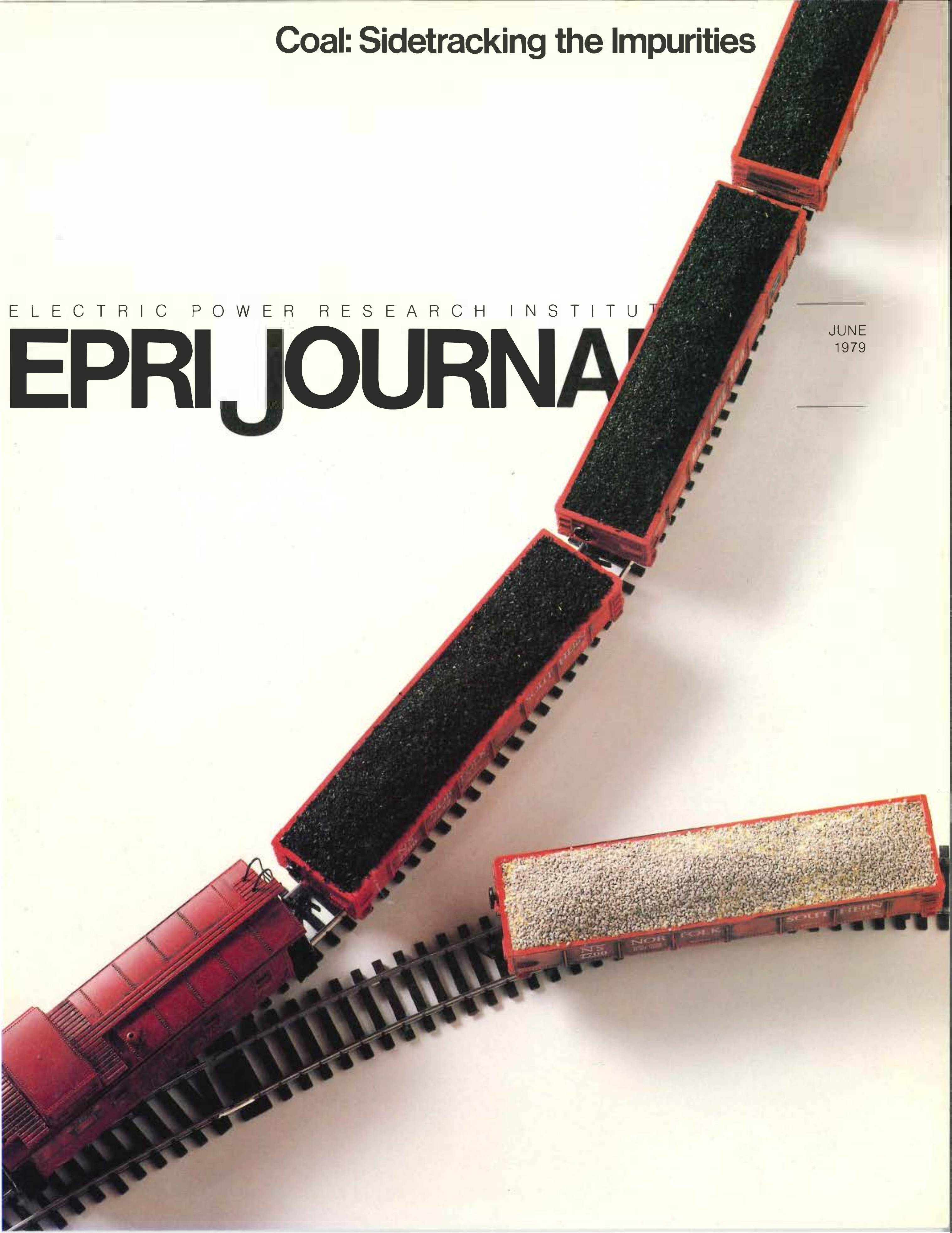
Coal: Sidetracking the Impurities

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

JUNE 1979



EPRI JOURNAL is published by the
Electric Power Research Institute.

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

EPRI JOURNAL Staff and Contributors
Brent Barker, Editor
Ralph Whitaker, Feature Editor
Nadine Lihach, Feature Writer
Jenny Hopkinson, Feature Writer
David Dietrich, Technical Editor
John Kenton, Nuclear Editor
Susan Yessne, Production Editor
Pauline Burnett, Copy Chief
Jim Norris, Illustrator
Barry Sulpor, Dan Van Atta (News Bureau)
Marie Newman (Washington)

Graphics Consultant: Frank A. Rodriquez

Robert A. Sandberg, Director
Ray Schuster, Assistant Director
Communications Division

Address correspondence to:
Editor
EPRI JOURNAL
Electric Power Research Institute
P.O. Box 10412
Palo Alto, California 94303

Cover: From four carloads of raw coal, roughly one carload of impurities can be removed by physical coal cleaning.

