."

Schwartz reported Con Edison's essential willingness "to pay a higher initial price in anticipation of long-term savings and relative price stability"; he proposed coal supply contracts to minimize the risk; and he suggested that "DOE, Congress, and the new federal Synthetic Fuels Corp. consider arrangements such as this in connection with the incentive programs that are being formulated to encourage development of a synfuels industry."

California: gas preferred

When Papay took the platform at the synfuels conference, he based his utility's interest on a similar oil dependence. "SCE has the distinction of being the largest utility consumer of oil in the United States." But it wasn't always so. "Before the 1970s our fuel mix featured natural gas, with oil only as a standby fuel in the winter."

Severe air pollution control regulations governed then and now, the Los Angeles basin being the nation's prototypical victim of temperature inversions and smog. Starting in 1958 local rules required that utility gas or oil in the summer months contain less than 0.5% sulfur. In 1968 the limitation was applied year-round, and in 1977 the permissible sulfur content was cut to 0.25%.

"The only readily available source of low-sulfur oil was Indonesia," Papay stated, "and natural gas scarcities in the early 1970s resulted in burgeoning oil imports. Our peak year was 1977, when SCE burned 58 million barrels. The energy crises of 1973 and 1979 were jolts in both supply and price: low-sulfur oil increased from $6 a barrel in 1973 to $33 in 1980."

Coal has never been a common utility fuel in California because of transportation and environmental control costs. Even so, SCE shares the ownership and output of a 1580-MW plant fueled by a 275-mile coal slurry pipeline from Arizona, and it shares in other coal-fired facilities outside the state. If coal is to be the basis of synthetic fuels for SCE, the choices are limited, according to Papay. "Solvent-refined coals and shale oil contain sulfur and nitrogen to the extent that they would be prohibited as oil replacements in the Los Angeles basin. Therefore, the synthetic fuels of interest to SCE are the gaseous forms, methanol, and Fischer-Tropsch liquids that are free of sulfur and nitrogen."

Like Schwartz, Papay emphasized that synfuel availability is a major planning issue for SCE in seeking ways to back out fuel oil. And like Schwartz, he suggested long-term synfuel purchase contracts by SCE and other utilities as one means to encourage the establishment of significant synfuel production. "This approach," he noted, "requires that regulating authorities provide rate-setting backup for firm purchase contracts in addition to the incentives that may be available from the federal Synthetic Fuels Corp."

Papay also suggested that utilities participate in synfuel projects as equity owners. "This is another way to ensure reliable supplies, and it might provide SCE ratepayers the most cost-effective source. However," he commented, "without timely regulatory support for assured recovery of equity contributions, the risk associated with financing substantial amounts would preclude participation.

"Timely development of synthetic fuels," he went on, "will require that the permit and licensing processes at federal, state, and local levels be streamlined. Requirements must be defined and held constant during the design stages of a project."

As an example of equity participation, Papay spoke of the Cool Water project, SCE's first venture into the construction

> **Timely development of synthetic fuels will require that the permit and licensing processes be streamlined. Requirements must be defined and held constant during the design stages.**

and operation of a synthetic fuel plant. This plant is designed to demonstrate the technical and economic feasibility of the Texaco, Inc., coal gasification process for producing clean medium-Btu gas for electric power generation. The fuel will be used in a gas turbine combined-cycle facility to generate 92 MW (net). The operation is expected to begin in 1983.

Illustrating the diversity and methodical nature of SCE's work in synfuel development, Papay also mentioned the utility's full-share partnerships in feasibility studies of shale oil retorting and of coal conversion to methanol and/or to synthetic natural gas. "The studies will develop comprehensive data in the areas of preliminary facility design, economic and financial analysis, siting considerations, market analysis, resource assessment, and environment, health, and safety. If the decision is to proceed, the next phases would involve regulatory application, final design, financing, and construction."

Utility influence

Against the background drawn by Schwartz and Papay, the synfuel conference program proceeded with successive reviews of processes, laboratory research findings, process development unit operations, pilot plant problems, and demonstration plant startups. A day and a half was devoted to 12 papers on liquefaction, including 2 on surface and in situ retorting of shale oil. In the final two days, 18 papers on coal gasification were presented, including 2 by turbine manufacturers.

Production of oil from shale continues to be the front runner in technological readiness and consequent amenability to early and detailed production costing. Fuels from this source and from direct liquefaction of coal are readily transportable and widely applicable in utility and other markets. Against this are the complexities in optimizing the processes for various products and the problems of holding down the sulfur and nitrogen content of those products.

Indirect liquefaction and gasification processes draw special interest for their flexibility and the prospect of cleaner fuels. But economic process operation, for utilities at least, will require integration of gas production and use (as at SCE's Cool Water demonstration site) to make best use of steam and feedwater flows, auxiliary equipment, and cleanup systems. Especially for low- and medium-Btu gas products, transportation costs suggest this approach. Additionally, production and sale of intermediate products (e.g., methanol) obtained from some processes could be considered collateral benefits of a utility's own stable fuel supply.

The conference clearly indicated that a sharp competition has emerged between technologic methods. Because the utility industry has needs for both liquid and gaseous fuels, it is thus in a position to influence the pace as well as the direction of their development. Conference discussion showed four liquefaction processes (SRC-I, SRC-II, H-Coal, and Exxon Donor Solvent) to be of particular U.S. commercial significance because of their development status or scale, and Schwartz pointed out how utility advance fuel purchase commitments aid the establishment of liquid synfuel production capacity.

Five gasification processes illustrate the alternative of utility involvement in the synfuel production demonstrations: the Texaco partial oxidation process with SCE (at Cool Water); the Institute of Gas Technology fluidized-bed U-Gas process with Memphis Light, Gas & Water Division; the Allis-Chalmers Corp. KILnGAS process with Illinois Power Co. and others; the Combustion Engineering, Inc., process with Gulf States Utilities Co.; and the Shell-Koppers entrained gasification process to supply fuel for a utility power plant in Holland.

Design studies for commercial synfuel plants that could be operational late in the 1980s involve still other utilities, among them Arizona Public Service Co., Boston Edison Co., Central Maine Power Co., Consolidated Edison Co. of New York, Inc., Florida Power & Light Co., Niagara Mohawk Power Corp., Pacific Gas and Electric Co., San Diego Gas & Electric Co., and the Tennessee Valley Authority.

There remain many synfuel questions that were beyond this conference, such as process plant reliability, production costs, and the environmental issues of coal and shale extraction. Michael Gluckman, technical director of EPRI's program for the engineering and economic evaluation of advanced power systems, reflected on this after the conference. "For example, there was a question from

"It is important that the momentum continue because at present inflation rates, the cost of a $2 billion synfuel plant today is increasing almost $30,000 an hour."

the floor about U.S. industrial capacity simply to fabricate the number of high-pressure vessels that will be needed for a truly functional synfuels industry. That issue and many others must indeed be addressed. But one conference and one pair of sponsors can't cover all the ground. This meeting had the unique value of being a forum where development people could share their technical status and insights—up to the point of the proprietary aspects of their work—in a way that hasn't been available to them before. This kind of technology transfer has to be good for the future of synfuels and for what utilities can hope to benefit from them."

Reducing needs, ensuring supplies

In a context devoted entirely to fuel supply options, conservation was for the most part only implied by the thermal and conversion efficiencies of synfuel processes. But George Fumich, DOE's assistant secretary for fossil energy, who also addressed the synfuels conference on its opening day, underscored the individual utility conservation efforts described earlier by Schwartz and Papay. He reported that "for every seven gallons of gasoline and fuel oil that America burned two years ago, we are burning six today. For every four gallons of oil that we imported two years ago, we are importing three today."

Fumich thus characterized conservation as one foundation and one growing success of federal policy in dealing with U.S. energy problems. One conference delegate expressed what may have been the thought of many when he remarked to a colleague that such short-term energy reductions might reflect the economic recession more than conservation.

Fumich also called attention to longer-term changes in energy attitudes and behavior when he added that "the same energy analysts who, in the years prior to the 1973–1974 oil embargo, were forecasting total U.S. energy demand as high as 200 quadrillion [200×10^{15}] Btu in the year 2000 are now feeling increasingly comfortable with estimates in the area of 100 quadrillion Btu.

"Conservation," he said, "is indeed helping us buy the time we need to develop a wider range of new, more reliable energy resources." Turning to that topic as the second goal of the federal energy policy, Fumich shared the frustration of the synfuel conferees. "Had we possessed the foresight to begin building the first plants immediately after the 1973–1974 embargo, we would today be producing domestic synthetic oil and gas, and because of inflation and the price hikes of the oil cartel, their costs would likely be competitive with world oil."

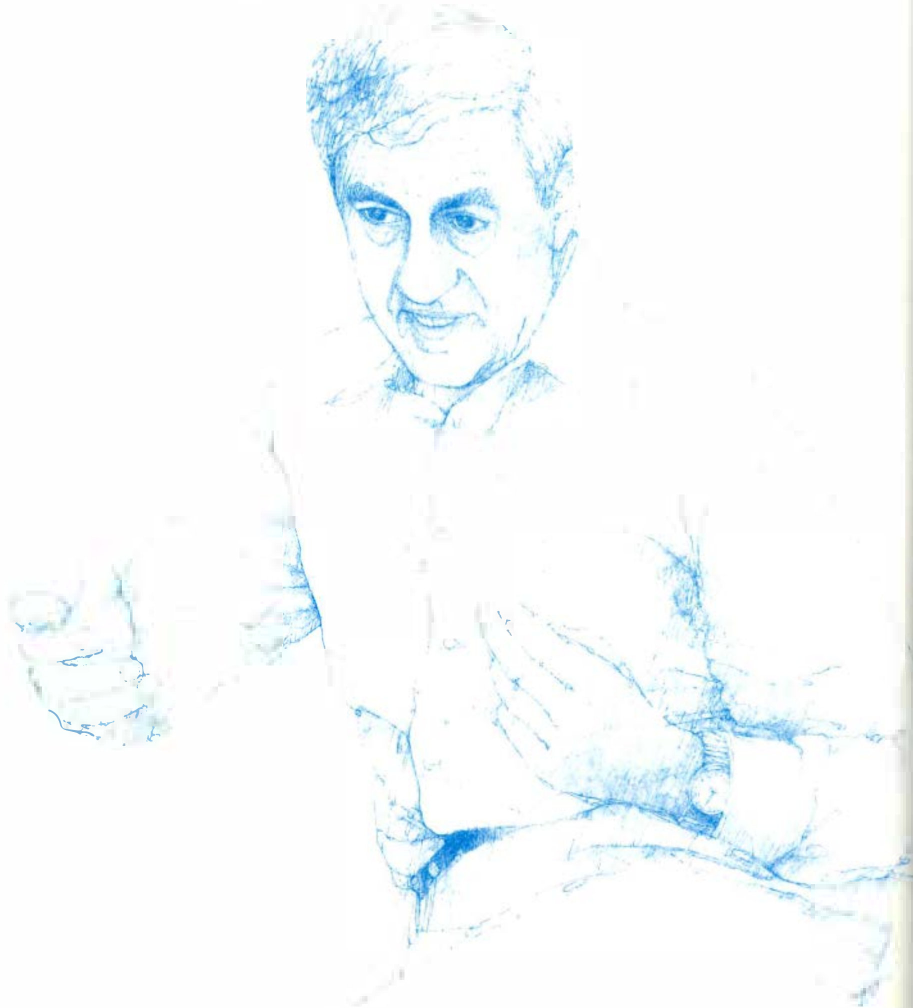
Fumich acknowledged the value of R&D that has continued during the intervening years, but he said, "We no longer have the luxury to orient an energy program around just R&D." He especially noted the luxury of "fighting ourselves," observing that he could elicit adverse comment somewhere in the conference for every process reviewed there. Fumich then went on to say, "No longer is it sufficient simply to bring new technologies to the commercial threshold. Today we must ensure that they cross over it. Our program must be geared to the deployment of technologies in the marketplace.

"This policy has emerged during the last year for synthetic fuels," he said, "and it has motivated creation of the Synthetic Fuels Corp. Incentives will be its responsibility—permitting companies to have access to capital through loans and loan guarantees while being assured of a reliable market by purchase commitments and price supports. These are fashioned to work within the marketplace, not to overwhelm it."

Fumich summarized a number of synfuel funding allocations, project sponsorships, and R&D expectations of DOE, but he acknowledged that "our imbalance between energy supply and demand has been a long time coming, and it will be a long time before we bring it back into order. There is no quick fix, no technological breakthrough in sight. Each new understanding is based upon the last.

"But it is important that the momentum continue," Fumich insisted, "because at present inflation rates, the cost of a $2 billion synfuels plant today is increasing almost $30,000 an hour." ■

This article was written by Ralph Whitaker. Technical information was reviewed by Seymour Alpert, Advanced Power Systems Division.



Elie Abel: Keeping the Lines Open

Official and corporate sources of information are looked on with suspicion by many, whether environmentalists or Third World leaders. A member of EPRI's Advisory Council, who is a professor of communication at Stanford University, suggests some reasons for the distrust.

Much of the extreme group in the environmental movement is protecting its own privileges. It doesn't want electric pylons striding across the landscape to spoil the view. It doesn't want growth. This is a class phenomenon, basically. By my observation, most Americans are not against growth. They want growth. And the poorest Americans want growth the most."

Fiery yet compassionate, outspoken yet modest, Elie Abel integrates these apparent extremes of expression by acknowledging his own impulsiveness. No stuffiness, no formality in his manner, this imposing, energetic man admits, almost apologetically, to being a verbal person. But it is his very verbal skill that is his asset. The words he speaks and writes are fast-moving and full of color.

Vigorously, he continues with the topic. "Whole-hog environmentalists, by and large, are not drawn from the ranks of the poor and disadvantaged. They are more likely to be the sons and daughters of Ivy League professors, corporate vice presidents, bankers, all the people who can afford to do without and who get this great inner glow from self-denial. 'Growth is wicked,' they say."

The topic under discussion is, in Abel's words, the "peak of obstructive efficiency" achieved by environmentalists in the United States. It is an example of the kind of clash that occupies Abel's attention. He seems drawn to the intellectual and practical challenge of untying complex political and sociological knots.

Interpreter of current history

In one of his books, *The Missile Crisis*, published in 1966, Abel sets in motion, as dramatically as the old literary masters, a vivid, close-up narrative of John and Robert Kennedy's most testing crisis —the battle of wills over Soviet missiles in Cuba. Reading the book and vicariously watching that knot being slowly untied is, to Abel's credit, still a gripping experience.

A seasoned journalist, recently dean of Columbia University's prestigious School of Journalism and presently a member of EPRI's Advisory Council, Abel was lauded by W. Averell Harriman in the foreword to *Special Envoy to Churchill and Stalin, 1941–1946*, the substantial book Harriman wrote with Abel in 1975: "I had long admired his writings—their clarity, the skill with which he assembled facts and illuminated recent history."

As foreign correspondent for the *New York Times* in earlier years, he was assigned to interpret and report news from Berlin just after World War II, Eastern Europe during the Hungarian revolution, and India at the time of the Tibetan uprising.

Abel worked nearer home for the next 10 years as a broadcaster with NBC News, first as State Department correspondent, then London bureau chief, and last as diplomatic correspondent. Although his wide international experience fitted him for diplomatic service, he enjoyed his work too much to contemplate a full-time government job.

During the last few years, however, he has been the U.S. member of a 16-nation commission of the United Nations Educational, Scientific, and Cultural Organization. The commission has been studying problems related to the way nations receive and transmit news and information, and its final report was debated this fall at UNESCO's twenty-first general conference in Belgrade, Yugoslavia. Abel attended the conference as a U.S. delegate.

The commission examined the changes in world communication brought about by economic, social, and political shifts and by the growth of technology. Abel explains that two-thirds of the world lacks the resources to develop national media networks. It is cheaper for these less-developed nations to buy U.S. comedy series for their television audiences than to produce their own programs.

Dependence on the United States and Europe for both entertainment and news builds Third World resentment of so-called cultural domination. The Third World leaders complain that their countries have become passive receivers of western information and culture because they lack the capability and resources to establish their own media.

Many Third World countries also maintain that their problems and accomplishments are either ignored or distorted by western media and so, explains Abel, UNESCO approved a declaration in 1978 that endorsed the idea of a new world information order that was meant to reverse the prevalent trend. Although the phrase has never been clearly defined, it calls for a more balanced flow of information between industrialized and developing countries. But to some western scholars and journalists, this seems an invitation to heavier control by Third World governments over information emanating from those nations. Some even fear less freedom for western journalists abroad and an increase in censorship of their material. The implications of possible closing of lines of communication between nations are sinister.

Communication in the United States

Underlying much of Abel's work is the opposite concept—keeping the lines open. Whether the lines connect world leaders, journalist and audience, or author and reader, Abel's interest focuses on opening and maintaining the free exchange of ideas and information.

Discussing such exchange between the public and those in positions of influence in the United States, Abel comments that the authority figure in general has for some time suffered a certain loss of credibility, whether politician or preacher, scientist or parent. "Despite this attitude," he continues, "scientists and technologists are still respected in the sense that Congress wouldn't dream of making a funding decision on technology or weapons systems without calling on a group of scientists or technologists to testify. What Americans have not learned to do, however, is to discriminate between experts."

What unfortunately tends to happen, Abel observes, is that "the quack and the politicized expert get equal time with the genuine expert." The result is public confusion.

Since the birth of the atomic age, he says, some scientists have allowed their political sympathies to color their judgment, thus undermining their own credibility.

Credibility of technologists has also suffered over the unresolved question of nuclear waste disposal. Abel harks back to 1954 when he wrote a long article in the *New York Times* magazine after a tour he made of atomic energy establishments of that time. "I raised the question with a number of scientists at Los Alamos and Argonne and Livermore about what was going to be done with the military wastes, and they said, 'Oh, we've got an answer.' The answer was a process they called vitrification. Well, vitrification is still the answer, except it's being done in France, not in the United States." It seems to be a moot point whether the reason for the 30-year delay is cost or politics.

Public unease about atomic energy has been exacerbated by the prolonged negligence on the part of federal authorities, states Abel, in not "locking up these wastes in fairly benign forms." He cites tanks of liquid wastes at Hanford, Washington, and elsewhere, "which have been sitting ever since the first bomb was made in 1945." In the public mind, he believes, the fear of and anger over military wastes are linked with the first use of nuclear energy as a terrifying and destructive weapon. He also refers to what he considers the basic source of public opposition to nuclear power, surpassing even the radwaste controversy: "My guess is that there are millions of Americans today who go on believing what is patently nonsense: that if a nuclear power plant goes out of control, it will explode like a bomb."

Yet another public misconception, according to Abel, is that there is no energy crisis in the world. This, he believes, is the result of a breakdown in credibility. "It is very hard to disentangle in people's minds the myth from the reality, partly because so many no longer trust official or corporate sources of information. The petroleum industry, in particular, has not been renowned for its candor. It has tended to understate its reserves, and, from the consumer's point of view, to speak with a forked tongue." Moreover, the cost of energy in whatever form keeps rising more steeply than the cost of other necessities, a circumstance that cannot be expected to delight the consumer.

Utilities, public, and press

Resistance, anger, and distrust—these are also the powerful public attitudes that utilities face, in addition to public resentment of inevitably higher prices, as new and replacement power plants are built. Though Abel is convinced that America needs more nuclear power, he tempers his opinion with a concern for safety and honesty in the utility industry.

"I don't think we can reindustrialize America without having nuclear power provide a significant and growing share of the energy we need. But we have to find ways of making nuclear power safer, which is basically an engineering problem. It does no good to pretend that there are no problems—and this is where I have to part company with some of the people in the utility industry."

Specifically on the Three Mile Island accident, Abel comments, "I know it's too much to ask that the power industry should take a dispassionate view of its own shortcomings. It's much cheaper and easier to blame the press." The press has a great deal to answer for, Abel admits, but he points out that the misinformation it distributed at times came from government and industry sources, who should have been better informed than the reporters, most of whom were untrained in nuclear science. ■

This article was written by Jenny Hopkinson and is based on information obtained in interviews with Elie Abel.

DOE Fosters Energy-Efficient Products

DOE's consumer products R&D supports the development of energy-efficient appliances. With government encouragement, these products may reach the marketplace sooner than expected and could make a big difference in the nation's energy savings.

The heat pump water heater, an application of the traditional heat pump used for space conditioning, extracts heat from the air and sends it into the water tank. A few years ago this new energy-saving appliance, which cuts in half the amount of energy needed to run an electric water heater, was a promising technology that faced difficulty in the competitive appliance industry. But with the help of a DOE research, development, and demonstration program for consumer products, prospects for the heat pump water heater, as well as for other energy-efficient appliances, have improved considerably.

Other projects in DOE's technology and consumer products R&D program include highly efficient refrigerator-freezers and lighting systems, the improvement of furnaces, and heat pumps for space heating and cooling. Some of the more promising products have been demonstrated in field tests in various parts of the country. For other products, the field tests still lie ahead; for a few, such as the heat pump water heater, marketing by manufacturers has begun.

The federal government's consumer product R&D program started in the mid-1970s in DOE's predecessor agency, ERDA. For the most part this effort has generated little publicity and has received only a modest budget over the years. But it has generally gained the respect of industry by its work to encourage the development and marketing of efficient technologies and equipment for residential and commercial buildings.

"There is one reason the program is working—it doesn't promise more than it can deliver," says Maxine Savitz, DOE's deputy assistant secretary for conservation, who has been the overall supervisor for the program since its beginning. According to Savitz, the program has been blessed with competent staff managers who have not tried to accomplish in one year what it may take two or three years to do. "You can't do R&D and expect to have a lot of success in a crisis environment." There also has been a bit of luck involved, she concedes. "When you have only so much funding and a lot of ideas to choose from, there is a certain amount of luck in picking the right ones, and by and large the choices have been proving out."

DOE operates on what is known as a decentralized management plan. Although overall program direction and policy comes from headquarters in Washington, D.C., day-to-day operations are headed by personnel at several DOE national laboratories. Projects covering appliances and heat pumps are managed by Oak Ridge National Laboratory (ORNL); space-heating projects are supervised by Brookhaven National Laboratory; and lighting work is handled at Lawrence Berkeley Laboratory.

The program has a yearly budget of about $14 million, of which $2.5 million is allocated for appliance development, $2.5 million for lighting products, $2 million for gas- and oil-fired burners for space heating, and $7 million for heat pump projects. Funding is given to companies that have developed concepts or equipment with a great potential for energy savings but with high technical or financial risk. "If the government did not get involved, many of the products would probably still reach the marketplace eventually as energy prices continue to rise and consumers search for ways to cut costs," says John Cuttica, acting director of the Consumer Products Division in DOE's Office of Buildings and Community Systems.

"We don't want to get into the business of developing new technologies ourselves," Cuttica continues. "But what the government can do is encourage development by private groups so that a product is ready for the market in perhaps three or four years instead of seven or eight—or maybe even not at all. That four-year head start can make a big difference in cumulative energy savings to the nation, especially now when it is still sorting out its energy priorities."

Company Participation

In all its projects, DOE attempts to involve a product or equipment manufacturer as the prime contractor or as a subcontractor. "We are not interested in dealing only with an engineering consulting firm or an R&D firm that is not in the manufacturing game and is not familiar firsthand with getting products to market," explains Cuttica, an electrical engineer who has been with the DOE program since its early days. "In all our contracts we try to have a manufacturer or commercializing agent involved from the very beginning."

Cuttica

In some cases the participating companies are large, such as General Electric Co. and Westinghouse Electric Corp. Sometimes they are small firms, such as Energy Utilization Systems, Inc. (EUS), a Pittsburgh company that is developing a heat pump water heater. In other instances manufacturers and engineering firms pair up for a project. Such is the case with Arthur D. Little, Inc., and Amana Refrigeration, Inc., which have been working jointly on a new efficient refrigerator-freezer.

Another general requirement set down by program officials is that participating companies pick up a share of the costs. "When a company agrees to put its own money in a project, it helps give us confidence that the company is committed to getting the product on the market and that it will put experienced, capable people in to get the work done," Cuttica says.

Some of the projects funded under the program focus on developing a concept or a piece of equipment that looks promising but still has technical bugs. Others focus on demonstrating and marketing products that are technically sound, but need to be proved in real-world tests. Still others involve all stages, from early laboratory development to field demonstrations in homes or commercial buildings. In addition, program staff members try to assist various projects by making sure that RD&D information gets to the right people, including state energy offices, other federal agencies, the federal supply system, and the general public.

The Heat Pump Water Heater

What is the public really going to get from the program? That is a question Cuttica and other DOE officials are often asked. In responding, they frequently start with the heat pump water heater.

"We think the heat pump water heater is a real winner," Cuttica says. "It presents a very good alternative to the standard electric water heater because it cuts energy use by at least 50%. It also presents a viable option to solar water heaters because it provides about the same energy savings at about one-third to one-half the cost."

Next to space conditioning, the hot water heater is the biggest energy user in the home. Major reductions in the energy consumption of electric water heaters would not only save consumers money but also help reduce utility loads during critical peak periods, according to Cuttica. "The 30 million electric water heaters in use nationally today consume an estimated one and a half quadrillion (1.5×10^{15}) Btu a year," he comments.

Replacing an old heater with a new heat pump water heater or adding the new product to an existing system could save the average homeowner $100–$200 or more a year, according to some industry estimates. Besides heating water, the unit can also cool and dehumidify the air, thus saving additional costs, according to industry brochures. Industry estimates indicate that it could take less than 30 months for the savings in energy to pay for the extra cost of the unit. But both the savings and payback will depend on a number of factors, including the local cost of electricity, the climate, and the location of the unit in the home.

DOE first got involved in the heat pump water heater in 1977 when EUS responded to a DOE request for proposals on innovative electric water heaters. This led to a demonstration project last year in which 20 participating electric utilities began installing units in 100 homes to determine how well the products performed. That work is expected to culminate in a final report from ORNL next spring.

Meanwhile, EUS is now marketing heat pump water heaters, as are at least two other firms, E-Tech, Inc., of Atlanta, Georgia, and Fedders Corp. of Edison, New Jersey. Northrup, Inc., of Hutchings, Texas, has expressed its intention to market the heaters, and other companies are also becoming interested in this concept. The EUS system is a replacement unit; basically, it is a heat pump sitting on a water tank. The E-Tech and Fedders systems are retrofit heat pumps that are connected to existing water tanks.

DOE recently sent promotional information to state and federal agencies so they can educate consumers on the benefits of the heat pumps through the Energy Extension Service and Residential Conservation Service programs and also promote the products for installation in government facilities. Cuttica emphasizes, however, that his office is promoting the concept and not endorsing any one product, giving as an example a workshop DOE and Tennessee Valley Authority sponsored last spring. At that workshop, representatives from both private and public utilities heard four firms describe the development of their products and their marketing plans.

"From what we have seen, there is a growing interest by electric utilities in the concept," Cuttica comments, adding that some of the manufacturers are particularly anxious to get utilities involved because the utilities could be a good first commercializing agent for the product, particularly for the smaller manufacturers, if there are no legal complications. Some of the manufacturers see the possibility of the utilities' providing a potential distribution and maintenance network that would serve to keep the price of the product competitive.

Initially, the cost of a unit to replace an existing water heater will be in the range of $600–$700. If a manufacturer has to go through a middleman, the price could be a lot higher, according to Cuttica. But if the utilities can get involved in programs to sell or lease the products to consumers, the price could stabilize and eventually drop to $400–$500 when the market matures.

One concern about the heat pump water heater has been the possibility of increased heating costs when a unit is installed in a heated part of a house and operated during the winter in a colder climate. As the unit pulls heat out of the air to keep the water hot, it may make the furnace operate more than it otherwise would. But studies at ORNL are showing that the penalty may not be very significant, and Cuttica comments that the best place to put a heat pump water heater is probably in an unheated basement or attached space in which the temperature remains above about 45°F, even in winter. This would allow it to operate adequately year-round.

In cases where a homeowner is concerned about the furnace overworking in winter, the water heater could easily be switched back to electric resistance heat, Cuttica explains. "Even if homeowners shut down the heat pumps in winter—and we are not sure that this will be necessary—they are still going to come out ahead in the long run by operating the unit most of the year."

Other Energy-Efficient Products

Although it is getting a good deal of attention, the heat pump water heater is not the only heat pump project that DOE officials are optimistic about. In the area of heat pumps used for space conditioning, a major emphasis has been on developing thermally activated heat pumps that use natural gas or other fossil fuels. This type of heat pump is especially attractive because waste heat from the engine can be captured to help heat a building, thus resulting in extremely high efficiencies.

Another major project under way is in the area of advanced electric heat pumps for space heating. DOE is supporting work by Westinghouse to develop a variable-capacity unit capable of improving the efficiency by about 20% over today's standard air-to-air heat pump. Emphasis is on developing an improved compressor. The unit will be designed to work at two levels of output, according to Cuttica. In effect, this will permit one setting for cool weather and another for cold winter weather, thus allowing the unit to be operated for a longer part of the winter without using backup electric resistance heating.

In addition, ORNL has carried out a number of in-house efforts on heat pumps, including testing three commercially available systems and using the information to validate a computer model ORNL developed. This work is aimed at assisting industry in the design of more-efficient units.

DOE has also supported a number of

promising space-conditioning projects to improve the efficiency of both gas and oil heating equipment. One success story has been the development of a blue flame burner and matching boiler under a contract with Blueray Systems, Inc. That product, which the firm says can save householders 30% or more on fuel bills, is now being sold commercially. Ongoing projects include development of variable low-firing-rate burners for both gas and oil units and high-efficiency gas furnaces based on pulse combustion and heat pipe concepts.

A promising product that is expected to attract increased attention is a refrigerator-freezer that uses about half the energy as a standard unit. The project, which is being carried out with Arthur D. Little and Amana, has already produced a successful 16-ft^3 prototype. Tests with the prototype have shown the energy consumption to be only 1.8 kWh a day, compared with about 3 kWh a day for Amana's most efficient unit now on the market.

The prototype includes improvements in door gaskets, a new evaporator system, and better insulation. Because of the improved evaporator design, the defrost cycle for the freezer occurs every four days instead of twice a day as in standard units. Plans now call for field testing some 25–30 similar units in homes beginning this fall, according to ORNL researcher Virgil Haynes.

When can consumers expect it to reach the market? That, of course, depends on Amana and whether the firm feels confident that the market will be receptive. "It may take six months or a year, or even longer, before Amana is confident enough to make the investment to change its production line," Cuttica explains. "But the R&D is done. So when the marketing decision is made, we know Amana can bring it out."

In another DOE-industry appliance project, Columbus Products Co., a division of White Consolidated Industries, has developed a motor-compressor for refrigerator-freezers that is about 25–30% more efficient than conventional equipment. The firm plans to produce some 1300 motor-compressors for installation and testing in home refrigerator-freezers next year, according to ORNL's Haynes. In addition, Columbus Products is working with DOE to modify the motor-compressor for use in refrigerated vending machines.

Other appliance projects include work on a biradiant residential oven, high-efficiency gas-fired residential and commercial water heaters, and advanced insulation materials for residential and commercial appliances.

In the lighting area, some of the most promising work is being done in the field of solid-state ballasts, according to Cuttica. The ballast is a component designed to start and regulate the operation of a gas-discharge lamp. Tests at Pacific Gas and Electric Co. headquarters building in San Francisco have demonstrated a 25% savings from fluorescent tubes with solid-state ballasts. Other work is now under way with three firms to develop solid-state ballasts for high-pressure sodium lamps. In addition to increasing the lamp life, the new ballasts are expected to improve energy efficiency of the products by about 20%. DOE has also been supporting the development of a solid-state ballast for residential circline fluorescent lamps.

Cuttica comments that products in these areas either are already on the market or are expected to be in commercial production in the near future. The new ballasts could begin to have major long-term effects, particularly in commercial buildings, where lighting is often the biggest energy user.

In addition, for several years DOE has sponsored work on an electrodeless fluorescent bulb designed to replace the standard incandescent lamp. Litek, developed by Lighting Technology Corp., a small California firm, attracted widespread interest from industry and consumers alike when it was first announced. It was supposed to use only one-third the energy of a standard incandescent bulb and last several times longer. But a number of technical and other problems have slowed development, and there is serious question whether that specific product will ever be a commercial success.

Nonetheless, Cuttica and other DOE officials do not believe that the project has been a failure. Although the Litek bulb has not made it to the marketplace, the project has spurred the industry to increase R&D and to come up with competing products. General Electric has announced development of a halarc bulb, and North American Phillips and Westinghouse have announced compact fluorescents, all of which are expected to be available next year. Cuttica notes that other companies are also working on new concepts, and although DOE certainly cannot take credit for everything the industry has done in the past couple of years, the program did set out to promote the development of a replacement for the incandescent lamp and this has been accomplished.

With the great variety of ongoing projects in the technology and consumer products program, Cuttica agrees that not all of them can be expected to be huge successes. There are too many potential roadblocks—technical problems, high costs, and unpredictable consumer tastes, to name a few. "We won't always have winners," Cuttica says. "Nevertheless, we think that our record so far shows that the program will pay off handsomely for some time to come." ■

International Exchange on Power Plant Cooling

Economic and environmental issues have become the driving forces behind the search for new cooling techniques. Ten nations recently shared their research emphasis and experience.

Cooling-tower specialists from 10 nations met in San Francisco recently to discuss an increasingly serious worldwide problem: the need to find better ways to cool new electric generating plants.

The meeting was an International Association for Hydraulic Research (IAHR) workshop sponsored by EPRI. In all, 65 cooling experts attended the sessions, and 34 technical papers were presented on subjects ranging from improved methods of gathering cooling tower data to the design of new cooling tower systems.

"This is the age of large-scale societal problems," observed John Kennedy, president of IAHR, at a press conference held in conjunction with the workshop. He noted that improving cooling tower technology touches on three of today's most pressing concerns: nuclear power, water shortages, and environmental pollution. "For example," he said, "every steam-electric power plant, regardless of its fuel source, produces about twice as much reject energy in the form of heat as it does usable energy. Reject energy must be dissipated for the plant to operate at an efficient temperature. This is where cooling towers come into use."

Conventional cooling towers rely almost exclusively on water and are completely adequate for the purpose of cooling. They do, however, consume enormous amounts of water—10,000 gal/min (631 m^3/s) for a typical 1000-MW plant. And they can produce adverse environmental effects, including fog and artificial clouds, or plumes, which disperse tiny droplets of salt water across a wide area. In some cases, these droplets may freeze, causing icing of roadways.

The purpose of the workshop was to exchange information on new techniques that lessen environmental effects but still provide efficient and effective cooling. It's possible, for example, to build dry towers that use no water. Three or four dry towers are needed to replace one wet unit, however, and this quadruples costs. A compromise is a combination of wet and dry units that reduces water consumption about 75%. This system costs about half as much as a dry system and about twice as much as a wet one.

In the United States, reducing power plant dependence on water is important both in the East, where water is still generally plentiful but siting is a problem, and in the West, where siting is less critical but water is becoming increasingly scarce. Because of the water shortage in the West, several dry and wet-dry cooling systems have been, or are being, built despite the added costs. One such plant, which was discussed at the work-

Responding to questions posed at the recent workshop on cooling towers were (from left) Lionel Caudron, Electricité de France; John Kennedy, IAHR president; and L. A. West, South African Electricity Supply Commission.

shop, is being built for Pacific Gas and Electric Co. in Bakersfield, California. This test system uses ammonia instead of water as the cooling medium.

In Europe, fuel costs and, more recently, environmental concerns have dominated cooling tower R&D. Because of the added cost of alternatives, the French are trying to improve the efficiency of wet systems and are resorting to dry or wet-dry towers only when forced to do so by extreme public reaction against plumes. Lionel Caudron of Electricité de France, for example, said his organization forecasts using ocean water as the source of cooling water for France's extensive nuclear power program over the next decade.

West Germany is just beginning to face water shortages, so research there has centered on analyzing the effects of wet-tower plumes in order to deal with the growing hostility to these artificial clouds. Gunter Ernst of the University of Karlsruhe explained that they have not been able to detect any measurable effect on plant growth beyond 1 km from a power plant, but he added that such reports have not convinced some German vintners, who claim the clouds are adversely affecting their grapes.

Concerns in South Africa are quite different. L. A. West of Electricity Supply Commission noted, "We have large reserves of coal but not much water. Consequently, we have a large program to use dry systems for our large power plants."

John Bartz, manager of EPRI's heat rejection activities, emphasized the importance of the international scope of the conference, noting that different aspects of the problem are being studied in different areas of the world. "There's a great deal of important cooling-tower R&D going on overseas," he said. "It's through conferences like this that we can make this information available to EPRI member utilities." ■

World's Largest Battery System

The world's largest battery system will soon be helping utilities find ways to lower their dependence on oil and natural gas. A 5-ft (1.5-m), 3000-t lead acid battery system will be built as part of a $20.3 million storage battery electric energy demonstration (SBEED) project in Hersey, Michigan. Under the cooperative agreement signed in October, DOE and EPRI will be joined in the project by Wolverine Electric Cooperative of Big Rapids and Northern Michigan Electric Cooperative of Boyne City.

DOE will put $11.3 million into the SBEED project, the two power cooperatives will contribute $8 million, and EPRI will provide $1 million. Completion of project design is expected in 1981, construction in 1984, and the beginning of commercial operation in 1985.

The two cooperatives will design, build, and test the SBEED plant, which will demonstrate the feasibility of a commercial-scale battery energy storage plant designed to help utilities meet peak demand, spinning reserve, and frequency regulation. These functions are usually met by burning high-cost oil and gas.

The results from SBEED will be combined with advanced battery performance information gained from the Battery Energy Storage Test (BEST) Facility, soon to begin operations in New Jersey. The two projects will assist in the early commercial introduction of advanced battery storage technologies.

Daverman Associates of Grand Rapids, Michigan, will act as project manager and architect-engineer for the two cooperatives. United Technologies Corp., Power Systems Division, of South Windsor, Connecticut, will supply the necessary bidirectional ac-dc converter to adapt the incoming and outgoing power for battery storage. ■

Seminar on Coal Transportation

The Second Coal Transportation Research Seminar, sponsored by the Supply Program in the Energy Analysis and Environment Division, was recently held in EPRI's Washington, D.C., office. The meeting brought together representatives of the electric utility and railroad industries, government officials, and members of interested trade associations to review and discuss past and present research in coal transportation.

The seminar was organized by Edward G. Altouney, project manager for energy delivery and storage, who pointed out that the research is vital because current EPRI estimates show that coal movement in the United States will grow from 600 Mt in 1978 to between 1.5 and 1.8 Gt by 1995.

Following a review of four completed research projects on transportation (RP437, RP866, RP944, RP952), Kenneth Ebeling discussed the EPRI-sponsored work now under way at North Dakota State University. Ebeling is gathering data on the location of new mines, the siting of new power plants, and the effect of expanded coal development on the national transportation system. The study is analyzing more than 3000 transportation links between mines and power plants in the United States, taking into account projected use of slurry pipelines and coal used at the source.

The seminar attendees also heard from C.A.C.I., Inc., a consulting firm in Arlington, Virginia, and its subcontractor, Synergic Resources Corp. of Bala-Cynwyd, Pennsylvania, who are conducting a major study on transportation network changes and their effect on energy supply (RP1912-3). C.A.C.I., Inc., reported that it is providing important information to utilities by analyzing existing data on all transportation networks—railroads, highways, barges, and pipelines; assembling a composite picture of coal movement throughout the country; projecting where future movements of coal are likely to increase beyond the current projected transportation capacity.

Future research recommendations discussed at the seminar included determining the costs of coal transportation through the year 2000, analyzing the rate-making procedure and its effect on the delivered price of coal to utilities, studying the costs of alternative coal transportation technologies, and improving transportation models and adapting them for utility use. ■

CALENDAR

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

FEBRUARY

22–24
Symposium on Integrated Environmental Controls for Coal-Fired Power Plants
Denver, Colorado
Contact: Dan Giovanni (415) 855-2442

MARCH

25–27
Load Forecasting Symposium
Kansas City, Missouri
Contact: Robert Crow (415) 941-6637

SEPTEMBER

15–17
Workshop on Modeling of Cooling Tower Plumes
Chicago, Illinois
Contact: John Bartz (415) 855-2851

21–25
Workshop on Zero Discharge
Steamboat Springs, Colorado
Contact: Roger Jorden (415) 855-2463
Ronald Kosage (415) 855-2869

Canadian Visitors

Several members of the Canadian House of Commons and their technical staff visited EPRI recently to discuss alternative energy and oil substitution. Among the participants were (clockwise from center) Ronald Wolk, manager of EPRI's Clean Liquid and Solid Fuels Program; Richard Rhodes, planning analyst in EPRI's Research Applications Section; G. M. Gurbin, MP, Canadian House of Commons; D. Clay, Canadian technical staff; and Kenneth Lundquist, Canadian Consulate, San Francisco. Other participants included A. MacBain, MP, Canadian House of Commons; G. S. McCauley, MP, Canadian House of Commons; J. E. Harrison, Canadian Embassy, Washington, D.C.; and L. Meyers and J. Beange, Canadian technical staff.

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

DYNAMIC RESPONSE OF A COMMERCIAL OXYGEN PLANT

In simulation studies, gasification–combined-cycle (GCC) power plants with oxygen-blown entrained gasifiers responded rapidly for electric load–following maneuvers (RP913). Moreover, the load-changing capability of the associate oxygen production plant was shown to be important to the design and operation of such GCC plants. A project was undertaken to verify experimentally that a large commercial oxygen plant (1000 t/d) can make rapid changes in production rate without sacrificing performance (RP1806). The results have particular significance for the Cool Water GCC demonstration plant being sponsored by EPRI and others.

Oxygen is produced commercially as a high-purity gas or liquid by cryogenic air separation processes, which also yield nitrogen and argon. Oxygen production plants are generally designed for steady baseload operation, with any load changing at relatively slow rates (10–15%/h) to maintain high levels of product purity. Higher rates of change may be met by evaporating stored liquid oxygen to increase load or by venting oxygen to reduce load, but this option would be expensive for frequent, large changes in load. GCC applications, however, do not require high levels of oxygen purity (exceeding 99%), nor must purity be held within close tolerances. Therefore, if it is possible to make reasonably fast load changes in air separation plants without drastic variations in product purity, GCC facilities will not need costly systems for storing and venting liquid oxygen.

Air separation unit tests

Dynamic response tests were conducted in April 1980 on a 1000-t/d air separation unit at a high-purity oxygen plant recently constructed by Air Products & Chemicals, Inc., in La Porte, Texas (Figure 1). This series of tests covered process equipment from the air compressor to the cryogenic fractionation column (cold box). The oxygen compressor was not available for testing at that time.

Changes in gaseous oxygen output (from the cryogenic fractionation column) were achieved at rates well beyond those targeted for demonstration. Step changes of up to 15% of design flow were virtually instantaneous under both full- and part-load conditions. Load was also changed continuously over the wider range from 75% to 108% of design flow at a rate of 2%/min. Oxygen purity was effectively controlled at 99%, ±0.2%, which is well within the operating requirements of a Texaco entrained gasifier.

Closed-loop computer control was an important factor in the success of these tests. Coordinated feedforward adjustment of plant flow rates permitted the load changes to be made under well-balanced operating conditions. The tests have shown that a computer-controlled oxygen plant is responsive enough to be coupled with a GCC power plant for load-following applications. Beyond the immediate results, the demonstrated success of coordinated oxygen plant control also sets a good example for GCC plant control. That is, a coordinated control strategy would permit each GCC process component to be varied according to an optimal load change schedule.

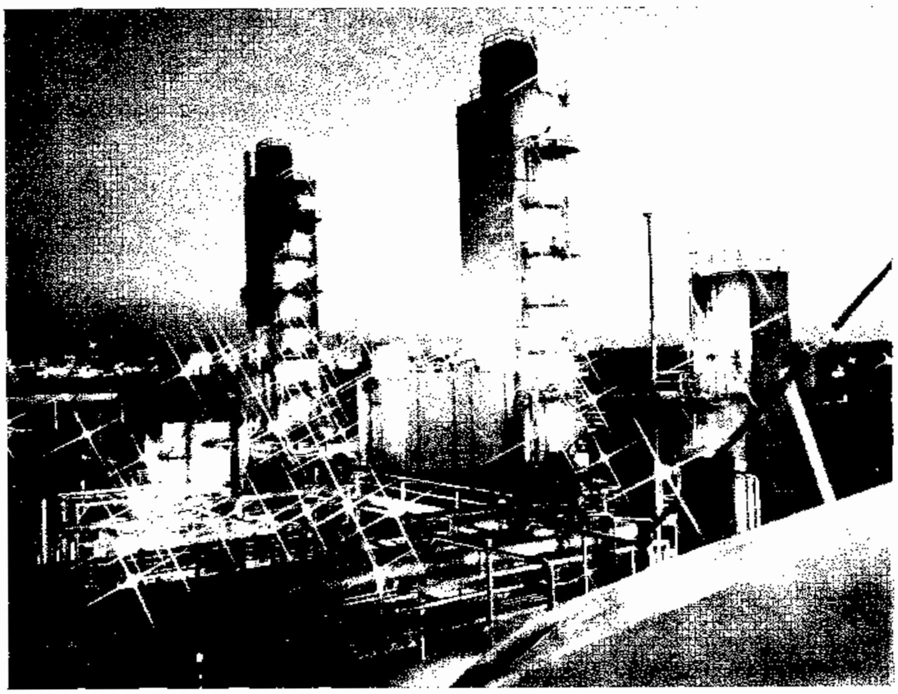


Figure 1 Air Products & Chemicals, Inc., conducted dynamic response tests at its oxygen plant in La Porte, Texas. Shown are the cryogenic fractionation columns of the plant's air separation units.

Oxygen compressor tests

Another series of dynamic response tests was conducted at the La Porte plant in August 1980 to include the centrifugal oxygen compressor, a key component in plants supplying pressurized oxygen to gasifiers. In GCC applications it is very likely that an oxygen plant will be a dedicated unit, which means it will not have the customary large supply header. Therefore, without this large buffering volume, good compressor control is essential.

Two types of test were conducted: (1) compressor-only transients, in which the oxygen supply from the fractionation column was constant and the compressor output flow was varied by venting at the inlet; and (2) overall plant transients, in which the inlet guide vanes to the oxygen compressor were opened wide and the compressor output flow was varied by changing the oxygen production rate of the air separation unit upstream. In both types of test, load changes in steps of 8–10% and 20–25% were achieved successfully. The compressor alone achieved rates of up to 25%/min. The total plant maneuvered over an 8% increment in 1 min and over a 20% increment at a rate of 3%/min; these results are consistent with those of the earlier air separation unit tests.