EPRI JOURNAL

Volume 4, Number 5 June 1979

Cleaning Up Coal

A major advantage of coal is the existence of huge reserves, widely distributed across the country. However, it is only in times of energy shortage that the nation acknowledges the ability of coal to relieve the precariousness of our energy supply. Today, we are again forced to acknowledge that our domestic coal resources provide the only means of securely supplying U.S. energy demands in the near future.

Unfortunately, coal is a relatively dirty fuel and environmental control has thus become a major specification that affects its cost, efficiency, and reliability. For example, about 40% of the investment in a new coal-fired power plant is used for meeting environmental requirements. Potentially, more stringent regulations resulting from recent air, water, and solid-waste legislation could further increase this percentage.

Two important technologies for decreasing cost and complexity of environmental control are described in this issue: cleaning coal and controlling NO_x emissions.

Coal cleaning was practiced in fifteenth-century England as a means of "sweetening" home heating fuel and "relieving the present misery." By 1985 we will have progressed to the point where the utility industry will be spending over $1 billion per month for coal, and over one-third of this coal will be physically cleaned to remove ash and pyrite. Cleaning technologies will permit using the large coal reserves of the U.S. interior and the Appalachian region that otherwise could not be used under sulfur oxide emission requirements.

Without the new technologies (and if we were to continue our current cleaning practices), the coal that would be wasted in 1985 would be enough to supply ten 1000-MW plants. The EPRI coal-cleaning effort is aimed at reducing that loss while producing the quality product the utility industry demands for both the environment and the improvement in power plant performance and reliability. The value of coal cleaning will be as much as $1/ton of coal for each percent of ash or sulfur removed.

Stringent NO_x control is a relatively new environmental issue stemming from a shift in regulatory emphasis from mobile to stationary sources and will be governed by the pending, short-term, NO_x ambient standards and visibility improvement regulations. The resultant best available control technology (BACT) decisions will have a major impact on both existing and developmental coal utilization systems. Major strides are being made today by the boiler manufacturers to meet this challenge through combustion modification. Based on these encouraging results, the nation should carefully consider whether the approximately 100 ppm additional NO_x emission improvement possible through postcombustion control is worth the $100/kW incremental cost on coal-fired power plants.

Kurt E. Yeager, Director
Fossil Fuel Power Plants Department
Fossil Fuel and Advanced Systems Division

Authors and Articles

Environmental assessment, statutory regulation, and applied research have been combined over the years to deal with many by-products of coal combustion: smoke, oxides of sulfur and nitrogen, and the fine-particulate matter that carries traces of other troublesome chemical elements and compounds. We filter and wash exhaust gases to curtail these emissions; we retard the combustion reaction, limit its temperature, and introduce reagents to suppress undesirable species; we chemically convert coal into liquid and gaseous fuel forms that contain far fewer impurities. Still relatively new among the remedial practices—at least for coal used by electric utilities—is to clean the raw coal itself.

In "More Coal per Ton" (page 6), *Journal* feature writer Nadine Lihach elaborates on the deceptive simplicity of giving coal a bath. The incentives are clear: tighter environmental standards, rising costs of coal and its transportation, and greater variety in coal quality. These lead to differences in prospective cleaning processes, mechanisms, efficiencies, and costs, all of which are under investigation by EPRI's Fluidized Combustion and Coal Cleaning Program. Three of the program staff provided background for Lihach.

Shelton Ehrlich, the program manager, owes his familiarity with coal properties and combustion criteria to 12 years of association with Pope, Evans & Robbins Inc., ultimately as its director of combustion research before joining EPRI in September 1975. Ehrlich is a 1957 mechanical engineering graduate of the University of Missouri, and he earned a master's degree in nuclear engineering at the University of California at Berkeley in 1964.

Kenneth Clifford, manager of EPRI's coal-cleaning research since November 1977, is a metallurgical engineer, experienced in ore beneficiation technology after four years in the laboratories and mills of St. Joe Minerals Corp., plus two years' teaching at the University of Missouri and a year and a half with Envirotech Corp.'s Eimco Division. Clifford holds BS and PhD degrees from the University of Utah in metallurgical engineering (1967) and metallurgy (1970).

Randhir Sehgal, project manager, has specialized for 12 years in coal chemistry and the flowsheet design of coal evaluation and preparation systems. He worked successively with Cyclone Engineering Sales Ltd. (Edmonton, Alberta); Kaiser Engineers, Inc.; and Allen & Garcia Co. before coming to EPRI in January of this year. Sehgal holds BS degrees in chemical engineering from the Indian Institute of Technology (1965) and the University of Alberta, Canada (1967).

■

With its theme "Energy, Technology, and the Human Prospect," April's Edison Centennial Symposium in San Francisco was keynoted by its chairman, Chauncey Starr. He proposed "The Growth of Limits" (page 14) as an inherent characteristic of technology application. In an adaptation of Starr's symposium text, the article emphasizes that technology is essentially an unlimited resource of our minds; as we reach higher, we indeed raise expectations, but we also build ramps to new plateaus.