It is important to note that the tests in the August series were made in rapid succession, involving seven sharp reversals in rate within a span of 45 min. This represents a stringent test of the mechanical equipment and of surge control capability. The successful results demonstrate reversal capabilities far beyond what GCC plant service is likely to demand under normal operating conditions.

Pressure control was well within a range of 5–10 psi (34–69 kPa) at a discharge pressure of 220 psi (1.5 MPa). The part-load performance of the compressor was also impressive, especially since this unit was not designed for load-following service. With attention to design criteria, part-load performance should be improved even further.

Results of this dynamic response demonstration lend further support to EPRI's emphasis on development of oxygen-based gasification technology. *Project Manager: George Quentin*

RELIABILITY AND AVAILABILITY MODEL FOR GCC PLANTS

Research is under way to ensure high reliability and availability in advanced power generation systems by (1) determining the critical components that adversely affect reliability and mitigating their impact, and (2) promoting improvements in system design and operating and maintenance philosophy early in the development cycle of a new system. As part of this work, more accurate reliability forecasting methods are being developed for thermomechanical parts and components, and reliability and availability assessments of proposed advanced power system designs are being performed. ARINC Research Corp. has constructed a reliability and availability model for coal gasification–combined-cycle (GCC) plants (RP1461-1). This report describes the model, the data collection effort, and early model applications.

Model development

The GCC plant design on which the model is based is shown schematically in Figure 2. A generic representation was used so that a variety of GCC plant types could be studied with only minor modifications to the model. The 1100-MW baseload system is composed of multiple gasification and power generation units. Thus, when one of these units is down for repairs, a large portion of the plant remains productive. For those subsystems in which a single large unit is technically possible and highly reliable (e.g., the coal handling and water treatment subsystems), the design has only one unit. The modularity and redundancy of the design contribute to a high operating availability for the total plant, analytically estimated to be 87%.

In the first phase of model development, a reliability-only model was prepared, reliability being defined as the probability that the plant will perform satisfactorily for a specified period of time. Because this version of the model does not include repairs but allows the plant output to steadily decrease as a result of subsystem failures, it highlights specific inherent weaknesses in reliability. In the second phase of development, the model was extended to provide an availability measure by incorporating time losses attributed to startup, cooldown, administration, waiting, and actual repair. In this version of the model, the plant output does not continuously decrease but reaches a steady-state average level, which is the operating availability of the system.

As a result of this two-part approach, system sensitivity to changes in component reliability can be analyzed without being obscured by maintenance policies. Also, the appropriate balance between maintenance and redundant configurations can be determined for unreliable components that are difficult or expensive to improve.

The model evaluates the possible capacity levels at which the plant may be operating over a series of discrete time intervals. The time increment used is short, making it highly unlikely that more than one event that might change the capacity level will occur during one interval. This facilitates computation, which might otherwise be quite burdensome. At the beginning of the analysis, the model assumes the plant to be fully operational; the probability assigned to this condition is 1 (100%) and that assigned to all other operating conditions is 0. Failure rates have been established for each component and are now applied to determine the likelihood that the plant's operating condition will change by the end of the first time interval. The plant may fail entirely, may continue to be fully operational, or may enter one of many other states.

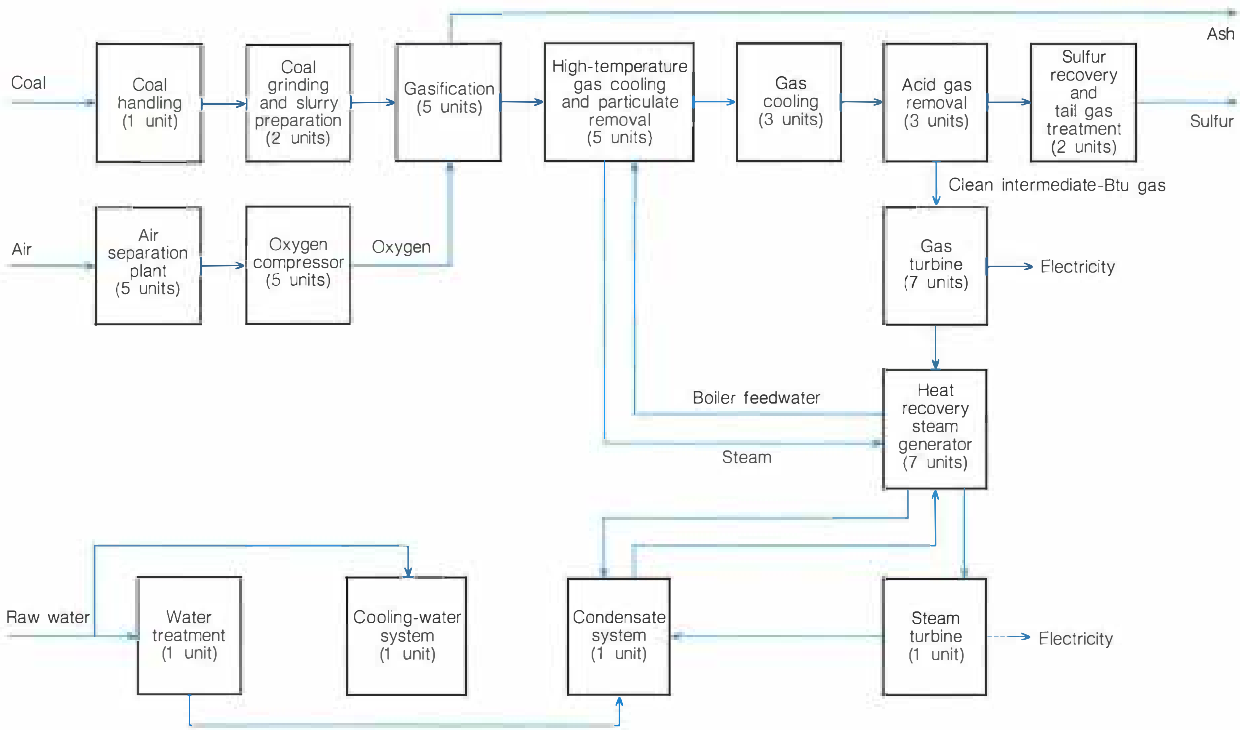
At the end of each time interval, the probability that the plant's capacity level will remain constant is calculated, as well as a probability for each possible change in level. The model keeps track of all the possible levels during each interval. A history of the plant's probability of operation at each level is thus developed through the analysis: reductions in output due to component failure, increases in output due to repairs, and the expected output at each time interval. In addition, sensitivity analyses of failure rates allow the identification of critical components.

Data collection

The model is one important aspect of reliability and availability evaluation; the data used are another. Just as the model must be correctly structured to give useful results, the data must realistically reflect probable field experience. Among those contacted for data for this project were major turbine manufacturers, the National Electric Reliability Council, gas transmission companies, the Government-Industry Data Exchange Program, the Institute of Electrical and Electronics Engineers, and the Nuclear Regulatory Commission.

The data collection effort produced few results and demonstrated that there is no readily accessible, consistent data base for use in evaluating a GCC plant design. Individual manufacturers may have data on their products, but these are usually not available. As a result, a complete and consistent data base of failure rates was constructed by ARINC, EPRI, and Fluor Engineers and Constructors, Inc., on the basis of published material, discussions with operating personnel, analyses of component failure modes and effects, and expert opinion. This

Figure 2 Major processes in the 1100-MW generic GCC plant model. The system includes multiple gasification and power generation units so that a large portion of the plant remains productive when individual units are down for repair.



data base has many potential applications beyond the current project.

Since there is uncertainty associated with the data used, component failure rates were varied over a wide range and the effects on predicted plant performance were determined. Some of the results are shown in Table 1. The first failure rate given for each component, called the baseline rate, is assumed to be representative of the most likely real value. It should be noted that if the baseline rate underestimates component reliability or if the component is improved, the effect is significant but small; however, if the equipment is not as reliable as expected, the effect is quite damaging. This stresses the need to ensure component quality at the earliest stages of design.

Model applications

A general case was run with the model. The data used are available for review by inter-

Table 1
IMPACT OF SELECTED COMPONENT FAILURE RATE CHANGES ON PLANT PERFORMANCE

Component	Failures/Yr	Average Operating Capability Over 20 Days' Operation Without Repair
Gasifier waste heat boilers (3 boilers)	3*	48.43
	0.3	49.58
	30	33.73
Gasifier	2*	48.43
	0.2	49.59
	20	37.78
Air separation unit	0.5*	48.43
	0.05	48.72
	5	45.56

*Baseline (most likely) failure rate.

ested persons; suggestions and field data are welcome for inclusion in subsequent work.

Specific components were ranked according to their criticality to the system, criticality being defined as the degree of impact on system performance of a 10% change in the component's failure rate.

- Gas turbine unit, including generator (rank 1)
- Heat recovery steam generator coils and refractory (rank 2)
- Gasifier waste heat boilers (rank 3)
- Gasifier system, unit 1 (rank 4)
- Gasifier (rank 4)
- Ash-handling system, unit 6 (rank 6)
- Belt conveyor No. 1 (rank 7)
- Belt conveyor No. 2 (rank 7)
- Makeup tank agitator (rank 7)
- First-stage oxygen cooler (rank 10)
- Fourth-stage oxygen cooler (rank 10)

This list is a guide to the value to the system of improving specific components. Plant design engineers who reviewed the list, although agreeing with it in general, were somewhat surprised at a few of the results. On further study, however, they accepted the list as prepared from the model analysis.

Figure 3 Plant operating availability as a function of time. The output of a plant decreases continuously when no repairs are made; with corrective maintenance, plant output reaches a steady-state level at 87% of maximum.

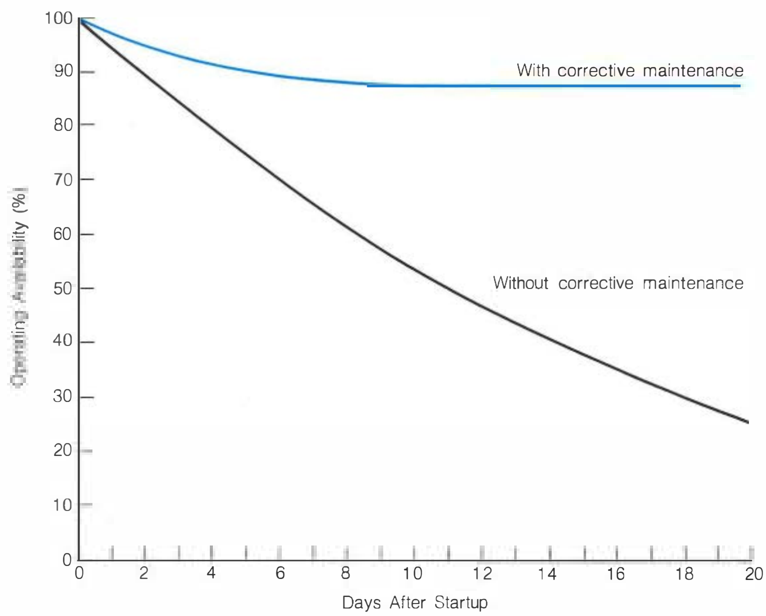


Figure 3 depicts expected operating availability as a function of time. At startup, expected operating availability is 100%; it then drops until it levels off at 87% after the tenth day.

The model has also been applied in connection with the GCC demonstration plant to be built by Southern California Edison Co., EPRI, Texaco, Inc., General Electric Co., Bechtel Corp., and others at SCE's Cool Water site. The general configuration of this prototype plant is similar to that in Figure 2. The subsystems generally do not have multiple units, however, since the planned output of the plant (100 MW) can be achieved with a single gasifier and a single power train, using available equipment. Reliability can be improved only by redundancy or by using different equipment. The model was applied to determine which of four design configurations would provide the highest level of availability. These configurations differed with respect to redundancy in different sections.

The results of this evaluation, with the supporting analyses and data, were presented in June 1980 to the board overseeing the Cool Water project. The board has accepted the methodology and the results as valid and has used them in making a decision to implement one of the four proposed design configurations. The analytic method will continue to be used in this project as better data become available.

The model and complete directions for its use are contained in EPRI report AP-1610. *Project Manager: Jerome Weiss*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

COAL-CLEANING TEST FACILITY

Conventionally cleaned coal has several advantages over raw coal as a fuel for power generation. In many cases its use can result in lower flue gas desulfurization requirements, an increased boiler capacity factor, lower waste disposal requirements, and lower shipping costs. Coal cleaning is receiving increased attention from the utility industry, and an EPRI test facility scheduled to begin operation in August 1981 will play an important role in the evaluation of its costs and benefits.

Project background

The concept of a cleaning test facility for steam coal originated about 10 years ago, when it began to become apparent that steam coal quality would become an issue of increasing economic and environmental importance to the utility industry. At that time cleaning was an accepted practice in preparing metallurgical coals for the steel industry, but the use of clean coal for power production was still regarded as too expensive in most cases.

In the last decade, however, important changes have occurred that are stimulating utility interest in coal cleaning. Although coal costs have escalated rapidly, run-of-mine coal has been deteriorating in quality because of an increased emphasis on mine mechanization and productivity; the higher ash content of this coal can create operating problems in many existing boilers. Also, concern about the environmental effects of ash and sulfur emissions from coal-fired plants has grown. As a result of these developments, EPRI revived the coal-cleaning test facility concept in 1978.

After discussions with representatives from the coal preparation industry, the engineering community, and the utility industry, EPRI engaged Birtley Engineering, a division of Sverdrup & Parcel and Associates, Inc., to develop a conceptual design for the facility. On receipt of Birtley's report in August 1978, the project was authorized, and the utility industry was canvassed for a site. From 24 sites offered by 16 companies, EPRI selected one in western Pennsylvania near the Homer City station of Pennsylvania Electric Co. (a subsidiary of General Public Utilities Corp.) and New York State Electric & Gas Co. These utilities and Empire State Electric Energy Research Corp. joined the project as cosponsors.

GAI Consultants, Inc., originally hired to evaluate the potential sites, later assumed responsibility for permit applications, geotechnical services, site engineering services, and excavation and inspection services (RP1400-1). Kaiser Engineers, Inc., undertook the engineering specification development necessary to enable fixed-price bidding on detailed design, procurement, and construction of the facility (RP1400-3). In October 1979 Roberts & Schaefer Co. was selected to undertake the detailed design, procurement, and construction phase of the project (RP1400-5). An EPRI project management office was also opened in Monroeville, Pennsylvania, in late 1979 to expedite work on the facility. The financing of the facility (by industrial revenue bonds sold in March 1980) represents a new approach for EPRI.

During the past year, design and procurement have been completed. Mass excavation and compaction work, begun in November 1979, was completed in August 1980. Construction is proceeding, and the facility should be under cover before severe weather sets in (Figure 1). Bids for operation were received in September, and the contractor will be selected by the end of the year so that facility operation can begin by mid-1981 (RP1400-6).

Operating plans

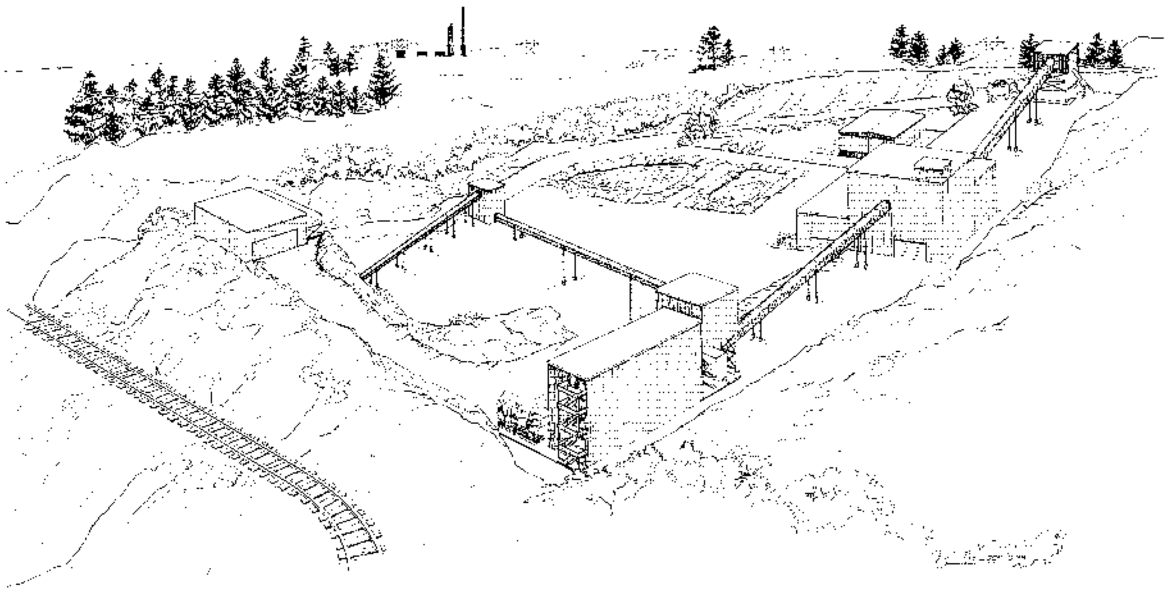
The objectives of EPRI's coal-cleaning research are to lower the cost of clean coal and to provide a fuel of better and less-variable quality. The test facility will be used to characterize the cleanability of various steam coals (including verification of cleaning plant flow sheets) and will provide a means of demonstrating coal-cleaning technology developed by EPRI, the utility industry, and others. It is also intended as a training center for coal preparation plant engineers and operators and coal-cleaning R&D managers. As presently designed, the facility can perform the following operations.

- Process large quantities of coal in conventional flow sheet configurations and simulate the conditions of a full-size plant
- Perform closed-loop testing on conventional equipment
- Perform open-loop testing on conventional equipment dedicated to fines recovery
- Verify sampling methods for solid and slurried coal
- Verify process control instrumentation that has not previously been applied in the coal-cleaning process
- Develop and demonstrate automated plant operation and control

Conventional coal-cleaning processes will be tested during initial operations to generate basic data on the facility's operating characteristics; such data are required before research into other methods of coal cleaning begins. Because the technology incorporated in the facility will be periodically improved on the basis of development and operating advances, tests and operating procedures will be adjusted to reflect these improvements. The facility is very flexible, and existing equipment can be modified or new equipment added without making significant structural changes. Also, the facility can be expanded to accommodate new coal-cleaning processes as they are developed.

Because of its large processing capacity, the facility will yield large quantities of clean

Figure 1 EPRI's coal-cleaning test facility in Homer City, Pennsylvania, where new coal-cleaning technologies will be demonstrated. The facility will also serve as a training center for engineers and operators.



coal and refuse for further testing. Extensive sampling, monitoring, and process control systems are installed in the facility for on-line data gathering; the suitability of these systems in coal-cleaning operations will be evaluated. Although the testing program will be primarily responsive to the needs of the utility industry, the technical information developed will be communicated to the other sectors of the coal industry; technical advice from these sectors will be sought through an EPRI coal quality advisory group.

A request will be made to utilities in the near future to assist EPRI in the selection of test coals and in startup and operation of the facility. This will give utility personnel an opportunity to gain experience at a plant that can simulate all the conditions of a full-size commercial plant using the specific coals of interest to the utility. *Project Manager: Douglas Trerice*

AFBC PILOT PLANT

Atmospheric fluidized-bed combustion (AFBC) of coal represents a potentially attractive alternative to conventional pulverized-coal combustion for several reasons. An AFBC boiler can be fired with a very broad range of fuels and does not require a flue gas desulfurization (FGD) system. Nitrogen oxide (NO_x) emissions are maintained below current New Source Performance Standards as a result of the boiler's relatively low operating temperatures, which also prevent ash slagging and fouling and thus enhance reliability and fuel flexibility. Through its AFBC research program, EPRI has been working to realize these benefits for utilities. Currently, it is participating with the Tennessee Valley Authority (TVA) in the development of a 20-MW (e) AFBC pilot plant that will be used to test full-size hardware and process designs (RP1860).

In AFBC, coal is burned in a fluidized bed in the presence of calcined limestone (CaO). Combustion air is supplied uniformly at the base of the bed, which causes fluidization; this produces the unique characteristics of high gas-solids mixing and high heat capacity in the bed. Because sulfur dioxide (SO_2) is absorbed by the limestone, the need for a postcombustion FGD system is eliminated. Heat is removed from the fluidized bed by submerged heat exchange surfaces designed to maintain the combustion temperature at approximately 1550°F (843°C) versus approximately 3000°F (1650°C) in pulverized-coal furnaces. At this temperature, sulfur capture by the limestone, which calcines in the bed to form CaO, is optimal and NO_x formation is reduced. Also, slagging and fouling of the heat exchange surfaces by coal ash are prevented because the temperature is well below the softening and fusion points of the ash for many coals (~2000°F, 1093°C).

Preliminary development efforts

Several small-scale, industrial AFBC boilers are currently under construction or operating in the United States, including installations at Georgetown University (built by Foster Wheeler Energy Corp.), the Great Lakes Naval Training Center (built by Combustion Engineering, Inc.), and the Ohio State Psychiatric Hospital (built by Babcock Contractors, Inc.). EPRI has been a leader in the development of AFBC boilers for utilities through the operation of its 2-MW (e), 6-by-6-ft test facility at Babcock & Wilcox Co.'s Alliance (Ohio) Research Center (RP718). This plant has substantially increased the data base on AFBC since it began operating in early 1978.

EPRI has also cooperated with TVA and DOE in developing conceptual designs for utility-scale AFBC boilers (200–600 MW [e]) since 1977, using design information and operating data from the 2-MW (e) facility. Although economic studies have shown AFBC boilers to be competitive with pulverized-coal boilers equipped with scrubbers, uncertainties still exist regarding hardware and process scale-up. These uncertainties involve the ability to feed coal and limestone to a large, shallow fluidized bed; boiler turndown and control; fly ash collection and reinjection into a large bed; and long-term operability and reliability.

Because of its relatively small size, the 2-MW (e) test facility cannot be used to evaluate some of the uncertainties identified in the commercial design studies by EPRI, TVA, and DOE. In early 1979 TVA, in conjunction with EPRI, developed the specification for an intermediate-size (20-MW [e]) pilot plant that would be large enough to address these uncertainties and to serve as the precursor of a 200-MW (e) AFBC plant. In September 1979 Babcock & Wilcox was selected to design this pilot facility and to construct it at TVA's Shawnee station near Paducah, Kentucky. The costs associated with design and construction are being borne by TVA, while the costs associated with operation and testing are being shared by EPRI and TVA.

The facility is scheduled for completion in early 1982. A formal test program will follow, running through 1986. The unit will be used to resolve large-scale hardware uncertainties, while EPRI's 2-MW (e) unit at Alliance, Ohio, will be used primarily for process optimization.

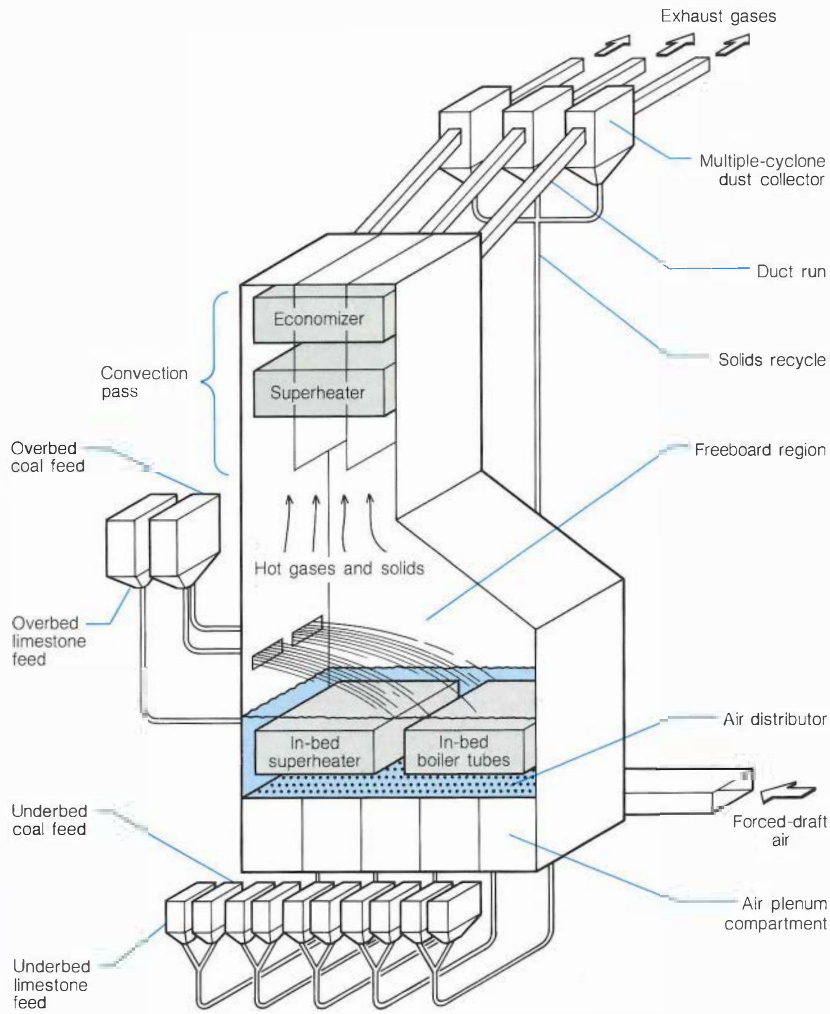
Pilot plant design

The pilot plant (Figure 2) is designed to provide extensive hardware and process flexibility and to be representative of a large-scale 200-MW (e) facility. The base of the unit, supported by an air distributor, contains the fluidized bed, in which boiler tubes and superheater tubes are located. The air plenum under the air distributor is divided into five compartments to allow portions of the bed to be removed from service at reduced loads. Each compartment has separate coal, limestone, and air control.

The hot combustion gases and fine solids are carried from the bed into the freeboard en route to the convection pass, which contains economizer and additional superheater surfaces. The freeboard height is designed to enable duplication of the time-temperature history of solids and gases in a large utility furnace. The convection pass and flue are divided into three segments, permitting flexibility in flow area and velocity. Each of the three streams passes through a multiple-cyclone dust collector. The collected solids are then routed through a recycle system and reinjected at the base of the bed. After passing through a regenerative air heater, the gases leave the unit through a baghouse.

The unit can operate with a bed depth of 2–6 ft and a nominal fluidizing velocity of 4, 8, or 12 ft/s. Coal and limestone can be fed underbed, overbed, or both, and the underbed feedpoint spacing can be changed. In addition to the baghouse, the unit has a small electrostatic precipitator, which will be tested on a slipstream in the gas flue.

Figure 2 The TVA 20-MW (e) AFBC pilot plant is designed for great flexibility. The unit can be fed from either overbed or underbed limestone and coal bunkers, and the air plenum and convection pass are compartmentalized. The duct runs are designed to facilitate extensive sampling and metering.



Test program

Testing at the 20-MW (e) pilot plant will seek to develop and demonstrate the following.

- Load-following and load-control capability
- Simplicity and reliability of coal and limestone feeding
- High combustion efficiency and sorbent utilization

- Materials integrity
- Long-term system reliability and operability
- Fuel flexibility (i.e., ability to burn lignites and high- and low-sulfur coals)
- Environmental acceptability

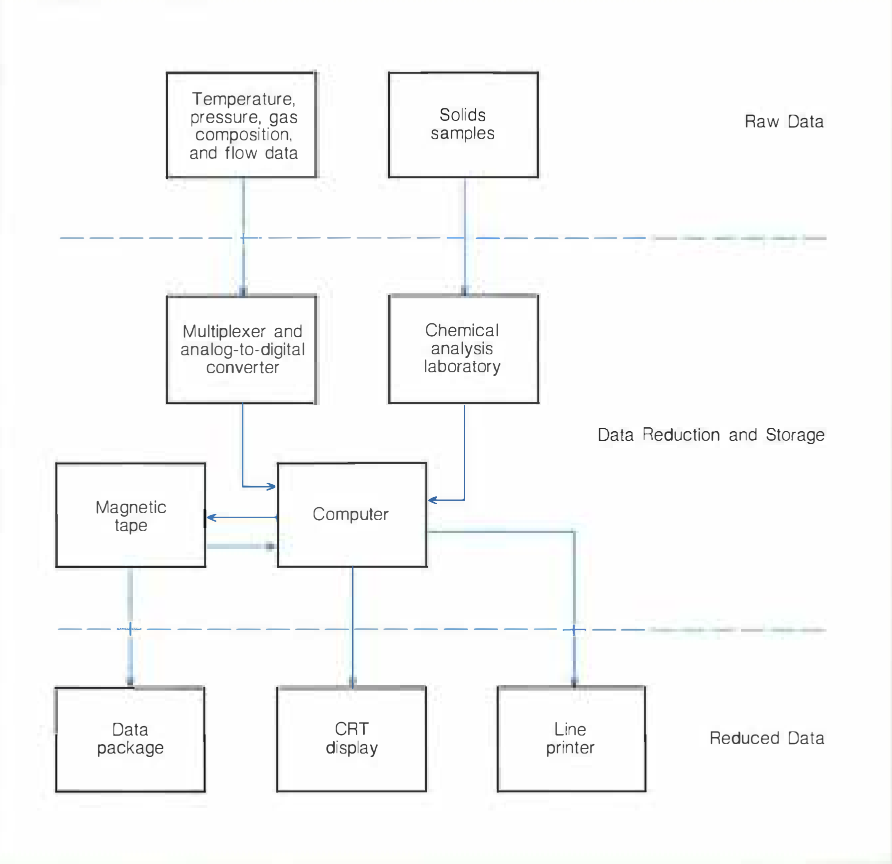
A comprehensive test program is now being developed by EPRI and TVA to define the scope and schedule of the testing. The program will specify the conditions of each run, the data required, and the analyses to be performed. Well-developed data acquisition, reduction, and reporting capabilities are necessary to support this program and permit the quick, on-site determination of test results. Thus the pilot plant's design features extensive monitoring and sampling equipment, a control and data acquisition computer, and a sophisticated chemical laboratory.

The scope of process performance calculations was determined early in the planning to ensure that the monitoring, sampling, and analysis capabilities of the plant would be sufficient. Because rigorous heat and material balances will be required, all input and output streams must be metered accurately and must permit sampling for both gases and solids. All pressures, temperatures, flows, and gas analyzer outputs will be multiplexed and inputted into a Bailey 1055 computer, which will periodically scan and average the data points. The computer will then use the reduced data to execute the performance calculations, which have been coded in Fortran IV.

Many of the calculations required results from the chemical analysis of solids samples (coals, limestone, fly ash). Thus an on-site chemical laboratory has been designed to expedite the handling of these samples. The main features of the chemical laboratory include an elemental analyzer, an atomic absorption spectrophotometer, a sulfur analyzer, a thermogravimetric analyzer, and a calorimeter. Results from the chemical analyses will be manually inputted into the computer for the performance calculations.

Outputs from the various performance calculations can be logged on magnetic tape, displayed on a CRT screen for the operator and the results engineers, and logged on a line printer. A typical data package from a particular test run will consist of logged performance summaries, process operating summaries, and heat and material balance summaries, as well as raw and reduced data stored on magnetic tape. Figure 3 shows the flow of information in the system. *Project Manager: William Howe*

Figure 3 Information flow for the TVA pilot plant test program. The computer scans and averages the data and executes performance calculations. Results can be monitored on a CRT display or a line printer or stored on magnetic tapes. Data packages, including performance calculations, raw data, and reduced data, are available from the tape storage.



R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

UNDERGROUND TRANSMISSION

PPP laminate for 138–550-kV pipe-type cables

In a continuation of a successful effort by DOE, EPRI, and Phelps Dodge Cable & Wire Co. to develop a 765-kV polypropylene-paper (PPP) laminate pipe-type cable (RP7812), Phelps Dodge is beginning a new project to apply the PPP technology to 138–550-kV commercial pipe-type cables (RP7880).

Based on longtime dielectric studies and tests on PPP laminates in many countries, this insulation system has exceptional stability, high dielectric strength, and a very low dissipation factor. These characteristics, which make PPP laminates excellent candidates for advanced, pipe-type cable designs, were evident in the extended 550/765-kV tests at the Waltz Mill Underground Cable Test Facility on Anaconda Wire and Cable Co.'s polypropylene cellulose joint insulation and have been corroborated by longtime cable model aging tests at 100°C in dodecylbenzene (Figure 1).

As a result of the high dielectric strength (30–35% greater than impregnated paper), very low dissipation factor, and reduced dielectric constant, substantial reductions in insulation thickness and dielectric losses are feasible. Although cellulose paper insulation thicknesses can be reduced by higher-stress designs, reduction of the insulation geometric ratio, ℓn D/d, results in increased charging currents and unacceptably high losses.

With PPP laminate insulation, on the other hand, there are now additional parameters for optimizing cable designs and thus reducing overall transmission costs and losses. One such preliminary approach to optimizing cable designs is indicated in Table 1, which shows PPP insulation thicknesses and design stresses. Note that for 345 kV and under, the design operating stresses are less

Figure 1 Longtime stability of PPP cable samples aged at 100°C.

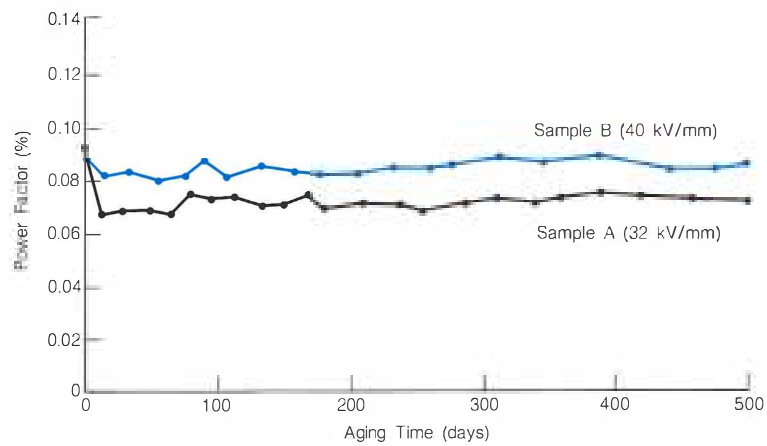


Table 1
PPP INSULATION DESIGN STRESS

Voltage Rating (kV)	Insulation Thickness (in)	Maximum Design Stress Operating (kV/mm)	Maximum Design Stress Surge (kV/mm)	BIL; BSL* (kV peak)
550	0.750	23.35	132.4 114	1800 1550
345	0.500	20.0	131 105	1300 1050
230	0.350	17.9	141.5 121.5	1050 900
138	0.250	14.3	117 90	650 550

*BIL = basic impulse level; BSL = basic surge level than half the longtime model-aging stresses of 40 kV/mm (1000 V/mil).

A preliminary economic analysis comparing PPP cable first-cut designs with designs of conventional paper cables indicated that the favorable reduction in cable dimensions (permitting reduction in pipe size) and reduction in dielectric losses can result in substantial savings in total, installed annualized costs, even for voltages as low as 138 kV. For example, the cost savings for using preliminary designs of 138–345-kV PPP cable for 914 km (3 million feet) of cable (which is 65% of *Electrical World*'s estimated five-year U.S. requirements) was calculated to be $21 million.

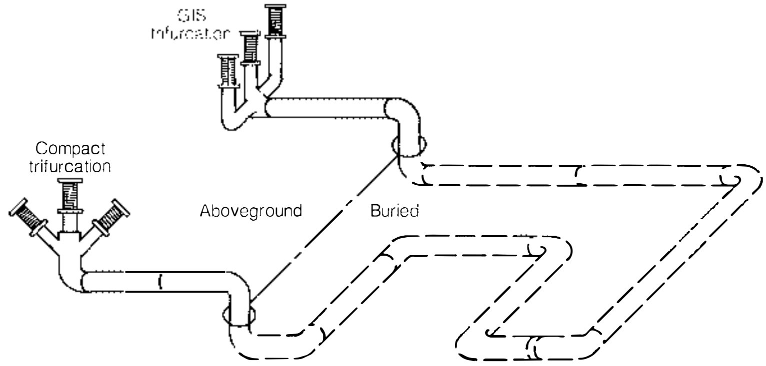
With these new laminate insulations it will be possible to economically uprate existing underground transmission systems by two voltage levels.

Overloaded subtransmission arteries in congested cities could be replaced in existing pipes with PPP-insulated cables, achieving an attractive two-step voltage uprating. With the higher power-transfer interconnections thus made available, it will be possible to upgrade subtransmission: 69 kV to 230 kV, 138 kV to 345 kV, and 230 kV to 550 kV. For example, it would be possible to upgrade 138-kV substations to 345 kV by using a gas-insulated (SF_6) enclosed bus. And in existing pipe, installation of PPP-insulated cables could increase a substation's capability from 250 MVA at 138 kV, to 700 MVA at 345 kV. These new arteries would substantially increase the capabilities of existing subtransmission systems and systems reliability (required for planned load growth) and reduce energy losses at the more efficient higher voltages. *Project Manager: Stephen Kozak*

Three-conductor gas cable field demonstrations

In a cost-shared effort, the Detroit Edison Co. has contracted with EPRI to be the first utility to demonstrate a new 345-kV, three-conductor, gas-insulated transmission cable (RP7840-2). Westinghouse Electric Corp., the cable manufacturer, has supplied a 183-m (600-ft) test loop to Detroit Edison for installation, test, and operation as an integral part of its transmission system. This loop includes two termination designs and a wide variety of cable sections and bends; most but not all of the loop is buried so that both above-grade and below-grade thermal environments can be represented (Figure 2). An extensive monitoring and data acquisition system has been installed, and the cable system will undergo two years of operation and testing.

Figure 2 Layout of the Westinghouse three-conductor, gas-insulated, underground transmission test loop. The 345-kV/2000-A loop, which is 183 m (600 ft) long, has been installed on the Detroit Edison system.



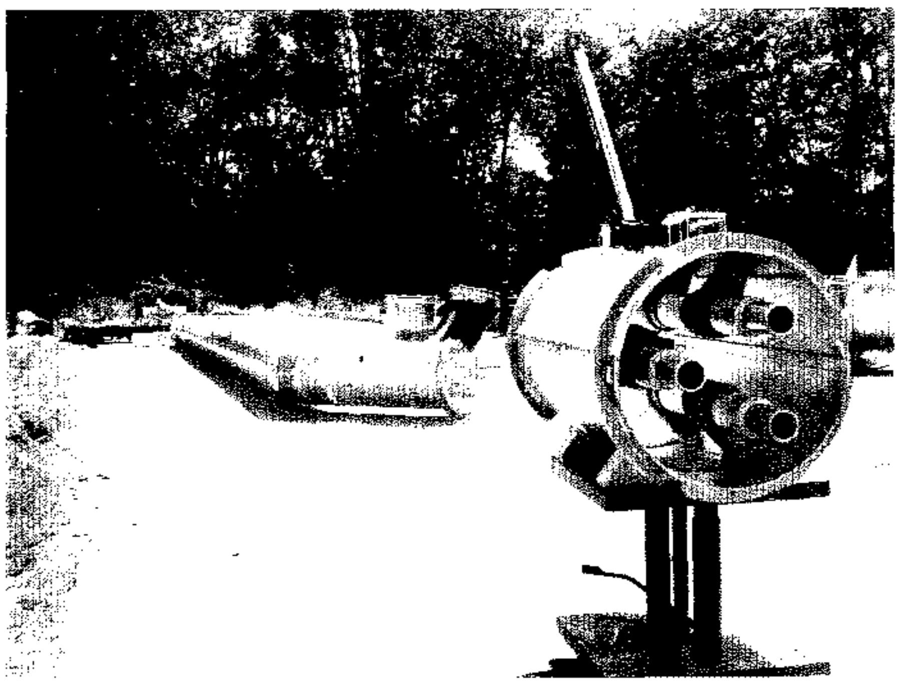


Figure 3 Three-conductor, gas-insulated sections ready for installation at Detroit Edison.

Because the 71-cm-diam (28-in) cable enclosures designed by Westinghouse are too large to be extruded in one piece, they are made of three 120° extruded aluminum segments that are welded together longitudinally (Figure 3). An automatic welding line for the enclosure segments has been developed to ensure uniform weld quality and to lower the hardware cost. *Project Manager: John F. Shimshock*

TRANSMISSION SUBSTATIONS

Transformer life characteristics

Because transformers are key elements in maintaining high customer service reliability and quality, a knowledge of their performance and reliability characteristics under all system conditions is essential. To develop a better understanding of transformer reliability, EPRI has sponsored work at General

Electric Co. (RP1289-1) and at Westinghouse (RP1289-2). The specific objectives of these projects are to establish which parameters influence transformer loss of life, focus on test methods that may be employed in future research and transformer design, and gain a better understanding of the mechanism of transformer failure.

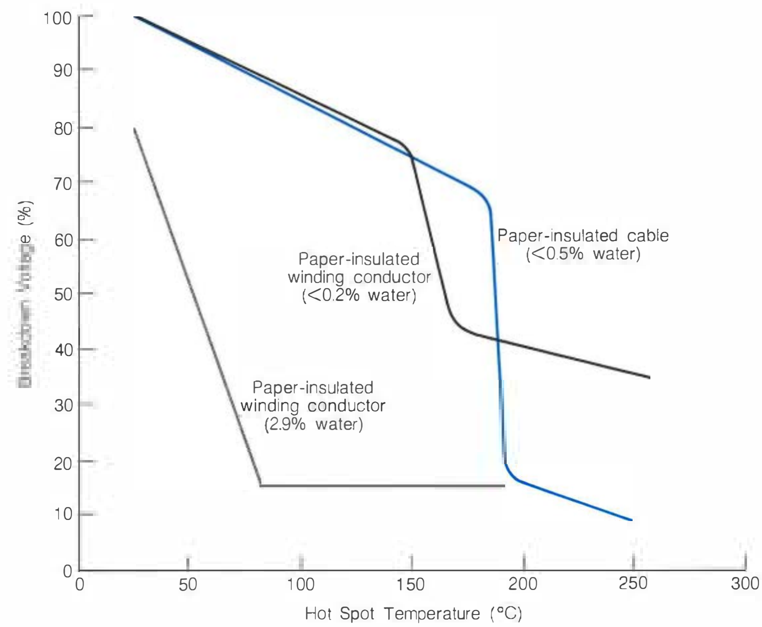
General Electric has tested the response of several types of cellulosic insulations to hot spot temperatures. In these tests, bubble formation occurred at as low a temperature as 140°C, and dielectric strength generally deteriorated in the 100–150°C range. Test results for winding and cable lead conductors gave similar results. The results also demonstrate that the dielectric strength of conductor insulation is much more sensitive to moisture content at elevated temperatures than at normal ambient temperature (Figure 4). Thus transformers that have accumulated high moisture content (during long periods of service aging, for example) could present higher risk when overloaded. Results also indicate that conductor insulation is most vulnerable to dielectric failure at the beginning of an overload, when the temperature is suddenly elevated to a level that can vaporize any moisture present.

Westinghouse has been evaluating the effect of bubble formation on dielectric strength from a slightly different perspective: The composition of bubbles formed during degradation was determined, and this gas mixture was then introduced into the turn insulation during testing. Westinghouse concluded that although dielectric strength is reduced by the presence of the bubbles, differences in the composition of the gas and in its flow rate affect the outcome only slightly. It was also concluded that under standard insulation processing conditions, the gases initially produced have a composition about equivalent to air; however, later degradation leads to formation of CO, CO_2, and other gases.

Both contractors have noted the detrimental influence of moisture, and both are currently testing subassembly models in an effort to simulate longer-term degradation phenomena.

The state of the art of evaluating transformer loss of life was reviewed at an EPRI-sponsored workshop in late 1979. The major conclusions to come out of the workshop were (1) the industry must come to grips with the bubbling phenomenon and related concerns; (2) research is needed to develop valid safety factors for loading; and (3) industry must focus on developing superior paper insulation or substitutes to ensure reliability. *Project Manager: Bruce Bernstein*

Figure 4 Variation of breakdown voltage with hot spot temperature for several paper transformer insulations shows that the dielectric strength is much more sensitive to moisture content at elevated temperatures. The breakdown voltage is given as a percentage of the dielectric strength of dry paper (<0.5% water) at 25°C.



Semiconductors for EHV switching applications

Power switching under surge conditions requires devices that can switch large momentary currents but need not be designed for continuous operation. By omitting the steady-state requirements, new latitude is permitted in the basic design of semiconductor devices used in such applications. Elimination of constant heat dissipation greatly reduces the ambient temperature of the device and allows it to tolerate a significantly greater temperature rise when it is eventually called upon to operate under fault conditions. In addition, package design can also be simplified.

Two contracts are under way to develop semiconductor devices for fault current switching. RP1511-1 and RP1511-2 are concerned with the design of surge phototransistors and surge photothyristors, respectively. Because a large number of these devices will be used in series at voltages of 100 kV and higher, it was deemed necessary to use a direct light-fired switching circuit to optimize electrical isolation. Because the devices will operate relatively infrequently, a simple, high-intensity light source, such as a xenon flash tube with a lifetime of 10,000 flashes, can be used. Such a design is simpler than that of the more esoteric laser diodes used for steady-state operation, where many billions of flashes are required over the life of the device.

Initial work on the projects involved computer modeling to determine optimal device parameters. The computations have suggested design improvements, and General Electric, the contractor, is preparing to fabricate the first devices. The surge phototransistor offers the greater challenge because it is inherently a lower-power device than the thyristor. However, the potential benefits of a successful transistor are great, as it could be used both in dc switching and in ac or dc current-limiting applications. The outlook is optimistic for greatly improving the state of the art of both the transistor and the thyristor. *Project Manager: Gilbert Addis*

Fields in HVDC converter stations

The ultimate goal of research on electric fields surrounding high-voltage lines and stations is to be able to predict, prior to construction, what electric field strength will exist during actual operations. A prediction method that uses scale models was recently successfully developed for ac substations (EL-632, Vols. 1 and 2). A follow-up contract with Ohio State University (OSU) was initiated for prediction of ground-level electrostatic field strength in converter stations. This three-year study concluded that energized scale models can also be used as design tools to minimize or eliminate undesirable fields under HVDC transmission lines or in converter stations (RP1097). OSU recently built and energized converter station and line models to prove the method (Figure 5).