Now vice chairman of EPRI and head of its Energy Study Center, Starr was the Institute's founding president. He had been dean of the UCLA school of engineering for 6 years, following 20 years with Rockwell International Corp. (including 6 as president of its Atomics International Division).

■

"Turning to the Sun for Power" (page 18) marks a turning point in research on electricity generation: the first demonstration of solar-thermal hardware at meaningful scale. The tracking heliostats at DOE's New Mexico test facility swung slowly into position last October, focusing on the first of two EPRI-sponsored solar receivers. The second design, with higher temperature and higher efficiency, will occupy the power tower this summer.

Jenny Hopkinson, *Journal* feature writer, reviews the test program and the scope of follow-on research planned by John Bigger, EPRI's project manager for solar-thermal energy conversion since May 1976. Bigger gained his first insight into Institute work as an advisory subcommittee member while he was with the Los Angeles Department of Water and Power. During 10 years with the municipal utility, he worked successively in transmission line design and construction and in resource planning—the latter involving uses of waste heat, geothermal, and solar energy. Bigger is a 1965 electrical engineering graduate of Iowa State University; he added an MS degree at the University of Southern California in 1970.

■

Well downstream from any coal-cleaning research, past the point of coal conversion developments, the processes and hardware of coal combustion are being explored and altered for the specific purpose of "Controlling Oxides of Nitrogen" (page 22). EPRI's J. Edward Cichanowicz explains the phenomena that govern NO_x formation and traces the successive refinements in burner and furnace design to suppress it. If this alone is not enough—and it may not be for some air quality regions in coming years—the technology research surveyed by Cichanowicz also deals with new flue gas treatments designed to scrub out the residual NO_x that may escape the furnace.

Since May 1978 Cichanowicz has been a project manager in the Air Quality Control Program of EPRI's Fossil Fuel Power Plants Department, specializing in the instrumentation and measurement of combustion emissions. He was formerly with Energy and Environment Research Corp. for three years, involved in the experimental development of low-NO_x burners for fossil fuels. Cichanowicz is a 1972 mechanical engineering graduate of Clarkson College of Technology in New York, and he earned a master's degree at the University of California at Berkeley in 1975.

■

Utility R&D is a methodical, time-consuming task, and there is often a frustratingly long additional time in bringing its results to practice, then gaining the experience that permits conclusive determination of its benefits. Two utilities that have already profited from recent research, including some of EPRI's findings, share their evaluations in "R&D Benefits: Getting Down to Cases" (page 28). Feature editor Ralph Whitaker abstracts speeches by A. E. Hunter of Utah Power & Light Co. and William Verrochi of Pennsylvania Electric Co.

Clifford Ehrlich Sehgal

Bigger Cichanowicz

Starr

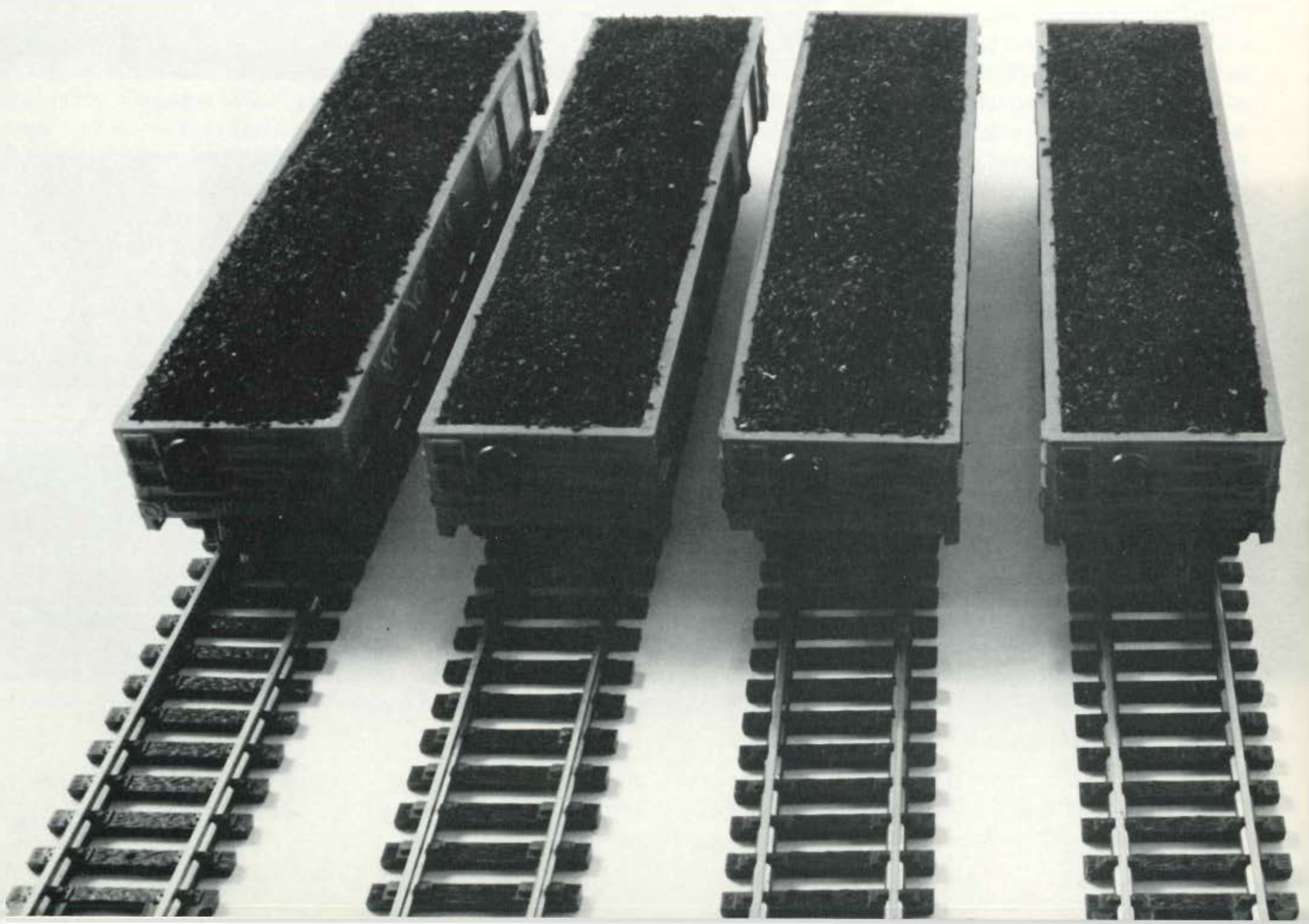
Most of the coal that electric utilities burn today arrives at the power plant boiler much the same as it left the mine: a less-than-perfect fuel, sullied with sulfur, ash-producing minerals, rock, and moisture. The imperfections make trouble for the utility industry, consumer of two-thirds of the nation's coal output. Rock and moisture bloat shipping costs; sulfur mixes with oxygen during combustion and forms SO_2; minerals give power plant pulverizers a rough time, then form molten ash that can slag and foul boilers and lead to unscheduled outages, deratings, and maintenance difficulties.

Some of coal's imperfections are here to stay, at least for now. Organic sulfur, bound up in the coal itself, cannot be removed, and inherent moisture, present in low-grade coals, is difficult to eliminate. However, many impurities can be reduced through physical coal cleaning: ash-producing minerals (ash) and pyritic (inorganic) sulfur can be minimized by existing crushing and separation processes; surface moisture can be evaporated. This results in a coal with improved Btu content—an all-round better fuel.

Changing circumstances

Despite the benefits of clean coal—lower shipping costs, improved boiler operation, reduced sulfur emissions—only about 20% of the nearly 500 million tons

MORE COA



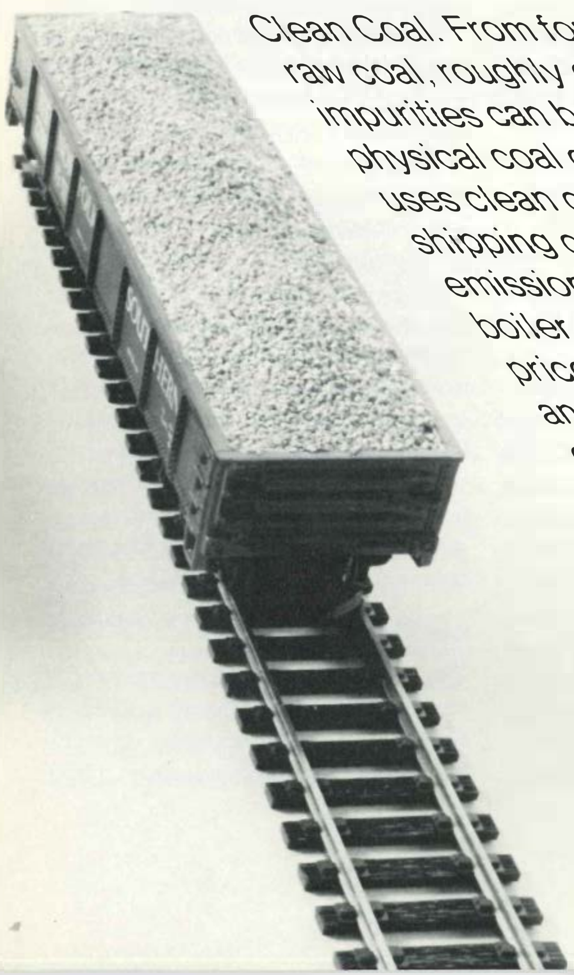
used yearly by the utility industry is cleaned, and that minimally. The rest is used raw. The reason is economics. "All things considered, raw coal has been cheaper," maintains Shelton Ehrlich, manager of EPRI's Fluidized Combustion and Coal Cleaning Program. Capital costs for coal-cleaning plants soar from $3000 to $31,000 per ton per hour of installed capacity, depending on the level of cleaning. Actual operating costs at these plants run from 80¢ to $4 per ton of raw feed. These costs are passed on to the utility industry by mine operators, who do most of today's coal cleaning. And so far, the benefits of clean coal to utilities just haven't balanced the high cost of cleaning.