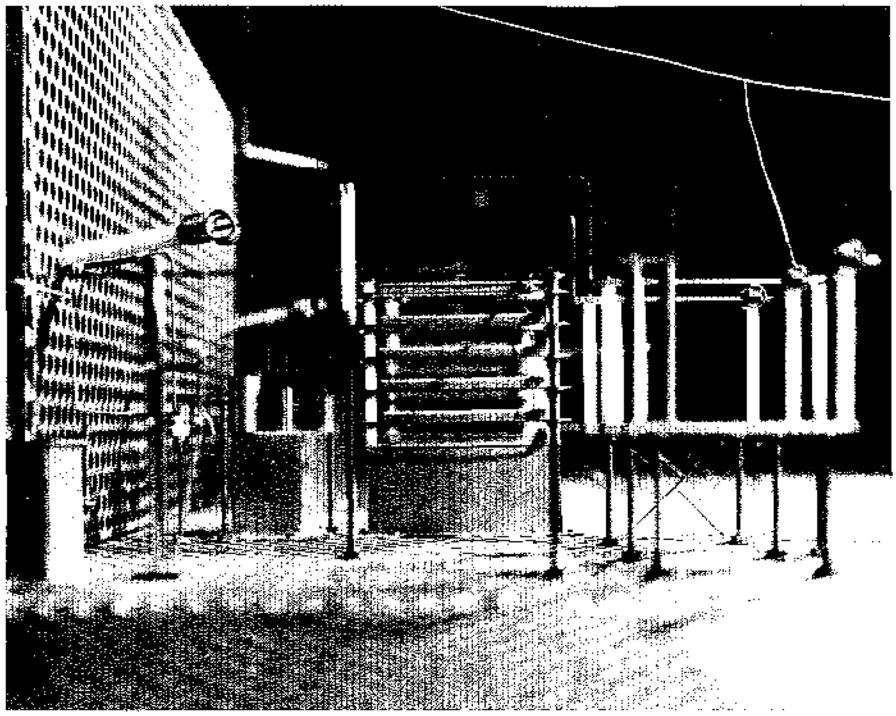
As reported earlier (*EPRI Journal,* November 1979, p. 50), the electrostatic field distribution surrounding an HVDC converter station is nonlinear. The nonlinearity is not caused by the station itself, which can be built to be essentially corona-free; rather, it is the corona from the HVDC overhead lines exiting the station that causes significant modeling difficulties. Therefore, a series of experiments was run to develop improved understanding of the scaling parameters.

After some fundamental problems were solved, components were designed and built for the prototype converter station model, and the validity of the model was established through a series of model experiments that were compared with similar experiments in full-size converter stations. Bonneville Power Administration's ±400-kV test line was used as the model for the line experiments. Minnesota Power & Light Co.'s ±250-kV Arrowhead converter station was used for the station experiments. A linear scale factor of 1 to 33⅓ was selected for the converter model. Correlation between the full-scale and the model measurements has been good.

After proving the modeling concept, OSU conducted model experiments on other field effect parameters—for instance, the effects of ground wires, partially energized operation, and short-circuit currents from vehicles. These tests have established the promise of the modeling approach as a complement to full-scale tests for special parameter studies.

RP1097 has now been completed, and the modeling method has proved feasible for prediction of the ground-level electrostatic field strengths in HVDC converter stations and under HVDC lines. These phenomena are statistical in nature, as wind and weather in general affect the field distribution. Several of these effects can be studied by using the model, but because the best correlation between full-scale and model facilities is found when the atmosphere is calm and dry, this may be a good baseline condition to use when comparing different systems. *Project Manager: Stig Nilsson*

Figure 5 Portion of a scale model of Minnesota Power & Light Co.'s ± 250-kV, 500-MW Arrowhead converter station. The linear scale is about 1:33. The model has been used to verify an electrostatic field prediction method developed by Ohio State University researchers.



ROTATING ELECTRICAL MACHINERY

Synchronous machine stability study constants

Millions of dollars are spent annually by the utility industry in the computer analysis of system stability, and a much larger amount is committed in construction to satisfy system design and reliability standards that are based on such stability studies. System tests and analyses have shown clearly that the mathematical models of synchronous machines used in these studies are inaccurate. The inaccuracies could result from inadequate model structures, incorrect parameters used in the models, or both.

In computer simulation studies, synchronous machines have been represented by passive electric circuit models. Normally, the parameters of the models have been determined by calculations performed by the machine manufacturer. Computer results (involving, for example, switching disturbances introduced into the model network system) do not always compare well with results of tests performed on the actual system.

An EPRI research project was initiated in 1977 with the goal of substantially improving the accuracy of synchronous machine modeling (RP997). The basic elements of this project were determination of model parameters by shop and field tests, development of alternative model structures, field tests of system behavior, validation of model performance, and evaluation of model adequacy.

The primary emphasis was on the development of model parameters through test techniques rather than by theoretical calculation. The project was a cooperative effort involving four contractors: Power Technologies, Inc., concentrated on using load rejection test techniques to ascertain model parameters; Westinghouse, NEI Parsons, Ltd., and Ontario Hydro used standstill and on-line frequency response test techniques.

Each of the four contractors has issued a final report. Although the conclusions do not completely agree in detail, some general results are clear.

- The standstill frequency response test has been developed to the point where it can provide complete, accurate model parameters for a synchronous machine. Its safety, simplicity, and ease of implementation in the factory make it an attractive alternative to the sudden-short-circuit test.
- Somewhat better results can be achieved in certain cases by using on-line frequency response tests, particularly when the machine rotor has a complete damper winding.
- Load rejection tests are practical and reliable for deriving machine model parameters and verifying the overall adequacy of model structures.
- In many cases, second-order model structures are adequate for the representation of the machine. Modifications of the direct-axis model may be necessary to properly represent field current transients that are affected by rotor iron effects. Higher-order models may be required for machines with complex rotor structures—for example, machines with complete damper windings.
- Better estimates of saturation seem to offer the most promise for improving the accuracy of machine models.

Incorporation of the results of this project into utility computer programs for system simulation should lead to significant improvements in accuracy. Additional work is now under way (RP1288 and RP1513) to further improve simulations through finite element analysis of machines. *Project Manager: J C. White*

DISTRIBUTION

Detection of high-impedance faults

Considerable progress has been made in the refinement of two instruments being developed to detect high-impedance faults on distribution circuits (RP1285).

Texas A. & M. University has developed a detector that uses the noise generated by a high-impedance fault to indicate the presence of the fault. The algorithm devised for the microprocessor-based instrument has been extensively tested against data recorded on operating systems. As the noise current must be detected at the substation rather than near the location of the fault itself, test faults were staged on very long lines, and the high-frequency components were recorded.

Similar noise data were recorded on several other systems during staged faults, load and capacitor switching, and other normal events. These recordings were used to develop and test the algorithm to be used in the detector. The fault detector was installed on an operating feeder in the monitor mode, where it still remains. The final report on the project, to be issued in 1981, will describe this successful demonstration in detail.

Hughes Research Laboratories have developed two versions of a detector, both of which use properties of third-harmonic currents to identify the presence of high-impedance faults. One version is useful on solidly grounded wye circuits, while the other is for use on delta circuits and those having delta-connected loads.

Recordings of third-harmonic current, made under faulted as well as normal system conditions, were used extensively in the development and testing of the detection schemes. In January 1980 the first detector was installed (in a monitor mode on a grounded wye circuit) for field evaluation. A second grounded wye and three delta-type detectors were subsequently installed on two other utility systems.

When it became apparent that the grounded wye detector could not discriminate between high-impedance faults and normal system events, modifications based on observation of these events were made. Since then, the detector performance has been mixed.

An analytic investigation of high-impedance fault detection by Power Technologies is still in progress. In this investigation a statistical analysis is being used to correlate currents of various frequencies and sequences with high-impedance faults. Analysis of existing field test data suggest that a proper statistical evaluation of prefault and postfault feeder currents can be used to detect a broad range of high-impedance faults.

The success of this method hinges on the statistical diversity of normal system conditions. Data on normal system behavior gathered over a 24-hour period on circuits serving loads of diverse characteristics are presently being evaluated. This work is scheduled for completion in the first quarter of 1981, at which time a report on the investigation will be published. *Project Manager: Herbert J. Songster*

Cathodic protection of copper concentric neutrals

Engineers continue to be frustrated by corrosion of concentric neutral conductors in underground rural distribution (URD) cables. It has been over 10 years since URD neutral corrosion was first detected, over 5 years since it was determined to be a serious, widespread problem, and about 3 years since EPRI initiated research projects to determine the causes of, and mitigating methods for the control of, such corrosion.

Jacketed neutral cables are certainly an alternative for new URD construction, and jacketed cables have been in operation for many years (EL-619). However, over a billion (10^9) feet of existing buried bare neutral cable still presents a problem to utility engineers. Some attempts to cathodically protect copper neutrals have been made. The criteria used in these attempts were originally developed over the years for pipeline protection. However, the interpretation of data developed by using pipeline theory for copper neutrals is extremely difficult, if not impossible, and the effectiveness of systems based on these criteria is questionable.

As part of a continuing project (*EPRI Journal*, December 1978, p. 56), Pacific Gas and Electric Co. has placed several URD cathodic protection systems in operation (RP1049). These systems, which are presently being monitored for postinstallation information, are the result of three years of extensive data gathering and analysis. Design and installation guidelines have now been developed that will be applicable in any part of the country.

Complementing the RP1049 project, work is under way by the National Bureau of Standards to develop field instrumentation that can detect a corroding neutral in situ (PR1732). A neutral that has corroded to the point of failure can be detected quite easily; however, the detection of a neutral that is corroding but still conducting is very difficult because the corrosion is usually microscopic.

If successful, this project could result in a major breakthrough in field corrosion instrumentation and provide the utilities with a much needed instrument. Project completion is scheduled for the end of 1980. *Project Manager: T. J. Kendrew*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

VISIBILITY IMPAIRMENT

The passage of the Clean Air Act Amendments of 1977 added a new dimension to air quality management in the United States—the prevention of visibility impairment in what are considered Class I areas (national parks, monuments, and wilderness areas). So far, 168 Class I areas in 38 states have been identified. As one of the major contributors of emissions that can cause visibility impairment, fossil-fueled electric power plants have been singled out for special attention in the proposed regulations. As a result, EPRI is sponsoring a comprehensive research program to develop a factual base for understanding the causes of visibility impairment and the utility industry's contribution to the problem.

The first major EPRI effort in visibility research was a field study to compare different methods of measuring visual range (RP862-15, RP1305-1). Measurements were made in southeastern California, eastern Ohio, and northeastern Pennsylvania. Comparisons have shown that measurements taken by telephotometry and other photometric techniques are in good agreement (±15%) with human observations. Nephelometer measurements also tend to be in good agreement, but they are less reliable when local anomalies in particle loading occur (e.g., blowing dust). As a result of this study, the telephotometer has been adopted as the primary instrument for measuring visual range. (Background information on visibility measurement is presented in EPRI P-80-2-LD, the proceedings of an EPRI conference on particulates.)

Data on particle loading and chemical composition were also collected in this initial field study. These data are still being analyzed, but preliminary results show that sulfates are a significant contributor to visibility impairment in the eastern United States. In the Southwest, however, visibility impairment is most closely correlated with nitrates.

Studies in the western United States, primarily the Southwest, are being continued under a major field program that is being coordinated with utilities, EPA, and the National Park Service (RP1630-3). The measurement stations in this combined network are shown in Figure 1. The program has two objectives: to gather baseline information on present regional and local visibility levels, and to provide a reliable data base on visibility variations and associated levels of particle loading for use in predictive modeling. Both of these objectives are important for the development of

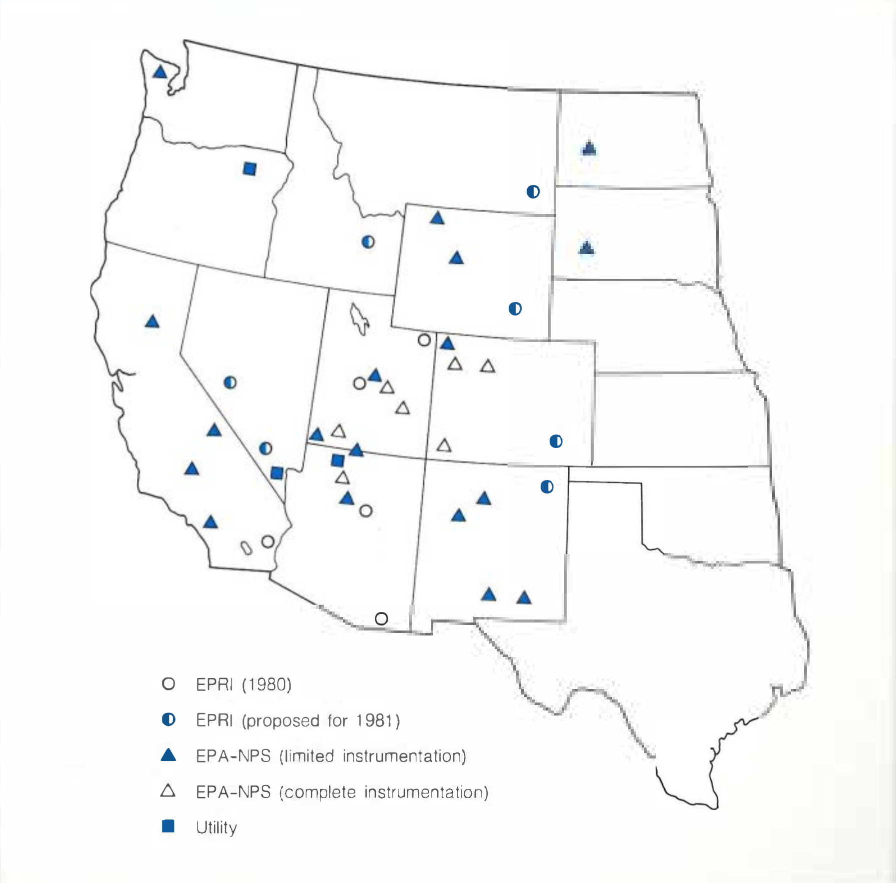
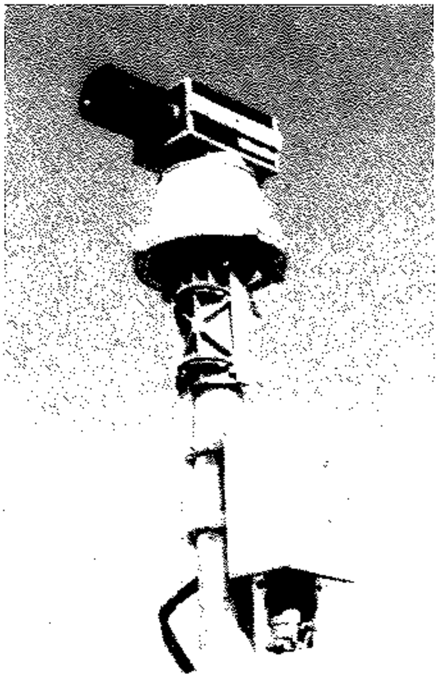


Figure 1 Visibility-monitoring stations operated or planned in the western United States by EPRI, EPA, the National Park Service, and utilities.

Figure 2 The automated telephotometer uses a Reticon camera to develop measurements of visual range for studies of visibility impairment.



emissions control strategies for visibility protection. Partial results are expected in 1982 and more definitive models in 1984 or 1985.

As a result of its instrument comparisons, EPRI has funded the development of an automated telephotometer (RP862-14). This device, which uses a solid-state camera of the type shown in Figure 2, provides much more extensive and reliable measurements of visual range than are possible with a manually operated telephotometer. It also enables the objective measurement of atmospheric discoloration, target texture, and target clarity or sharpness. These parameters are covered by the proposed visibility impairment regulations, but only subjective methods of quantifying them have been available until now. The device, which is ready for field testing, should be available for general use in 1981 or 1982.

EPRI's visibility research is part of an integrated air quality studies subprogram within the Physical Factors Program. The results of other efforts under way in this subprogram (e.g., on plume model development and validation, regional transport of air pollutants, and chemical transformations) will be applied to the problem of visibility impairment, as appropriate. *Project Manager: Glenn R. Hilst*

NEW ISSUES IN DEMAND AND CONSERVATION

During the past six months the Demand and Conservation Program has been reorganized in response to the changing needs of utility and EPRI R&D planners. The organizational changes reflect an increased research emphasis on load management, conservation, load research, and end-use technologies in the context of resource planning at the utility service area level. The research orientation has also been changed to emphasize the transfer of results to utilities. The research in the Demand and Conservation Program is organized into seven subprograms, briefly described below.

Conservation

The goal of the conservation subprogram is to develop methodologies for analyzing the effect of energy conservation on the electric utility industry and on national energy use. Conservation is defined to include the effects of government-mandated standards and voluntary programs offered by utilities and the price-induced responses of energy consumers.

An important part of this subprogram is the development of models that analyze energy consumption in each sector—residential, commercial, industrial, and transportation—by specific end use (RP1211, RP1216, RP1762). These models will be used to determine how new, more-efficient household appliances and industrial processes affect electricity consumption and loads (RP1292). The effect of other conservation-related factors is also being investigated; under RP942, for example, models for forecasting industrial cogeneration output are being developed.

In the future the subprogram will develop methodologies for identifying optimal conservation strategies for each customer sector. This will involve developing cost curves, estimating incremental energy savings, and evaluating customer acceptance of different conservation programs.

Load research

The collection and interpretation of time-of-day and end-use load data require special equipment, data management systems, and analytic techniques. Several projects in the load research subprogram are focused on these needs.

Metering equipment represents an important cost component of load research. To reduce this cost, a remote power sensor is being developed under RP1589. Small transmitters placed on energy-using equipment will send signals to a central data collection point, such as a power pole or meter panel. This system will significantly cut the cost of instrument installation at test sites.

There is a great need for computer software that will make load research data more manageable in terms of general access, report-generating capability, and other data processing objectives. An ongoing project is helping utilities choose and implement new systems and avoid duplication of effort (RP1588). Another project is studying the basic statistical properties of loads in order to improve the design of projects and the analysis of results; a number of innovative approaches are being evaluated (RP1816). The key issue of the transferability of load data from one utility to another is being examined under RP1820.

In addition to studies of equipment and methodology, the subprogram conducts load research projects on major generic loads. These projects usually involve a national sample and go hand in hand with the development of engineering or simulation models. They serve two major purposes: They provide primary load shape data on specific end uses, which are very much needed for forecasting and for estimating the impacts of conservation and load management; they contribute to an understanding of the nature of specific loads, which may enable data transfer and extrapolation. Initial projects have focused on the major residential loads—heating and cooling systems, heat pumps, and electric water heaters. Future work will involve apartment houses, commercial buildings, and solar energy systems.

Load management

Load management is aimed at deferring or reducing the need for future capacity. As the costs of construction and capital financing have escalated, load management has acquired considerable significance as an alternative to generation expansion. Its strategic role is recognized in the Public Utility Regulatory Policies Act of 1978, which defines it as a federal standard that must be considered by state regulatory commissions by November 1980.

Load management includes methods that directly control end-use loads and those that indirectly affect customer load profiles, such as the use of time-of-day and seasonal rates. Both types of methods recognize the time-varying nature of electricity production costs, seek to reduce growth in system peak demand, and try to shift energy use from peak to off-peak periods.

The load management subprogram plans to investigate a number of issues.

- Research will be conducted on customer acceptance of load management programs.
- The impact of specific programs on customer-class load shapes will be analyzed and quantified for selected utility systems.
- The transferability of results from one region to another will be examined.
- The cost-effectiveness of load management programs will be assessed.

New end-use technologies

Research in this subprogram seeks to determine the impact of new end-use technologies on electricity consumption. This requires a multidisciplinary approach combining economics, forecasting, market analysis, and technology assessment to estimate market penetration and public acceptance. One major concern is the potential for electrification in the transportation sector (in applications ranging from mass transit to personal automobile travel), where penetration will be determined by the interplay of consumer choice, technological development, and incentives from utilities and government. Other research will examine the market penetration and effects of solar heating and air conditioning, heat pump water heaters, and efficient electric motors.

Load shape forecasting

Utilities need long-term forecasts of hourly load shapes for capacity, generation-mix, and transmission and distribution planning and for assessing the cost-effectiveness of load management and conservation programs. Traditionally, forecasts of hourly load shapes have been made by combining forecasts of energy sales and peak loads with historical load shape data. This procedure has several drawbacks. Most notably, it precludes the analysis of economic, weather, and policy factors.

This subprogram is developing new methodologies and data bases to help utilities forecast load shapes. Two econometric models have recently been completed and are being tested at the regional level; they will soon be made available to interested utilities. These models can be used to forecast regional load shapes under a business-as-usual case and to conduct analyses that indicate the sensitivity of load shape to energy prices, appliance stocks, economic indicators, sociodemographic conditions, and weather variables. Research is planned to develop models for predicting load shapes at the utility service area level. As part of this research, alternative approaches, such as end-use modeling, will be evaluated and demonstrated by means of case studies.

Energy forecasting

This subprogram uses the results of much of the other research in the program to produce regional and national forecasts. Another important task is to develop forecasting and modeling approaches for the utility service area level. Toward this end, the subprogram investigates the degree to which approaches developed for the national or the state level can be applied to utility service areas.

Value of service

This subprogram, which has been transferred to the Demand and Conservation Program from the Supply Program, will develop methodologies for analyzing the environmental and socioeconomic consequences of electricity shortages, the benefits of service reliabilities, and the impact of uncertainty on planning decisions. Under RP1104-1 two case studies of the cost associated with energy and capacity shortage have been made, one dealing with the widespread natural gas shortage in the winter of 1976–77 and the other with an electric power shortage in Key West, Florida, during a one-month equipment breakdown in 1978. Costs per unit of energy undelivered varied greatly, but these estimates are representative: the economic loss per million cubic feet of undelivered natural gas was approximately 30 times the market price of the gas, and the loss per kilowatthour of undelivered electricity was about 50 times the electricity's market price. These case studies are reported in EA-1215, Volumes 1 and 2, and EA-1241. *Program Manager: Pradeep Gupta*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

THERMAL ENERGY STORAGE

Thermal energy storage (TES) by energy consumers offers the potential to control peak electricity demand for either heating or cooling on a daily, weekly, or seasonal basis. For utilities with weather-sensitive peaks, such end-use TES could lead to reduced capacity requirements and increased load factors. Under EPRI contracts, field tests are being conducted to assess the state of the art of recently installed TES systems in the United States and to determine the effects utilities can expect when consumers begin to use TES on a significant scale. Specific issues addressed in this research include the operating characteristics of present-design storage systems under U.S. conditions; the effectiveness of storage systems in shifting energy demand to off-peak periods; the impact of TES on utility loads and distribution systems; and the costs (in terms of both money and primary energy) of shifting loads through TES.

TES by consumers can be used to shift electric heating and cooling loads from peak to off-peak periods; thus it has important potential for helping utilities manage their loads. In Europe, for example, heat storage in ceramic-brick room units has been used extensively to change the profile of electricity demand and improve utility load factors. The widespread use of TES technology in Europe, however, has required the strengthening of selected distribution systems, and in proportion to load factor improvements, it has reduced the ability to perform generation plant maintenance during off-peak periods. The energy losses in TES systems result in the use of more energy than in electric heating and cooling without storage. Therefore, the benefit of shifting space-conditioning demand from peak to off-peak periods is accompanied by the need for some additional kilowatthours.