A tangle of developing circumstances—including higher coal prices, diminishing coal quality, increasing coal use, and mounting environmental awareness—are tipping the balance in favor of coal cleaning in many cases. Suddenly, present-day cleaning techniques are undergoing careful scrutiny by interested parties, and where those techniques are found wanting, research (such as EPRI's $25 million coal cleaning effort) is being intensified to increase efficiency and lower costs.

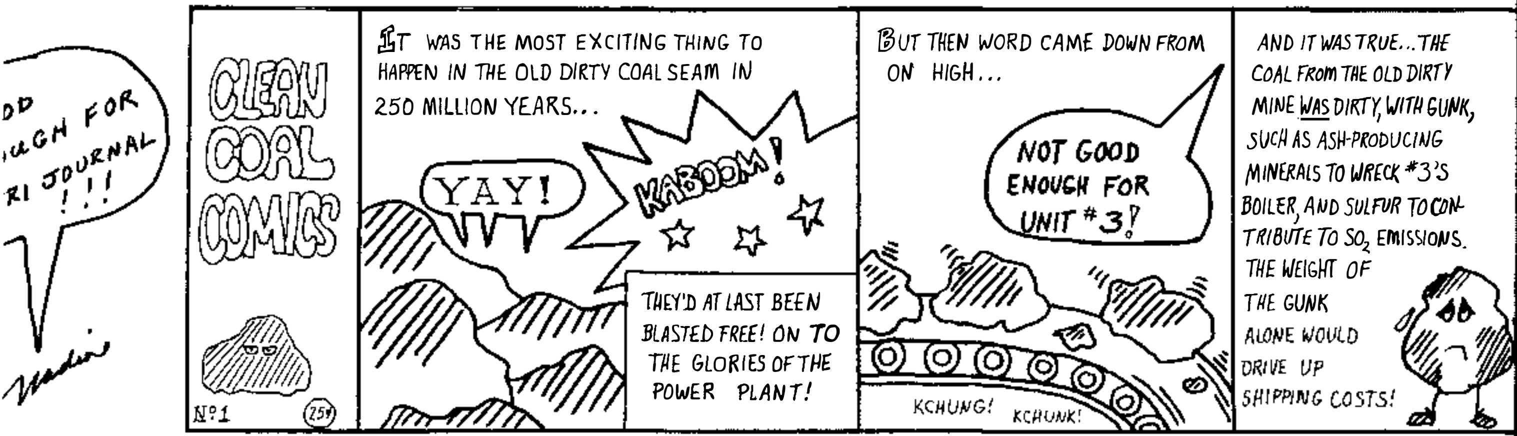
Past prices

A look at past coal prices should begin to unravel today's coal-cleaning economics. The average price of raw, deep-

PER TON



Clean Coal. From four carloads of raw coal, roughly one carload of impurities can be removed by physical coal cleaning. The utility that uses clean coal can benefit from lower shipping costs and reduced sulfur emissions, and, in some cases, improved boiler availability and reliability. As coal prices rise, as run-of-mine quality diminishes, and as coal use increases, the coal-cleaning option becomes more attractive.



mined coal no more than 10 years ago was \$3–\$5 a ton, and at those rock-bottom rates, utilities found it easy to forgive coal's faults. Rather than pay top dollar for premium or cleaned coal, the industry preferred to pay low prices for raw coal, absorbing the cost of shipping superfluous rock and moisture and compensating for the fuel's shortcomings by conservative boiler designs. Emissions standards were still in their infancy. All that utilities really needed was heat to generate the steam to generate electricity, so they bought their fuel on a cents-per-million-Btu basis, according to Kenneth Clifford, manager of EPRI's coal-cleaning research. Accordingly, coal quality specifications for the utility industry have been minimal.

Other coal users are more exacting in their requirements. The steel industry, in particular, must specify narrow quality parameters for coking coal to ensure the production of high-quality steel. Consequently, steelmakers pay premium prices for top-quality coking coal, most of which is cleaned at preparation plants.

Today, some utilities buy cleaned coal to satisfy state or local air pollution restrictions, explains Ehrlich. Others, those that hold captive mines rather than having to buy on the market, clean their own coal and can benefit from lower shipping costs. Still, what cleaning is done is minimal, performed at relatively simple preparation plants.

Present situation

Mining costs are rising, and so is the price of coal. A ton of deep-mined subbituminous coal commands anywhere from \$25 to \$40 today; a ton of strip-mined coal, \$10–\$15. Coal is the single highest cost component of a coal-fired power plant's operating and maintenance expenses.

At the same time, general run-of-mine coal quality is going down. The nation's prime coal seams are being depleted through aggressive mining, and the use of mechanized and continuous-mining methods (which produce a poorer-quality product) is increasing.

Coal use is on the upswing as the nation's other fuel sources are choked off. Utility coal consumption in 1978 amounted to 480 million tons. By 1985 the figure is expected to reach 800 million tons, and by 2000, about 1600 million tons.

Combine increasing coal use, higher coal prices, and diminishing run-of-mine quality with the possibility of lower shipping costs, better boiler operation, and reduced emissions, and coal cleaning begins to look much more attractive.

Cleaning may eliminate waste that accounts for perhaps 15–35% of the raw coal's mass, paring away at shipping expenses.

Coal cleaning can also remove up to 65% of the ash, resulting in improved boiler availability and reliability, especially with older boilers. Most older boilers are less tolerant of higher-than-design ash coals and are more prone to ash-related fouling, slagging, and corrosion problems, with attendant deratings, unscheduled outages, and maintenance difficulties. Newer boilers are, or can be, designed to be more trouble-free, although they are still subject to derating, observes John Dimmer, a project manager with EPRI's Fossil Plant Performance and Reliability Program.

The effects of ash on power plant operations have yet to be precisely quantified and may depend much on site-specific factors, cautions Dimmer. But by and large, higher ash content usually spells trouble for older boiler systems, and cleaning the ash out of coal before combustion may prove a boon to many troubled utilities. Reduced ash content also reduces the load on electrostatic precipitators and baghouses, whose job is to remove fly ash from power plant emissions. Less ash in coal also means that the power plant operator has a smaller volume of combustion by-products to dispose of, an important consideration in view of possible EPA regulations affecting coal ash disposal.

Coal-cleaning credit

The final coal-cleaning incentive for electric utilities is the chance to eliminate some of coal's inorganic sulfur content before combustion can transform it into

SO_2, necessitating a costly postcombustion scrubbing with flue gas desulfurization (FGD) equipment. As much as 30–35% of coal's total sulfur content could be removed by cleaning, according to Ehrlich, if technological improvements in the coal-cleaning process can be made. Costly FGD scrubbers would still be necessary to meet the June 1979 revised New Source Performance Standards. The law limits sulfur dioxide emissions to 0.6–1.2 pounds or less per million Btu of coal fired and sets a sliding scale of 70–90% sulfur removal. A coal-cleaning credit is included in the new regulations. The utility that augments scrubbers with clean coal processes stands to save money on FGD-related costs, such as sludge disposal and limestone. Exactly how much clean coal can save over scrubbing is now the subject of an EPRI study, but Ehrlich guesses, "It sometimes costs 10 times as much money to remove a pound of sulfur with scrubbers as it does with coal cleaning."

The credit will be a powerful incentive for coal cleaning, maintains Ehrlich. In addition, the high sulfur content of many U.S. interior and Appalachian coals may make them unusable under the new EPA standards, even with scrubbing, unless the coal is vigorously cleaned, according to Kurt Yeager, director of EPRI's Fossil Fuel Power Plants Department.

A coal-cleaning credit might also offer utilities in some areas of the country a measure of flexibility in responding to emission regulations, suggests Stephen Baruch, EPRI technical manager for Environmental Affairs. Suppose, for example, a utility burns raw coal and requires more generation, yet is in an environmentally sensitive area and just meets emissions standards. The utility might switch from raw coal to clean coal, and the resulting lower emissions could provide just enough leeway to allow installation of needed generation capacity. Similarly, a utility using raw coal and still meeting emissions regulations in an otherwise sensitive area might be able to shift to clean coal and sell or bank its unneeded credit.

From art to science

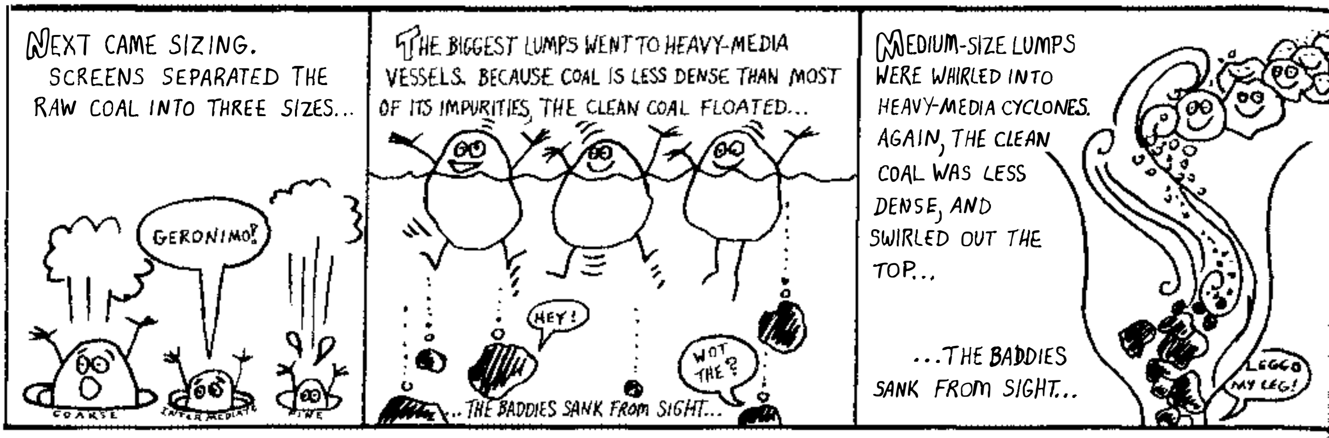
Coal preparation—a broad term that encompasses all coal processing from mine to power plant, including coal cleaning—is of significant potential value to the nation's electric utilities. But the state of the art today is exactly that, an art. Preparation must now be transformed from an art into a science, asserts Randhir Sehgal, EPRI project manager in coal-cleaning research. Existing technologies, some admittedly primitive, must be improved upon, and other, newer, technologies developed.