Both EPRI and DOE are supporting TES work. DOE is sponsoring 12 field test projects with utilities to investigate the effect of TES systems on electricity generation, transmission, and distribution. The DOE effort is being complemented by two EPRI projects assessing state-of-the-art heat and cool storage equipment (RP1089, RP1090-1). In addition, EPRI is cofunding (with DOE and others) a load management demonstration under RP1090-2.

Cool storage

In 1978 a project was initiated with Carrier Corp. to establish the applicability and technical readiness of several prototypical cool storage systems (RP1089). Twenty-two utility-sponsored cool storage installations were instrumented and the performance data analyzed. All these systems used prototypical water-ice storage tanks coupled to conventional compressors and air handlers. The systems were monitored for thermal energy input and output; tank temperature; air flow; and fan, compressor, and pump power. Indoor and outdoor temperatures and total building energy use throughout the cooling season were also measured.

The field tests indicated that with this type of equipment 80% of air conditioning demand can be shifted off-peak. Also, the systems made it possible to shift 90% of cooling energy use from the experimental peak period (8 a.m. to 9 p.m.) to the off-peak period (night). The cool storage units monitored used more energy than conventional central air conditioners operating with the same condensing unit would be expected to use. This excess energy consumption probably could have been reduced if a predictive weather model had been used in determining how much energy to store and if the compressor had been controlled by the utility instead of by a time clock. A component-sizing model (and computer code) for determining cool storage system economics was also developed under this contract. The economic break-even point for each cool storage site is now being calculated.

Five of the cool storage systems monitored in this project did not perform at expected levels. These are being modified to improve performance and will be monitored for another cooling season. Follow-on R&D activities include a demonstration of cool storage cost-effectiveness for commercial establishments and the development of advanced cool storage control concepts to improve seasonal performance and efficiency.

Heat storage

As mentioned earlier, the use of heat storage has improved load factors for European utilities. Arthur D. Little, Inc., instrumented 17 utility-sponsored heat storage systems to investigate whether heat storage can provide load management benefits at acceptable levels of cost and comfort in the United States (RP1090-1). Four system types were represented: ceramic-brick room units, central ceramic-brick units, pressurized-hot-water units (tanks), and heated floor slabs. Most of the units were controlled by a time clock. Thermal energy input and output, temperature of the storage medium, indoor and outdoor temperatures, total house energy use, and weather data were measured. Monitoring was conducted for two years at 13 sites and for one year at 4 sites. It was completed at the end of April 1980, and the data are now being analyzed.

Load management demonstration

EPRI, Niagara Mohawk Power Corp., DOE, the New York State Energy Research & Development Authority, and the New York Public Service Commission are funding a field test on the Niagara Mohawk system to determine how TES affects utility system design and operation (RP1090-2). The project differs from earlier heat storage experiments in two important respects: Five identical buildings (dormitories at the Lake Placid Olympic Games site) will be electrically heated by five different systems, with electric service provided by a common feeder; this approach is expected to yield very good data for comparative evaluation. Experimental data will be acquired and made available in real time, and control may be exercised as appropriate or desired. The five heating systems are:

- Slab heating on grade (10 circuits ranging from 22 kW to 33 kW). This system operates at approximately 24 V and is regulated by a local controller on the basis of building and slab temperatures. The manufacturer is Peak Suspension Control, Ltd.

- Ceramic-brick storage furnaces (eight 48-kW units). Each unit is designed to be charged in less than eight hours. Air is delivered to the heated space at 130°F (54°C) by thermostatically controlled dampers; the temperature of the storage medium can be as high as 1450°F (788°C). The manufacturer is Allgemeine Elektrizitäts Gesellschaft.

- Pressurized-hot-water storage (eight 36-kW units). Each unit is designed to provide 10 hours of heat (discharge) daily. The water temperature can reach 280°F (138°C) at 50 psi (345 kPa). A secondary water coil is used to transfer heat to an in-duct coil in a standard air system. The manufacturer is Megatherm Co.

- Heat pumps with water storage (four units rated at 15 tons). These pumps can operate in an air-to-air, air-to-water, water-to-air, or water-to-water mode, as determined by a local controller. Each system has an electric boiler that can provide off-peak heated water if needed in some of the test modes. The manufacturer is Carrier.

- Conventional system (eight 22-kW electric furnaces).

Storage medium, building, slab, ground, and outdoor air temperatures will be monitored, together with weather conditions. In addition, energy input and output profiles will be determined for each system. Data from each building can be sampled every 30 seconds by a remote terminal unit. The raw data will be transmitted over leased telephone lines on a real-time basis. A PDP-11 computer in Palo Alto, California, will receive and check the data and store them for later evaluation. The TES units will be controlled by on-site inputs and logic, but the charge and discharge periods may be extended by control signals transmitted by the PDP-11. The collection and review of data in real time—as opposed to the customary accumulation of 30-day tape recordings at each site—will enable researchers to locate system and component failures quickly so that little information is lost and to override local control for experimental purposes.

The heating and storage systems will be monitored through 1982. Instrumentation has been installed on Niagara Mohawk's transmission and distribution system in the test area in order to study the effects of TES. Load management strategies will be developed, simulated, and evaluated.

Future research

Field tests have demonstrated the potential of heat and cool storage technology to shift demand off-peak. However, energy losses from TES systems are adversely affecting the overall economics and must be reduced.

Since the beginning of EPRI's field tests and demonstrations in 1977, many existing heat and cool storage systems have been modified and new systems have become available. In the future, EPRI will consider coordinating the evaluation of new TES systems in terms of performance and economic attractiveness. Under RP1670-2 researchers will identify appropriate procedures and equipment for measuring the performance of residential TES systems, heat pumps, and solar heating systems. Another area of future study is the application of cool storage to commercial facilities. To increase the attractiveness of end-use TES, further efforts are also necessary to reduce thermal losses and assess impacts on utility transmission and distribution systems. *Project Manager: Robert Mauro*

HEAT PUMPS

The heat pump is the only practical device capable of transferring heat energy from a low-temperature source to a high-temperature sink. A basic law of physics holds that some energy must be supplied for this process to occur. The electric heat pump (the only type commercially available) does this by the input of work to a compressor in the form of shaft power developed by an electric motor. Unlike an electric resistance heater, the heat pump delivers more units of heat than the thermal equivalent of the electricity it consumes. The additional heat is derived from the environment (e.g., from ambient air or groundwater). This energy-saving characteristic—coupled with the fact that heat pumps can be used either to heat or to cool buildings—explains why interest in electric heat pumps is increasing among utilities and their customers. EPRI's Energy Utilization and Conservation Technology Program is sponsoring research to advance the state of the art of electric heat pumps and improve their compatibility with electric power systems. A further objective is to broaden the use of heat pumps for the recovery of waste heat and for the displacement of scarce fossil fuels by coal- and nuclear-derived electricity in residential and commercial space conditioning, domestic water heating, and industrial process applications.

Air-source heat pumps

The low ambient temperatures typical of northern winter climates (those with more than 5000 annual heating degree-days) impose severe operating conditions on air-source heat pumps and create potential peak load problems for winter-peaking utilities. During 1975–1977 Westinghouse Electric Corp. investigated ways to improve heat pump performance and reliability in cold climates (RP544). It concluded that dual-capacity (two-speed or dual-compressor) machines could be designed to economically attain a heating seasonal performance factor near 3 in cold-climate applications. (*Seasonal performance factor* is defined as the ratio of seasonal heating or cooling load to the energy consumption of the heat pump system.) This work is reported in EM-319 (3 vols.).

At about the same time as this study, manufacturers introduced more efficient single-speed compressors and redesigned other system features: The compressor was moved indoors; the heat exchanger surface area was increased; fan power requirements were reduced by changing to larger, slower fans; and solid-state controls with some fault diagnosis capability were introduced. More recently, two-speed, single-phase motors and parallel-staged dual-compressor units have been introduced. These developments represent a response to the changed energy economics of the post-oil-embargo period (i.e., higher fuel and electricity prices and different ratios between the prices of electricity, oil, and gas). Supporting research activities by EPRI are designed to provide the utility industry with carefully measured, objectively analyzed data on the actual performance of these heat pumps in typical residential and commercial installations. These data will also provide manufacturers with a rational basis for equipment modifications and further development.

Carrier is field testing and analyzing the performance of selected heat pump equipment in residential and commercial buildings in cold climates (RP789). Both conventional, pre-1975 designs and the newer, high-efficiency designs are being studied. The project, cosponsored by Niagara Mohawk, is in its third phase, and an interim report is being prepared. The results to date indicate that well-designed and properly sized and installed electric heat pump equipment can achieve heating seasonal performance factors above 2 in northern climates. Future work will include field testing of hybrid heat pumps (i.e., heat pumps in combination with warm-air furnaces), two-speed and dual-compressor equipment, and a three-piece single-speed heat pump (i.e., a split-system heat pump with a separate indoor compressor section) equipped with a superheat-recovery water preheater.

As part of this study, a transfer function model of the air-source heat pump and its thermostatic control system was validated by field data from several residential and commercial heat pump installations. The model is capable of predicting heat pump seasonal performance for normal weather conditions, estimating defrost frequency, and performing other parametric analyses. It was used by Carrier to predict the field performance of advanced heat pump equipment on the basis of data from a laboratory prototype.

Retrofitting a residential oil or gas warm-air furnace with a heat pump may offer considerable oil or gas savings. Science Applications, Inc., assessed the state of the art of such hybrid heat pumps (RP1201-6). The results, reported in EM-1261, indicate that potentially significant reductions in peak electric heating load are possible through wider use of hybrid heat pumps because a combustion furnace can be used instead of resistance heating for supplementing the heat pump.

Work just begun at General Electric Co. involves laboratory and field verification and further analytic development of improved algorithms for estimating heat pump seasonal energy use (RP1495). Field data will be obtained from nine residential heat pump installations in three cities (Memphis, Philadelphia, and Schenectady). This project will provide information on how DOE's proposed heat pump performance rating methods relate to actual performance in typical residences.

In a project cosponsored by EPRI's Energy Analysis and Environment Division, Gordian Associates Inc. has analyzed extensive field data on heat pump demand characteristics and energy consumption (RP1100). The data were collected during a previous EPRI field study of 120 electric heat pumps in 12 utility areas. This work has resulted in the preliminary development and field verification of a Monte Carlo simulation method for estimating the diversified demand characteristics of heat pumps. A final report is being prepared.

Solar-assisted heat pumps

Solar-assisted heat pumps are another important subject of EPRI research. The efficiency advantage of using solar-heated hot water as the heat source for a heat pump in the heating mode is well recognized. Such a solar-assisted heat pump usually includes a thermal storage system on the evaporator side in what is called a series arrangement. However, because most heat-pump-heated buildings require summer air conditioning as well, a parallel arrangement is preferred—one in which the solar-thermal storage system heat exchanger is installed in the supply air duct downstream of the heat pump. In this case the heat pump is an air-source unit. The parallel configuration permits the rejection of heat directly to the ambient air in the cooling mode. Combinations of the series and parallel arrangements are also possible. Research under RP544 identified the parallel configuration as more economical than the series, but neither appeared to be attractive in the near term when compared with an efficient air-source heat pump without solar augmentation.

Solar-assisted heat pumps are being evaluated and compared as part of EPRI's solar heating and cooling (SHAC) residential demonstration project (RP549). In this project, 10 houses with SHAC systems have been built (5 on Long Island, New York; 5 in Albuquerque, New Mexico) and are being monitored. Eight of the heat pump installations are parallel systems with conventional air-to-air equipment. Two are series-parallel systems with developmental three-coil heat pumps that maximize heating efficiency as well as provide air conditioning capability. Data on system performance and backup energy consumption have been collected for about one year; analysis is in progress.

A commercial SHAC demonstration project is also under way and involves six buildings (RP844). Two of these have water-source heat pumps—one a parallel system with a hydronic loop and the other a three-coil heat pump connected to thermal storage tanks heated by both solar energy and off-peak electricity. The other buildings are equipped with a reciprocating chiller, an absorption chiller, and an ice-making heat pump for cooling. Data collection has begun at one building. The other systems are still under construction. Delays have been caused by a solar collector fire at one site and a thermal storage tank implosion at another.

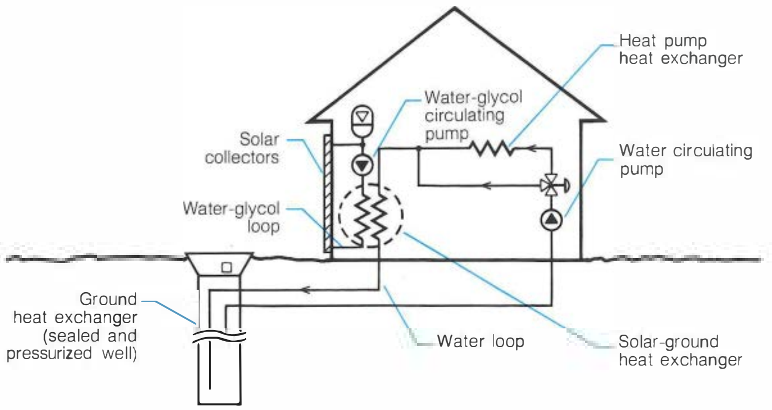
EPRI is also helping utilities monitor solar-assisted heat pump performance. For example, a project with Southern California Edison Co. involves a system of multiple water-to-air heat pumps connected on the water side to a single loop (RP925). The loop also incorporates solar-heated thermal storage tanks, an electric boiler, and a cooling tower installed on the administration building of a local college radio station. Such a system (sometimes called a California heat pump system) is capable of transferring heat from one conditioned space to another (i.e., heat extracted by the heat pumps operating in the cooling mode can be used by the heat pumps operating in the heating mode). Auxiliary heating or cooling capacity is provided by the storage system, the solar collectors, the boiler, and the cooling tower. The results of this study indicated that inclusion of the thermal storage system enabled full utilization of the internal heat recovered from the building. Any shortfall in recovered energy was met by the fast-responding electric boiler; thus it was possible to maintain the temperature of the thermal storage tanks without the considerable cycling losses typical of a gas-fired reservoir boiler. The final report on this project is being prepared, and monitoring of the building's energy use will continue.

Ground-source heat pumps

A heat source that on the average has a higher temperature than ambient winter air will improve the seasonal efficiency of a heat pump. Except very near the surface, the temperature of the ground and of groundwater in the 48 conterminous states varies between 4.4°C (40°F) and 21°C (70°F)—considerably higher than winter air temperatures in the northern states. EPRI is sponsoring research to explore the feasibility of using this superior heat source as a substitute for ambient air and to develop a model for estimating the performance of groundwater-source heat pumps.

One project (RP1191-6) involves the construction and monitoring of two single-family houses with water-to-air heat pumps that use water circulated from capped wells 76 m (250 ft) deep. Because the wells penetrate deep into the zone of saturation, they should provide better thermal contact between the ground and the circulating fluid than a shallow, horizontal heat exchanger. One of the wells is coupled to a solar collector system (Figure 1), which serves two functions. In the heating mode of operation, solar energy can be used to raise and maintain well temperature and even to store energy in the ground. In the cooling mode, the collectors can be used to reject condenser heat from the well to the air, thus enhancing system performance by minimizing the difference between the condenser and evaporator temperatures. A third house, which has a conventional single-speed air-source heat pump, will serve as an experimental control. All three heat pumps have superheat-recovery devices for water preheating.

Figure 1 Ground-source, solar-assisted heat pump system being tested at Perkins, Oklahoma.



Construction of the three houses is complete, and the heat pump systems are operational. One house is occupied, and data acquisition has begun. Oklahoma Gas and Electric Co. is the contractor, and Oklahoma State University at Stillwater is the subcontractor.

Another project will measure the performance of two well-water-source heat pumps in homes in rural western Pennsylvania (RP1201-14). This project is being conducted in cooperation with the Allegheny Electric Cooperative, Inc.

Industrial heat pumps

EPRI has just begun research on industrial heat pumps. This work will focus on the development of electric heat pump systems for recovering process waste heat and for displacing scarce fossil fuels in water heating, low-pressure steam generation, and other uses of low-temperature heat. United Technologies Corp. is investigating the technical feasibility and economics of using heat pumps, heat exchangers, and thermal storage systems in specific processes in several industries, including pulp and paper, cement, glass, food and dairy (RP1275).

The principal technical problem that must be solved to make the widespread industrial use of heat pumps feasible is the development of high-temperature working fluids that meet the thermophysical, toxicity, flammability, and chemical stability criteria necessary for process applications. The critical temperature of most halocarbon refrigerants is too low for most practical process heat pump applications or for best cycle efficiency. There are only a few fluids that meet most of the requirements of Rankine-cycle heat pumps operating at condenser temperatures above 104°C (220°F). DOE is currently sponsoring the development of two electrically driven industrial process heat pumps. One is designed to operate in a closed-loop methanol Rankine cycle for heat recovery from a pulp digester in a paper mill. The other is an open-loop subatmospheric Brayton-cycle machine for recovering heat from a milk evaporation process. (This project has now been redirected toward solvent recovery applications.)

Future research

In the near term EPRI will expand and systematize its program for field testing improved and new heat pump equipment. This work will provide utilities with objective, reliable data on the performance and impacts of this equipment in typical applications. An aggressive program is in the planning stage, in cooperation with manufacturers and the government, to identify, evaluate, and develop advanced heat pump technology concepts. The purpose of this development program is to ensure the orderly evolution of electric heat pump technology as an efficient, cost-effective method of using coal and other noncritical domestic energy resources for heating and cooling in the residential, commercial, and industrial sectors. *Subprogram Manager: Arvo Lannus*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

MULTIDIMENSIONAL SIMULATION OF STEAM GENERATOR THERMAL HYDRAULICS

Thermal-hydraulic analyses of existing and proposed steam generators will greatly contribute to more efficient system design and operation and will provide support for studies of material degradation. These analyses must produce detailed spatial distributions of the thermal and hydraulic field variables in the steam generator under operating conditions. For this purpose a computer program capable of detailed simulation of the thermal hydraulics of different types of PWR steam generators is being developed under EPRI contracts (RP1066-1, -2, -3, -4, -5).

The distributions of the thermodynamic and hydraulic variables in an operating steam generator are governed by conservation laws for the mass, momentum, and energy of the two-phase steam and water mixture and by laws that determine the transfer of these quantities between the phases. The conservation laws can be derived from first principles, whereas the laws governing the interphase transfers are obtained from empirical correlations based on experimental data. These correlations are dependent on the description of two-phase-flow morphology in terms of flow regimes. Flow regime descriptions have been determined on the basis of the mass flow rate and the vapor-phase volume fraction, but further work of a fundamental nature is required in this area to characterize the nature of flow regimes and their transitions precisely.

The interactions between solid surfaces and the fluid are described by another set of empirical correlations based on experimental data. These, together with property data presented in the form of tables or functional fits, complete the mathematical description of two-phase flow in steam generators. This mathematical description essentially consists of a set of coupled, nonlinear partial differential equations and a set of nonlinear algebraic relations. One-dimensional or multidimensional solutions of this system of equations have to be found numerically, together with pertinent initial and boundary conditions.

Steam generator model

A schematic of a typical PWR U-tube steam generator is presented in Figure 1. High-temperature, high-pressure primary water from the nuclear reactor flows through the U-tubes, rising on the left side of the steam generator (referred to as the hot side) and coming down on the right side (the cold side). The secondary fluid (a mixture of steam and water) flows in the shell surrounding the tubes. About 90% of the feedwater is let in at the economizer section at the bottom of the steam generator; the rest is let in at the top through the downcomer. The separators at the top of the shell separate the steam from the water; the water then flows through the downcomer and reenters the shell at the bottom. Structural components in the shell include tube support plates, distribution plates, divider plate, baffle plates, and the separator deck.

In a once-through steam generator, the tubes are straight. The secondary fluid flows in the shell and can be superheated at the top. This steam generator essentially functions like a countercurrent-flow heat exchanger.

For the purpose of computer simulation, a computation domain is established, usually the region of the steam generator shell between the bottom tube support plate and the separator deck. This region is divided into a number of subregions, or computation cells; the governing continuous field equations have been recast in a discrete form for numerical solution.

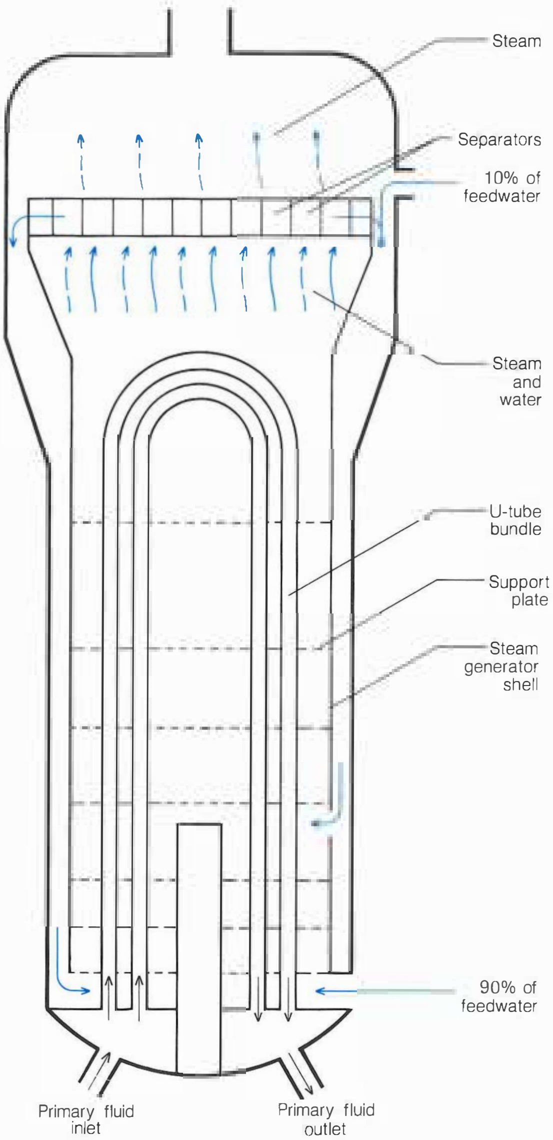
URSULA2 code

A computer program known as URSULA2 is being developed at CHAM of North America, Inc., under RP1066; this program computes three-dimensional distributions of thermal-hydraulic variables (e.g., velocities, pressure, enthalpy, void fraction) in the shell of a steam generator and the distribution of primary fluid temperature within the tubes.

In the URSULA2 code the steam generator is represented as a vertical cylinder symmetrical about a diametral plane that runs along the tube bundle. The computation domain is divided into a number of cells formed by planes in the horizontal and vertical (along radii) directions and by cylindrical surfaces whose radii at any height are fixed fractions of the shell radius at that height. These computation cells fill the entire steam generator shell, from the tubesheet to the separator deck. Two parts of the steam generator outside this domain are also considered in the computations—the steam dome above the separator deck and the downcomer annulus. In the case of computation cells partially occupied by solid objects (e.g., tubes, tube support plates, distribution plates, partitions), blockage factors are introduced to define the unblocked fraction of a cell volume available for flow.