Coal preparation engineers pursue two major goals: improving removal of impurities—ash-producing minerals, sulfur, and moisture—and reducing Btu losses.

Pyritic sulfur and most ash-producing minerals either happened to share the same swamp as the plants that were metamorphosed into coal or were deposited into the coal bed at a later date. Also, shale, slate, sandstone, and limestone from the roof and floor of the mine are often extracted with the coal. These extraneous impurities can be removed by physical crushing and separation, and the only limits on how much can be removed are economics and technology. (Some pyrites, for example, are so finely and evenly disseminated throughout coal that removal is virtually impossible.)

The organic sulfur, as well as small amounts of ash-producing minerals, is chemically combined with the coal. These inherent impurities cannot be removed by physical crushing and separation. Chemical coal-cleaning methods, such as leaching with acid, can remove a small percentage of organic sulfur; more advanced methods, such as solvent refining (which actually dissolves the coal under increased temperature and pressure), would eliminate more of this sulfur. However, such chemical methods more than double the cost of coal, according to Ehrlich, and have not yet been commercialized.

Total ash content in run-of-mine coals can typically range from as low as 9% to as high as 30%. Total sulfur content, often roughly half pyritic, half organic,



varies from less than 1% to over 6%. Inherent moisture, which lowers a coal's fuel value and adds to shipping costs, can fluctuate from 1% in top-quality coal to over 45% in low-grade coal. It is extremely difficult to remove. Surface moisture, on the other hand, is more easily removed.

Once ash and sulfur have been removed from raw coal, they must be properly disposed of to avert possible environmental problems, reminds Stephen Baruch.

In the process of mining, handling, and cleaning, as much as 25–30% of the coal is reduced from coarse lumps to fine particles (called fines). These fines are difficult to clean and expensive to dewater. They can also be a dust problem and a fire hazard. At many plants, even today, fines are simply discarded. Despite the nation's much-vaunted wealth of coal reserves, those lost fines represent lost Btu and lost money. As Ehrlich is quick to point out, "Coal is worth nothing underground. When you go to the trouble of proving a reserve, the coal is worth 10¢ a ton. By the time you've mined the coal and loaded it into a railroad car, it's worth $25 a ton." Ehrlich concludes, "It's unacceptable to leave the fines, perhaps 25% of this product, in a waste pond or refuse pile." Coal preparation engineers are zeroing in on improved means to recover these valuable fines.

The plant itself

There are some 500 coal preparation plants in the United States, typically designed when coal prices were low in relation to capital cost and substantial Btu losses were acceptable. These plants use a variety of circuits, or systems. Some simply screen and crush coal. Others clean the coarse coal and mix it with the raw fines before shipment. Still others clean unsized feeds. Modern plants separate coal into as many as four size ranges, or fractions, cleaning each fraction with the equipment best suited to it.

There are also advanced physical cleaning plants. For example, at Homer City, Pennsylvania, a 1200-t/h facility is undergoing testing by its owners, General Public Utilities and New York State Electric and Gas, cofunded by EPRI and EPA. EPRI is sponsoring the design, construction, and initial two-year operation of a flexible 4–20-t/h coal-cleaning test facility near Indiana, Pennsylvania. Construction of this $6 million installation is expected to begin this summer, and completion is scheduled for late 1980. Technology development under EPRI management will begin shortly thereafter.