To minimize the effort required to describe steam generator geometry for computation purposes, a separate computer code has been developed that derives the necessary geometric parameters as required by the URSULA2 code from the detailed steam generator design information.

Figure 1 Typical PWR steam generator. Heat from the primary fluid circulating through the U-tube bundles boils the secondary water, which moves up through the steam generator shell. Water is separated from the steam at the top of the shell and is recirculated.



Computation models

Three models are presently available in the URSULA2 code. The first scheme treats the two-phase mixture of steam and water as a homogeneous fluid in which both phases are at the same temperature (thermal equilibrium) and move with the same velocity. Hence it is called the homogeneous equilibrium model or the EVET (equal velocity, equal temperature) model. The main variables describing the secondary fluid are pressure, enthalpy, and the three components of the velocity (in the r, θ, and z directions). Spatial and temporal distributions of these variables are obtained by numerical solution of the partial differential equations governing the mass, momentum, and energy balances.

The second model, called the algebraic slip model, accommodates some nonhomogeneity in the flow by allowing the two phases to move at different velocities in the vertical direction. In addition to the main EVET variables, this model includes an expression for the slip between the liquid- and vapor- phase velocities in the vertical direction in the form of an algebraic equation. The two phases are still treated as being at thermal equilibrium.

The third model is called the three-component slip or the UVET (unequal velocity, equal temperature) model. It allows the two phases to have different velocities in the three coordinate directions, but still considers them to be at thermal equilibrium. The main variables are the three velocity components (r, θ, and z directions) for each phase and the pressure and enthalpy of the two-phase mixture. Spatial and temporal distributions of these variables are obtained by numerical solution of the partial differential equations governing momentum balances for each phase in the three coordinate directions and those governing mass and energy balances for the two-phase mixture.

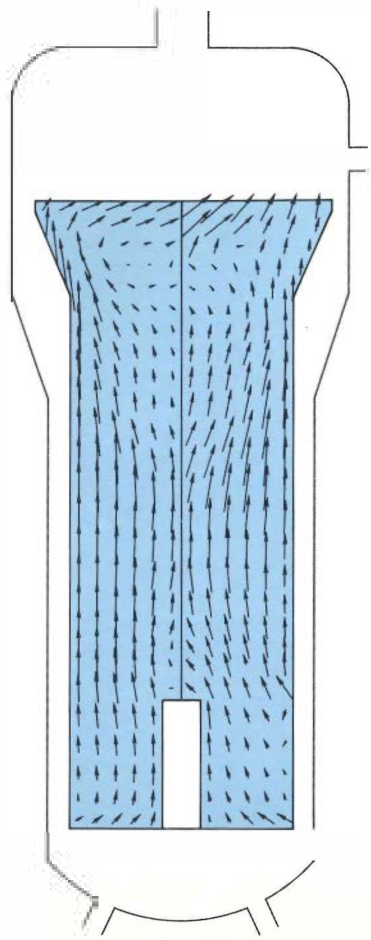
At this time the third model is being reconstructed with further generalization to allow for thermal nonequilibrium between the two phases; the resulting model will be a full UVUT (unequal velocity, unequal temperature) model. In all the URSULA2 models, the temperature of the primary fluid is described by an energy balance equation. Algebraic equations describe such factors as interphase transfers and material properties.

The set of relevant partial differential equations for mass, momentum, and energy is converted into a set of algebraic finite difference equations by carrying out integrations over the cell volumes and by using a differencing scheme that is upwind in space and first-order-implicit in time. The resultant set of nonlinear algebraic equations is solved by an iterative procedure.

Applications

URSULA2 has been used to simulate steady-state thermal-hydraulic conditions for a Combustion Engineering, Inc., System 80 U-tube steam generator operating at full and part power. Calculations were made with EVET and algebraic slip models. To form the 936 computation cells used in the model, the steam generator was partitioned into 26 horizontal sections, each divided into 36 cells by

Figure 2 A velocity vector plot of the inside of the steam generator shell shows the magnitude and direction of secondary steam-water mixture in each computation cell calculated by URSULA2.



6 radial planes and 6 circumferential boundaries. The computer time required for calculating the steady state is about 1 ms per cell per iterative step. The convergence criterion used in these computations was a maximum pressure correction of 5 Pa (0.000725 psi)—that is, the cell pressures are accurate to this extent in the framework of the URSULA2 numerical model. Given this criterion, the EVET and algebraic slip models required 140 and 240 iterative steps, respectively, for convergence.

A velocity vector plot for a typical EVET model calculation is shown in Figure 2. The velocity vectors are not completely axial at the separator deck, which indicates that there is a recirculating region in the flow field above the tube bundle. Calculations are being made to identify the causes of this recirculating flow. Other calculated parameters, such as mean void distribution and circulation ratio, compare well with results from other codes.

Future development

Future work on URSULA2 will focus on three areas: (1) input and output improvements (e.g., graphic display plots) to make the code more user-oriented; (2) improvements in the numerical solution procedure, including an improved convergence scheme; and (3) improvements in the physical models, including generalization of the slip model to allow for thermal nonequilibrium between phases, development of a countercurrent-flow model, automatic selection of flow regimes during calculations, and generalization of the numerical procedure so it can be used for all types of steam generators. Further sensitivity and checkout studies will be performed to enhance the code's usefulness as a tool for the thermal-hydraulic analysis of steam generators. *Project Manager: G. S. Srikantiah*

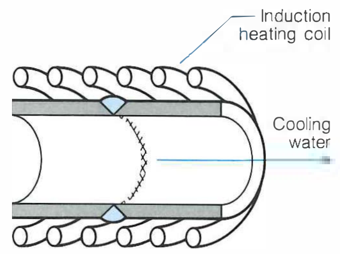
INDUCTION HEATING STRESS IMPROVEMENT

A significant problem for the nuclear power industry in the past few years has been the intergranular stress corrosion cracking (IGSCC) of type-304 stainless steel pipe welds in BWRs. Approximately 200 incidents of BWR pipe cracking have been reported. A process has been developed in Japan that could help prevent IGSCC by changing the residual stress distribution in the pipe weld zone. EPRI and General Electric Co. are currently studying this process to determine its effectiveness as a pipe-cracking remedy in operating BWRs.

Three conditions are considered to be essential for IGSCC to occur in BWR piping: sufficient stress, a sensitized material condition, and a facilitating environment. Stress analyses of BWR piping systems in which IGSCC has occurred suggest that service-related stresses are not sufficient to cause the cracking. As a result, considerable research has been devoted to finding additional sources of stress. This research has identified the residual stress that results from welding as a major contributor to the overall stress state of a pipe weld. Therefore, the goal of certain stress-related pipe-cracking remedies has been to change the weld residual stress distribution.

One of these remedies is a process called induction heating stress improvement (IHSI).

Figure 3 In the IHSI process, heating the outside wall of a girth-welded pipe while cooling the inside wall changes the residual stress distribution in the pipe weld zone, making it less susceptible to IGSCC.

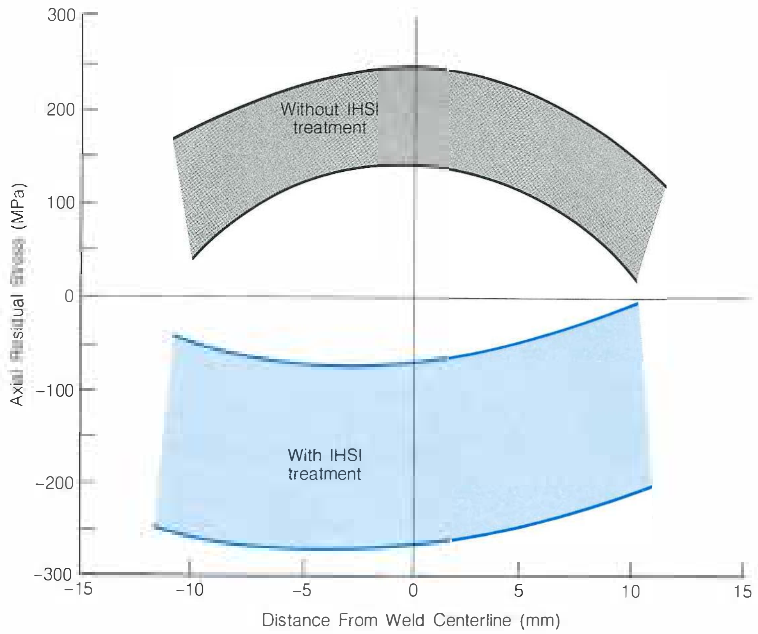


It was first developed in Japan by Hitachi, Ltd., and Ishikawajima-Harima Heavy Industries Co., Ltd. The process uses an induction coil to heat the outside of a pipe to 550°C (1022°F); the temperature on the inside of the pipe is maintained at about 100°C (212°F) by means of flowing water (Figure 3). Heating times are 1–3 minutes, depending on the thickness of the pipe wall. The induction heating produces a temperature distribution through the pipe wall that plastically deforms the inner pipe surface in tension. When the induction coil is turned off, the thermal contraction of the outer portion of the pipe wall forces the inner portion of the wall into a state of residual compression. It is this compressive residual stress state that makes the pipe more resistant to IGSCC. Typical residual stress measurements on the inner pipe surface before and after IHSI are presented in Figure 4.

Tests conducted in Japan with boiling magnesium chloride have demonstrated qualitatively that the IHSI process produces a favorable residual stress distribution on the inner surface of girth-welded type-304 stainless steel pipe. In these tests untreated pipes exhibited evidence of high tensile residual stress on the inner pipe surface, while IHSI-treated pipes showed no such evidence. Although there is no doubt about the validity of these results, the effectiveness of IHSI as a remedy for IGSCC in BWR environments has yet to be established.

With funding from the BWR Owners Group (RPT113-1), researchers at EPRI and General Electric Co. are attempting to explain the role played by residual stress in IGSCC of type-304 stainless steel BWR piping and

Figure 4 Residual stress distribution of the inside surface of a 4-in girth-welded pipe, with IHSI treatment and without.



to develop an IGSCC model that can be used to determine the quantitative benefit of IHSI in BWR environments at operating stress levels. The preliminary findings of this research indicate that IHSI does result in a significant IGSCC benefit at realistic BWR stress levels and this benefit decreases as the applied stress level appreciably exceeds the pipe material's yield strength.

The IHSI process is an especially attractive pipe-cracking remedy because it can be applied nondestructively to operating BWRs as well as to BWRs under construction. Furthermore, it is not limited to BWRs but can be applied to piping systems wherever stress corrosion cracking is a concern. *Program Manager: J. C. Danko; Project Manager: A. J. Giannuzzi*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP434-43	Topic Paper: Costing and Rate Design	6 months	49.4	Temple, Barker & Sloane, Inc. *J. Malko*
RP545-4	Ceramic Heat Exchanger Technology	9 months	55.1	Solar Turbines International *W. Bakker*
RP608-2	Experiment With Simulated and Controlled AE Steels	3 years	243.4	Cornell University *J. Quinn*
RP742-2	Induced AC Potential on Pipelines	2 years	258.9	Science Applications, Inc. *J. Dunlap*
RP849-6	Test Data Acquisition Support Services	22 months	80.0	Texas A&M Research Foundation *J. Mitsche*
RP1009-5	Coal Supply Analysis System: Task II, Resource Procedures and Data Bases	21 months	139.4	ICF Incorporated *T. Browne*
RP1180-12	Coal-Water Slurries as Utility Boiler Fuels	5 months	15.0	Atlantic Research Corp. *R. Manfred*
RP1266-21	Educational Research in Solid-Fuel Technology	6 months	59.4	Center of Occupational Research and Development *K. Lehner*
RP1319-5	Advanced Cooling: Full-Scale Engine Demonstration	3 years	5244.3	Westinghouse Electric Corp. *A. Cohn*
RP1348-7	Development of an EPRI R&D Program Plan for Biomass	6 months	50.0	Battelle, Columbus Laboratories *S. Kohan*
RP1557-2	Hydrocyclones for Radwaste Processing	9 months	62.0	Radiological and Chemical Technology, Inc. *M. Naughton*
RP1579-6	Tests of the Durability of Solidified Nuclear Waste	21 months	275.3	NPD Nuclear Systems, Inc. *R. Williams*
RP1590-1	Evaluation of Electric Utility Experience With Wind Power Generation	2 years	393.3	JBF Scientific Corp. *F. Goodman*
RP1606-1	Agglomeration of SRC Residues	10 months	86.7	Conoco Coal Development Co. *H. Lebowitz*
RP1616-21	Plume Model Validation—Operation of the Kincaid Air-Monitoring Network	5 months	14.1	Dames & Moore *G. Hilst*
RP1632-1	A Microcosm Approach to the Evaluation of Simulated Acid Precipitation Effects on Forest Ecosystems	21 months	154.4	Tennessee Valley Authority *R. Goldstein*
RP1637-1	Human Engineering Guidelines for Operations	22 months	660.0	Essex Corp. *H. Parris*
RP1649-6	Root Cause Failure Analysis: Fossil-Fired Power Plants	21 months	490.0	Battelle, Columbus Laboratories *I. Diaz-Tous*
RP1676-2	Investigation of New Fuel Cell Electrolyte and Electrode Concepts	1 year	59.9	Lawrence Berkeley Laboratory *J. Appleby*
RP1677-3	Portfolio Analysis for Establishing the Market Feasibility of Phosphoric Acid Fuel Cells	3 months	132.4	NUS Corp. *T. Yau*
RP1733-3	Marviken IV Jet Impingement Experiments	13 months	116.9	Intermountain Technologies, Inc. *A. Singh*
RP1750-1	Benchmark of an ENDF/B–V CASMO–CPM Nuclear Data Library	1 month	174.9	Studsvik Energiteknik Ab *O. Ozer*
RP1756-1	Requalification Standard; Commentary Report	6 months	49.4	Teledyne Engineering Services *S. Tagart*
RP1756-2	Requalification Plan for Pressurized Components	6 months	50.7	Aptech Engineering Services *S. Tagart*
RP1760-2	Coupling of Hydrogen Generation and Thermal Hydraulics in Reactor Core Under Core Uncovering Conditions	4 months	30.0	University of Illinois *B. Sun*
RP1830-1	Modification and Update of EMPSS Computer Program	16 months	138.9	Arthur D. Little, Inc. *G. Purcell*
RP1839-2	Use of Additives to Facilitate the On-Load Cleaning of Coal-Fired Boiler Surfaces	15 months	187.8	Battelle, Columbus Laboratories *J. Dimmer*
RP1840-2	Oil Agglomeration of Fine Coal	1 year	149.5	Atlantic Richfield Co. *R. Sehgal*
RP1860-2	Orientation Program for AFBC Engineers and Operators for TVA and Other EPRI Member Companies	5 months	48.5	Babcock & Wilcox Co. *W. Howe*
RP1867-1	High-Sulfur Coal Fabric Filter Pilot Plant	4 months	99.3	Stearns-Roger, Inc. *R. Carr*
RP1929-1	Metallurgical Investigation of Disk Cracking in the LP-2 Turbine at a Nuclear Power Station	7 months	50.0	Southwest Research Institute *M. Kolar*

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) 965-4081. 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

Operational Analysis of Open-Cycle MHD

AP-1463 Final Report (RP639-1); $10.50

Conceptual designs for first-generation open-cycle magnetohydrodynamic (MHD) power plants were studied in the context of a utility system. The utility system was described by load growth, fuel availability and cost, size and operating characteristics of existing units, and various economic factors. On the basis of projected plant costs and performance characteristics, assumed economic and escalation factors, and a coal supply and delivery scenario, a limited study of open-cycle MHD market potential was conducted. The contractor is Westinghouse Electric Corp. *EPRI Project Managers: Andrew Lowenstein and Paul Zygielbaum*

Theoretical Analysis of Carbon Cluster Formation in Solid Iron-Based Alloys: A Review of the Alex-McLellan Mathematical Model

AP-1478 Interim Report (RP838-1); $3.50

This report describes the Alex-McLellan model (a statistical thermodynamic model for metallic solutions containing interstitial species) and its application in a study of the carburization of iron alloys containing chromium and molybdenum. Topics covered include the partition function, interaction energy calculations, the correlation of interaction energy with electronegativity, the nature of carbon clusters in metallic solutions, and methane formation. The contractor is Pennsylvania State University. *EPRI Project Manager: Ramaswamy Viswanathan*

Study of the Feasibility of Cogeneration Using Wood Waste as Fuel

AP-1483 Final Report (TPS79-736-1); $8.75

The feasibility of establishing a wood- and refuse-burning steam-electricity cogeneration facility in Lewis County, Washington, was evaluated. Fuel sources, costs, and availability were studied, along with local thermal markets and regional electricity markets. Conceptual designs, including the selection and sizing of principal equipment, were developed for both cogeneration and condensing-cycle plants. A plan that outlines the requirements and the schedule for acquisition of the facility was also developed. The contractor is Rocket Research Corp. *EPRI Project Manager: B. M. Louks*

Design Properties of Steels for Coal Conversion Vessels

AP-1508 Interim Report (RP627-1); $3.50

This report presents fracture toughness measurements made in simulated coal conversion environments on specimens held under sustained load or sustained deflection for six months. The materials tested included two grades of $2\frac{1}{4}$Cr-1Mo steel. Base metal, weld metal, heat-affected zone, and temper-embrittled steel were investigated. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Ramaswamy Viswanathan*

COAL COMBUSTION SYSTEMS

Disposal of PCBs and PCB-Contaminated Materials: Test Incineration of Electric Capacitors Containing PCBs

FP-1207 Final Report, Vol. 4 (RP1263-2); $6.50

A trial burn was conducted to determine whether liquid polychlorinated biphenyls (PCBs) and shredded capacitors can be incinerated according to EPA regulations. This report reviews the published literature on PCB burning, describes the incineration facility, discusses in detail the sampling and analysis procedures used for the burn, and summarizes the results. Raw data and sample calculations are presented in the appendixes. The contractor is Acurex Corp. *EPRI Project Manager: R. Y. Komai*

Resource Handbook for Power Plant Training Programs

CS-1432 Resource Handbook (RP1266-6); $22.75

This handbook lists available educational materials relating to three coal-fired power plant job categories—instrument and control technician, environmental and chemical analysis technician, and power plant operator. It has sections on printed materials, audiovisual aids, and specialty and package programs. Also listed are organizations that supply materials for review, organizations with information-retrieval capabilities, and professional and trade associations. The contractor is the Center for Occupational Research and Development. *EPRI Project Manager: K. P. Lehner*

Air-Gas System Dynamics of Fossil Fuel Power Plants

CS-1444 Final Report (RP1651); Vol. 2, $5.25; Vol. 3, $5.75

Large-amplitude, low-pressure pulsations have occurred in the air-gas system of a number of fossil fuel power plants, causing severe equipment damage. A mathematical model has been developed to study the response characteristics of such systems. Volume 2 describes the model, and Volume 3 describes techniques that were developed for instrumenting plants and analyzing the data collected. Volume 1, published earlier, presents an overview of the project. The contractors are Westinghouse Electric Corp., the Massachusetts Institute of Technology, and NUS Corp. *EPRI Project Manager: I. A. Diaz-Tous*

Preliminary Assessment of Alternative PFBC Power Plant Systems

CS-1451 Final Report (RP1645-2); $5.25

Preliminary cost estimates for three alternative 1000-MW (e) pressurized fluidized-bed combustion (PFBC) power plant systems were developed and compared with economic data on conventional pulverized-coal-fired power plants. Two of the PFBC systems had a steam-cooled design; the third had an air-cooled design. Cases were calculated for both eastern and western coals. The contractor is Burns and Roe, Inc. *EPRI Project Manager: W. W. Slaughter*

Materials Problems in FBC Systems: Review of Information on Gas Turbine Materials in Coal Combustion Environments

CS-1469 Interim Report (RP1337-1); $7.25

This report summarizes information on the behavior of gas turbine materials exposed to coal combustion gases. The information is based on work to establish the potential for direct coal firing of gas turbines, on the operating experience of gas turbines in particulate-laden environments, and on evaluations of gas turbines for use with pressurized fluidized-bed combustors. Results show that the potential for erosion, corrosion, and deposition exists in such systems to the extent that performance and endurance may be substantially reduced. The contractor is General Electric Co. *EPRI Project Manager: John Stringer*

Materials Problems in FBC Systems: Effect of Process Variables on In-Bed Corrosion

CS-1475 Interim Report (RP979-1); $8.25

Tests were run on a wide range of ferritic, austenitic, nickel-based, and cobalt-based alloys to investigate the effects of several operating variables on in-bed sulfidation-oxidation corrosion. This report describes the test facility and specimen preparation, compares alloy performance, and discusses indications of important parameters affecting corrosion. The contractor is the National Coal Board. *EPRI Project Manager: John Stringer*

Cold Modeling of Fluidized-Bed Combustors

CS-1476 Final Report (RP315-1); $12.50

A cold-flow test rig was constructed and instrumented in order to develop data useful for the design and operation of FBC plants. Data were collected on bubble movement, solids mixing, bed-to-tube heat transfer, gas flow and mixing, forces on the tube array, elutriation of fines, and defluidization and refluidization characteristics. Physically reasonable models for bed-to-tube heat transfer, solids mixing, gas flow and mixing, and elutriation coupled with particle attrition were developed and compared with experimental data. The contractor is Oregon State University. *EPRI Project Manager: W. C. Howe*

Recommended Design Guidelines for Feedwater Pumps in Large Power Generating Units
CS-1512 Final Report (RP1266-18); $5.75

This report provides guidelines on design and performance requirements for feedwater pumps, in particular boiler feed pumps for fossil fuel plants over 600 MW. Recommended language for specifications is presented, as well as questionnaires to aid in the preparation of specifications and the evaluation of vendor proposals. Pump problems and their roots in design, manufacture, and operation are discussed. The contractor is Energy Research & Consultants Corp. *EPRI Project Manager: I. A. Diaz-Tous*

Adsorption and Coprecipitation of Trace Elements From Water With Iron Oxyhydroxide
CS-1513 Final Report (RP910-1); $9.50

This report presents the results of laboratory experiments that evaluated the feasibility of using freshly precipitated ferric oxyhydroxide to extract trace elements from power plant wastes. The contractor is Stanford University. *EPRI Project Managers: R. M. Jorden and Winston Chow*

FGD Sludge Disposal Manual, Second Edition
CS-1515 Final Report (RP1685-1); $25.75

This edition includes updated information on the chemical and physical properties of flue gas desulfurization (FGD) sludges and a description of current disposal practices worldwide; information on site selection, environmental monitoring, and site reclamation; proposed and final federal regulations on solid-waste disposal; and computation methods of checking waste quantities and characteristics, leachate production rates, and new plant system and transportation costs. The contractor is Michael Baker Jr., Inc. *EPRI Project Manager: D. M. Golden*

ELECTRICAL SYSTEMS

Research Into Load Forecasting and Distribution Planning
EL-1198 Final Report, Vol. 1 (RP570-1); $3.50

This volume summarizes the major accomplishments and philosophies of a project that investigated methods of improving the forecasting of distribution loads for short- and long-range planning. Two small-area load-forecasting computer programs and a distribution planning model were developed and tested; they are documented in Volumes 2 and 3, published earlier. The contractors are Westinghouse Electric Corp. and the Salt River Project. *EPRI Project Manager: W. E. Shula*

Determination of Synchronous Machine Stability Study Constants
EL-1424 Final Report, Vol. 4 (RP997-1); $5.75

This report describes work to develop generator model parameters by using frequency response techniques. For administrative and technical reasons, EPRI terminated the project before the work was completed. The findings differ from those of companion projects, and no definite conclusions about the frequency response test approach can be drawn. The contractor is NEI Parsons, Ltd. *EPRI Project Managers: Paul Anderson and D. T. Bewley*

Controlling Biological Deterioration of Wood With Volatile Chemicals
EL-1480 Final Report (RP212-1); $4.50

A supplemental treatment process for wood poles that uses agricultural fumigants is described, and inspection methods for predicting when supplemental treatment is necessary are evaluated. Also discussed are ways to improve the effectiveness of fumigant treatments, the residual characteristics of fumigants in poles and their effect on wood strength, and the role of microorganisms in the reinfestation of fumigant-treated poles. The contractor is Oregon State University. *EPRI Project Manager: R. S. Tackaberry*

Superposition Gas Breakdown
EL-1484 Final Report (RP7863); $4.50

A severe problem in compressed-gas-insulated transmission systems is the reduction of breakdown voltage caused by the presence of metal particle contaminants. This report describes a project that investigated how the superposition of impulse voltages on the 60-Hz system voltage affects breakdown in a particle-contaminated system. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: J. F. Shimshock*

Bipolar HVDC Transmission System Study Between ±600 and ±1200 kV: Development of Controlled Cascade Rectifier for Insulator Testing
EL-1496 Final Report (RP430-2); $5.25

This report describes the development of a half-wave cascade rectifier with a high-speed control circuit, which was previously identified as the most economical power supply for flashover tests on contaminated insulators. The circuit elements of the rectifier source were determined on a model circuit, and the results were generalized by means of a computer program. Proper operation was verified with a full-scale circuit. Results on power supply performance and leakage-current values from tests of heavily contaminated insulators are also presented. The contractor is Institut de Recherche de l'Hydro-Québec. *EPRI Project Managers: John Dunlap and R. E. Kennon*

High-Temperature Gas-Insulated Systems
EL-1500 Final Report (RP7850-1); $9.50

Insulators, conductor joints, and spiral-welded enclosures for high-temperature operation of SF_6-insulated transmission lines were developed and tested in this project. The economic effects of increased operating temperatures were evaluated by computer optimization programs. A 9-m-long section of a 362-kV prototype was built and tested in three modes of installation—open air, covered trench, and direct burial. The contractor is Gould–Brown Boveri Inc. *EPRI Project Manager: J. F. Shimshock*

Development of 500-kV AC Cable Employing Laminar Insulation of Other Than Conventional Cellulosic Paper
EL-1518 Final Report (RP7810-1); $5.75

This report describes work to develop a 500-kV ac cable with a laminar insulation that has lower losses than conventional cellulosic paper insulation. Included are a summary of previous research, an evaluation of insulating tapes and impregnants, and a discussion of the manufacture and testing of three prototype cables. The contractor is General Cable Corp. *EPRI Project Manager: J. F. Shimshock*

Development of 345-kV Capacitive-Graded Joint
EL-1519 Final Report (RP7814-1); $6.50

This report describes the design of a prefabricated capacitive-graded joint for 345-kV oil-filled cables. Prototypes were manufactured and tested, and the adequacy of the printed circuit design was demonstrated. It was not possible to consistently obtain high-quality capacitive sheets, and substantial effort will be required to remedy this problem. The report summarizes the advantages of prefabricated joints and presents recommendations for further development work. The contractor is Phelps Dodge Cable & Wire Co. *EPRI Project Manager: J. F. Shimshock*

ENERGY ANALYSIS AND ENVIRONMENT

Methodology for Evaluation of Multiple Power Plant Cooling System Effects: User's Guide to Model Operation
EA-1111 Final Report, Vol. 4 (RP878-1); $10.50

A methodology was developed to evaluate the impact of multiple power plant cooling systems on the ecosystem of a single body of water. This volume describes the models in the methodology and provides instructions for applying them. Program codes, flow charts, data requirements, and definitions of variables are presented in the appendixes. The contractor is Tetra Tech, Inc. *EPRI Project Manager: I. P. Murarka*

Chemical Measurements in the Los Angeles Atmosphere
EA-1466 Final Report (RP1315-2); $2.75

A study was made of the Battelle megavolume particulate sampler—a device that collects gram quantities of atmospheric particles (in three size ranges) by impaction and electrostatic precipitation. The usefulness of various sample treatments and analyses was examined. Samples taken at a Los Angeles site were extracted into organic or aqueous solvents for chromatographic and spectroscopic treatments. The contractor is Global Geochemistry Corp. *EPRI Project Manager: P. W. Jones*

Trends in Energy Use in Industrial Societies
EA-1471 Final Report (RP864-1); $9.50

This report examines the relationship between energy consumption and economic growth in the United States, Canada, Japan, and six European countries, and analyzes trends and differences. The effects of energy supply systems, output composition, energy prices, geographic characteristics, and consumption preferences are discussed. The contractor is Resources for the Future, Inc. *EPRI Project Manager: A. N. Halter*

Labor Outlook for the Bituminous Coal Mining Industry
EA-1477 Final Report (RP1147-1); $11.25

This report analyzes labor supply as a constraining factor in the expansion of U.S. coal output in the period to 1990 and in the longer term (to 2030). It presents regional projections of coal industry labor requirements, labor supply, and unit labor costs to 1990, as well as projections of longer-term labor demand and supply factors; the report also discusses the reliability and major limitations of such projections. The contractor is The Conference Board. *EPRI Project Manager: T. E. Browne*

Review of Open Literature on Effects of Chlorine on Aquatic Organisms

EA-1491 Interim Report (RP877); $12.00

The pre-1980 open literature on the effects of chlorine in marine, freshwater, and estuarine systems is reviewed, with emphasis on the potential impacts of power plant chlorination practices. Information is presented on aqueous chlorine chemistry, biological effects, and analytic methods for differentiating and measuring chlorine-produced residual oxidants. The contractor is Oak Ridge National Laboratory. *EPRI Project Manager: I. P. Murarka*

Development of a Particulate Sulfate Analyzer

EA-1492 Final Report (RP678-1); $5.75

A prototype particulate sulfate analyzer for continuous ground-based monitoring was developed and then tested in the laboratory and under actual field conditions. The instrument's performance during ambient-air-monitoring tests compares favorably with the performance of other developmental analyzers. The contractor is Environmental Research & Technology, Inc. *EPRI Project Manager: Charles Hakkarinen*

Plume Conversion Rates in the SURE Region

EA-1498 Final Report (RP860-1); Vol. 1, $7.25; Vol. 2, $9.50

In a satellite project of the Sulfate Regional Experiment (SURE), chemical reaction rates of sulfur and nitrogen oxide emissions in three midwestern fossil-fired power plant plumes were measured. Volume 1 outlines the project, summarizes previous plume studies, describes the experimental design, and presents data analyses. Volume 2 summarizes the daily activities of each sampling experiment, describes the data reduction techniques used, and presents data tables. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: Charles Hakkarinen*

Inclusion of Cogeneration in Electric Utility Models

EA-1504 Final Report (RP1368-1); $5.25

This report describes the design of an analytic model for studying the economic and energy production effects of cogeneration. It discusses the technical and economic aspects of the cogeneration units that can be simulated; model input, logic, and output; the nine modules that make up the model; and potential applications. The development work necessary to make the model dynamic is also discussed. The contractor is Resource Planning Associates, Inc. *EPRI Project Managers: E. G. Altouney and J. K. Delson*

Workshop Proceedings: Data Management Needs for Atmospheric Deposition

WS-79-163 Workshop Report; $2.75

EPRI sponsored a workshop in February 1979 in Washington, D.C., to review existing and planned North American programs for collecting acid deposition data and to identify requirements to be met in establishing a coordinated, readily accessible data base. Discussions were limited to physical deposition data; ecological effects data were not considered. Specific characteristics and capabilities of the data management function were defined, including general data formats, accessibility, output representations, and quality control. The contractor is Colorado State University. *EPRI Project Manager: Charles Hakkarinen*

Proceedings: Workshop on Water Supply for Electric Energy

WS-79-237 Workshop Report; $5.25

A workshop was held in Palo Alto, California, in March 1980 to develop recommendations for research to help the electric utility industry meet its water needs. Seven priority research areas and 20 other important areas were identified. Papers on needed research are reproduced in full in this report, and papers on current EPRI water-related research are summarized. The contractor is Linsley, Kraeger Associates. *EPRI Project Manager: E. G. Altouney*

ENERGY MANAGEMENT AND UTILIZATION

Analytic Predictions of Circulation and Vortices at Intakes

EM-1485 Final Report (RP1199-8); $3.50

Vortices at the intake structures of pumped-storage plants have detrimental effects on flow capacity and pump and turbine operating stability. This report describes the first phase of a study to develop a two-dimensional finite element model to predict vortices at intakes. The origin of intake vortices, predictions of vortex activity, and model applications are summarized. The contractor is Worcester Polytechnic Institute. *EPRI Project Manager: Antonio Ferreira*

Assessment of Fuel-Processing Systems for Dispersed Fuel Cell Power Plants

EM-1487 Interim Report (RP1041-1); $5.75

Testing was conducted to verify the capability of Toyo Engineering Corp.'s sulfur-tolerant catalysts to process No. 2 fuel oil at typical fuel cell system conditions. The effect of the catalysts on power plant costs and efficiency was also assessed. This report reviews the experimental results, correlates the data, and develops preliminary catalyst design parameters. The contractor is Kinetics Technology International, Inc. *EPRI Project Manager: E. A. Gillis*

Solar Heating and Cooling of Buildings (SHACOB): Requirements Definition and Impact Analysis, II

EM-1506-SY Summary Report (RP553-2); $3.50

This report summarizes a study to determine the potential effect of the widespread implementation of solar heating and cooling systems on utility load, utility operating costs, and customer costs for the years 1990 and 2000. Although findings varied among utilities and regions, the study concluded that such systems could result in reduced electricity demand and in savings in operating costs and capital requirements for utilities. The contractor is The Aerospace Corp. *EPRI Project Managers: J. W. Beck and F. W. Keith, Jr.*

Industrial Cogeneration Case Studies

EM-1531 Final Report (RP1276-1); $5.75

This report presents the results of a survey of 17 industrial cogeneration sites. It covers equipment and operating practices, thermal and electric output, capital investments, operating and maintenance costs, fuel costs, institutional arrangements for ownership and operation, and interaction with local electric utilities. An extensive list of operating U.S. cogeneration systems is also included. The contractor is Synergic Resources Corp. *EPRI Project Manager: R. L. Mauro*

NUCLEAR POWER

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

NP-1410 Final Report, Vol. 1 (RP519-4); $5.25

Design and operating data for the first two fuel cycles at Three Mile Island Unit 1 are presented. Design data include core-loading plans and descriptions of fuel pins, guide tubes, control elements, spacer grids, and instrumentation. Operating data include primary- and secondary-side flows and temperatures, the operating rod pattern, and an in-core detector signal map for each state-point measurement. In addition, representative startup test results are provided for both cycles. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: R. N. Whitesel*

Assessment of Condenser Leakage Problems

NP-1467 Final Report (TPS79-729); $8.25

Condenser leakage is a leading cause of denting and other forms of corrosion damage in steam generators. This report discusses several problem areas, including air leakage, locating cooling-water leaks, tube inner-diameter inlet attack, fouling, steam-side erosion, flow-induced vibration, outer-diameter corrosion, and tube-to-tubesheet leakage. Appendixes summarize condenser-related unit shutdowns and power reductions, as well as the results of a survey on condenser performance by the Heat Exchange Institute. The contractor is MPR Associates, Inc. *EPRI Project Manager: R. L. Coit*

Corrosion-Related Failures in Power Plant Condensers

NP-1468 Final Report (TPS79-730); $9.50

This report reviews the literature on modes of corrosion failure in surface condensers: pitting and crevice corrosion, erosion-corrosion, galvanic attack, stress corrosion fatigue, and dealloying. It describes each failure mode, the experimental techniques used to study it, the parameters that influence failure, and the alloys affected. It also presents a survey of service failures for each alloy system and discusses experimental studies. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: R. L. Coit*

Effects of Valve Performance on Boiling Water Reactor Unit Capacity

NP-1473 Final Report (RP894-5); $4.50

Data from an operating BWR were studied in order to identify valve-related forced outages and power reductions. Valve problems were found to be responsible for 26,000 MW (e) days of lost power production at the plant during a three-year period.

Approximately 19,000 MW (e) days were attributable to valve-stem-packing leakage and packing-related failures in recirculation system valves, and approximately 2800 MW (e) days to a relief valve failure in the off-gas system. Suggestions for improving valve performance are presented. The contractor is Nuclear Services Corp. *EPRI Project Manager: T. W. Libs*

Effect of Out-of-Plane Denting Loads on the Structural Integrity of Steam Generator Internals

NP-1479 Final Report (S169-1); $2.75

A study was conducted to determine the structural effects when PWR steam generator tubes become locked into support plates as a result of denting. This report describes the techniques, equations, and conservatisms used in the analysis. Tube structural integrity was considered in terms of flow-induced vibrations, fatigue, and tube buckling. Tube support plate in-plane stresses were calculated and compared with allowable ASME design stresses. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: D. A. Steininger*

Temperature Sensor Response Characterization

NP-1486 Final Report (RP1161-1); $9.50

This report describes follow-up work on response-time degradation in resistance temperature detectors and on in situ testing procedures. Theoretical heat transfer studies were conducted to examine the factors that control sensor response, and procedures for response-time testing under PWR operating conditions were evaluated experimentally. Limited testing of thermocouples was also conducted. The contractor is the University of Tennessee. *EPRI Project Manager: D. G. Cain*

Hydrodynamic Impact Loads With SURGE

NP-1490 Final Report (RP965-1); $5.25

An effort was made to modify the SURGE computer code so that impact loads on a rigid, simplified ringheader (which may occur during pool swell) can be computed. The generalized arbitrary Lagrangian-Eulerian method is described in detail, along with mesh generation, rezoning, smoothing, and modification for the impact problem. A listing of the SURGE code as modified is given in the appendix. The contractor is Jaycor. *EPRI Project Manager: J. J. Carey*

Subchannel Thermal-Hydraulic Experimental Program (STEP)

NP-1493 Final Report (RP765); Vol. 1, $5.25; Vol. 2, $8.25

Experiments were conducted to obtain data for improving fluid flow and heat transfer models used in reactor fuel and core analyses. Volume 1 describes work to determine the mixing characteristics of mass and energy for a simulated PWR fuel rod bundle; Volume 2 describes the measurement (by a gamma-scattering technique) of void fractions for selected heat transfer conditions in a simulated bundle. Each volume outlines the test hardware and procedures used and presents the results of data analysis. The contractor is Babcock & Wilcox Co. *EPRI Project Managers: D. G. Cain and H. A. Till*

Activity Levels of Transuranic Nuclides in Low-Level Solid Wastes From U.S. Power Reactors

NP-1494 Final Report (RP613); $7.25

The results of radiochemical assays of low-level solid wastes from U.S. commercial LWRs are presented. The complete nuclide data base is given, including the number of units, measurement time period, and isotopic assay. Distributions of measured ^{239}Pu concentrations are presented for the principal sample categories, and median values of transuranic and other nuclide concentrations are calculated for these categories. The contractor is Science Applications, Inc. *EPRI Project Manager: M. E. Lapides*

One- and Two-Dimensional STEALTH Simulations of Fuel-Pin Response

NP-1495 Final Report (RP1117-2); $4.50

EPRI's STEALTH computer code is a general code designed to simulate the transient mechanical or thermomechanical responses of complex physical systems. This report describes a study that assessed STEALTH's applicability to transient fuel rod analysis. The code was modified and used to simulate fuel rod response in the blowdown phase of a hypothetical loss-of-coolant accident. Analytic models of one- and two-dimensional formulations and features included in the two-dimensional simulation are discussed. The contractor is Science Applications, Inc. *EPRI Project Manager: R. N. Oehlberg*

Hydraulic Investigation of a 4 × 6 Rod Bundle

NP-1497 Final Report (RP1229-1); $3.50

During mixing experiments in EPRI's Subchannel Thermal-Hydraulic Experimental Program, rod deflection occurred. This report describes later work to determine the effects of such deflection. The mixing experiments were reconducted with and without rod deflection, local velocities were measured, and the data were compared with COBRA-IV predictions. The contractor is Babcock & Wilcox Co. *EPRI Project Managers: D. G. Cain and H. A. Till*

Elimination of Impurity-Induced Embrittlement in Steel: Impurity Segregation and Temper Embrittlement

NP-1501 Interim Report (RP559); $5.75

The effects of compositional and microstructural parameters on impurity segregation and the temper embrittlement susceptibility of NiCr and CrMo steels are discussed. Equations are presented that correlate embrittlement susceptibility with grain size, hardness, and the composition of grain boundaries in laboratory-made NiCr steels. A new surface analysis technique for rapidly estimating the kinetics of the segregation of impurities to grain boundaries is described. The contractor is the University of Pennsylvania. *EPRI Project Manager: Ramaswamy Viswanathan*

Analysis of Belgian Mixed-Oxide Critical Experiments

NP-1502 Final Report (RP1074-1); $4.50

A number of critical lattice experiments performed in Belgium from 1967 to 1971 are analyzed to determine their adequacy for benchmarking LWR design methods and data. The overall computation methods are described, including the HAMMER code, which was used for cell calculations, and the ANISN code, which was used for reactor calculations. The report also discusses geometric and nuclear properties of fuel elements, resonance calculations and material buckling, and space-dependent cylindrical reactor calculations. The contractor is Stanford University. *EPRI Project Manager: Odelli Ozer*

Improvements to the COBRA-TF (EPRI) Computer Code for Steam Generator Analysis

NP-1509 Final Report (RP1121-1); $5.25

This report describes improvements in the COBRA-TF code for PWR steam generator analysis. New features and models were added in the areas of subcooled boiling and heat transfer, turbulence, numerics, and global steam generator modeling. The code's new capabilities were qualified against selected experimental data and demonstrated for typical global and microscale steam generator analysis. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: H. A. Till*

Basic National Data System for Power Plants

NP-1520 Final Report (RP1391-1, RP1391-2); $4.50

A study was undertaken to define the applications, analysis concepts, reporting requirements, and operation of a proposed national data system on power plant reliability and productivity. The study examined the needs of the electric power industry for plant and equipment performance data to support critical decisions in the areas of system planning, plant design, plant operation, and equipment improvement. The contractors are Holmes & Narver, Inc., and The S. M. Stoller Corp. *EPRI Project Manager: J. M. Huzdovich*

PLANNING

Research Results and Applications, 1980 Edition

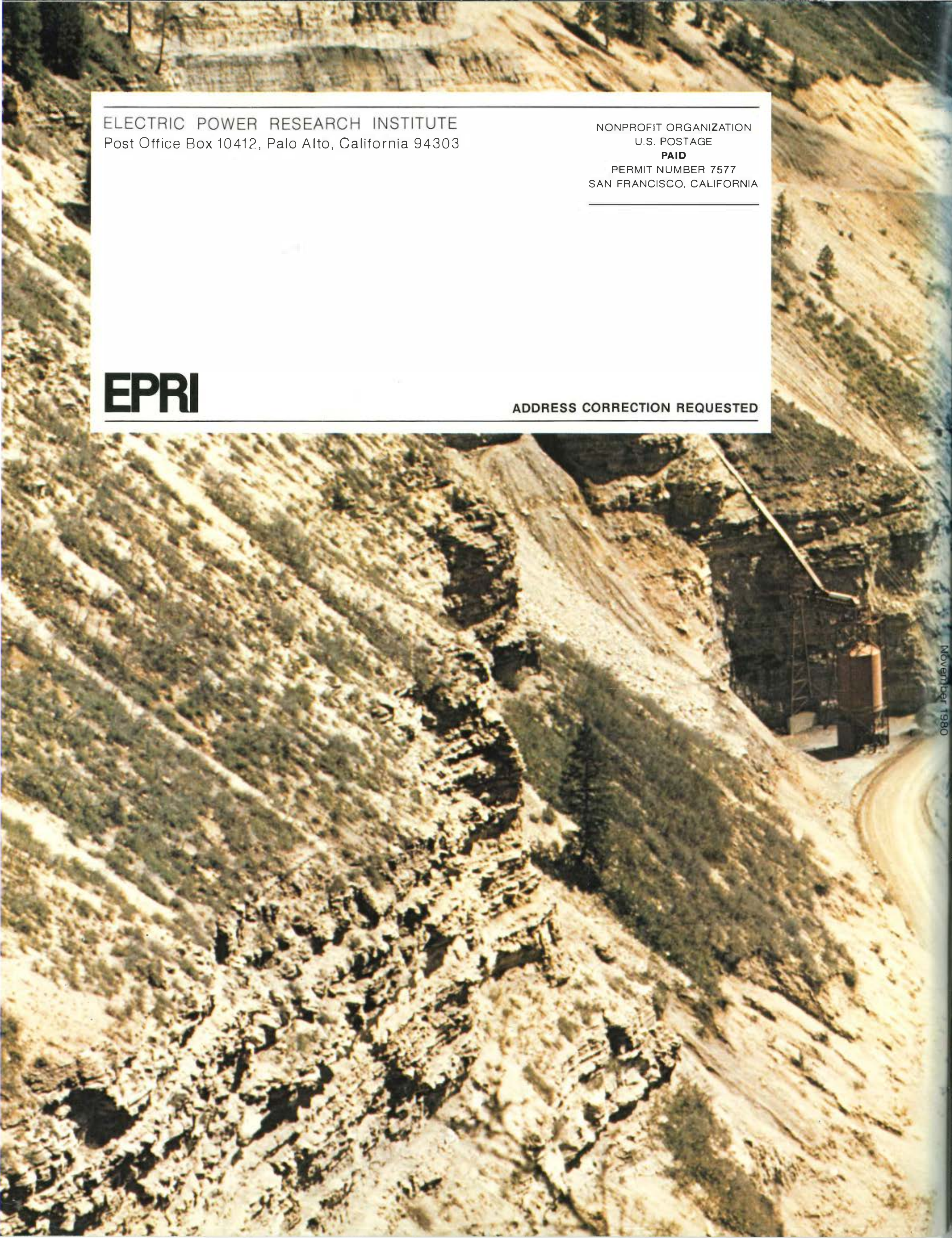
P-1561-SR Special Report; no charge

A significant portion of EPRI's R&D projects seek practical solutions for urgent problems faced by the utility industry. This report presents 36 examples of new EPRI research accomplishments that are ready for utility application. It also describes how 45 previously reported accomplishments have been successfully applied by utilities. Examples are presented in the areas of fuel processing, power generation, transmission and distribution, energy storage and management, energy analysis, and environmental assessment and control. *W. H. Seden and D. L. Watson, Research Applications Group*

Progress on Significant R&D Projects, 1980 Edition

P-1618-SR Special Report; no charge

This report describes 145 current EPRI projects that are expected to yield significant benefits to the utility industry. Included are projects that have an EPRI funding authorization of over $5 million, smaller projects soon to be applied on utility systems, and bench-scale and analytic studies that will guide future research. *W. H. Seden and D. L. Watson, Research Applications Group*



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