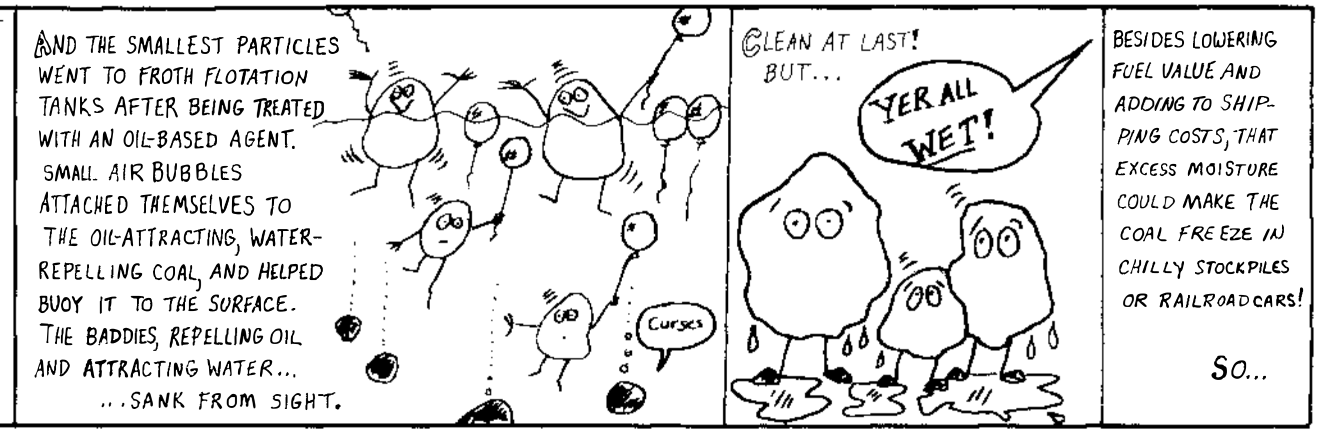
Although preparation specifics vary from plant to plant, the initial treatment is much the same everywhere: when run-of-mine coal arrives at the preparation plant, it first undergoes size reduction, or comminution. This process, largely accomplished by breakers, liberates coal from grosser rock and debris. These devices essentially drop the raw lumps so that the softer coal shatters while the harder rock remains intact and is discarded. For very hard coals, a crusher is necessary. Breakers and crushers both do the jobs they are supposed to do, but perhaps too well: the fines produced, particularly in crushers, are excessive, and better comminution techniques are needed to minimize fines production.

After size reduction, plant flowsheets begin to diverge. Some clean unsized feeds; others separate coal into different size fractions with the help of a series of dry and wet vibrating screens, and clean each fraction separately. Modern plants typically treat three coal fractions: coarse, intermediate, and fine.

All cleaning circuits in use today operate on physical principles, and most operate on the gravity separation principle. Gravity separation takes advantage of the fact that coal has a lower specific gravity than do most of its impurities, and, therefore, the impurities settle out at a faster rate than coal does.

Coarse-coal cleaning

One popular device for cleaning coarse coal is the jig, although it may be used on a full range of coal sizes. In a jig, coal rests on a screen plate. Currents of water are pumped up through the plate, and when the feed is pulsated by the moving water, the less-dense particles—coal—



move toward the top of the mixture. The more-dense particles—refuse—tend to sink. This process may be repeated as many as 50 times a minute.

Jigs have a drawback, however. When they must clean a feed that contains a large amount of near-gravity material (i.e., refuse whose specific gravity is very close to the coal's specific gravity) their efficiency goes down.

The heavy-media vessel and the heavy-media cyclone are two other devices used for cleaning coarse coal. They are the most efficient systems of coal cleaning presently available, functioning well in the presence of large amounts of near-gravity material.

Heavy-media, or dense-media, cleaning works by gravity separation. The heavy-media vessel is a tank or drumlike device through which move streams of raw coal and a heavy medium, usually magnetite and water. The specific gravity of the heavy medium is the gravity of separation, between what the engineer considers coal and what he considers refuse. As the raw coal slowly travels through the medium, the more-dense refuse particles settle out and leave the vessel through a low-level exit; the less-dense coal particles exit at a higher level. The magnetite is later recovered from both clean and refuse fractions with magnetic separators.

The heavy-media cyclone has the added benefit of centrifugal action. Cleaning is done in a cone rather than a tank. Coal and the medium are whirled into a stationary cone; the combination of centrifugal force and gravity does the work. The more-dense refuse tends to concentrate at the sides of the cone and exits at the bottom; the less-dense coal swirls up and out an opening in the top of the cone.

Separation gravities in heavy-media systems can be controlled by adding or removing magnetite. However, these systems are generally costly to install and operate, and they do not work well on fine coal when an entire range of coal sizes is fed to the unit.

Intermediate-coal cleaning

Intermediate-size coal fractions may be cleaned by heavy-media cyclones, as well as by water cyclones and cleaning tables.

Water cyclones, or hydrocyclones, are essentially the same as heavy-media cyclones, except that water rather than a magnetite slurry is the separating medium. A coal-water slurry is pumped into the cyclone; the less-dense clean coal exits through the top of the cyclone, and the more-dense refuse leaves through an opening in the bottom. Like most water-based coal-cleaning processes, water cyclones operate inefficiently when the slurry contains large amounts of near-gravity material.

Cleaning tables (also called concentrating tables) are slightly tilted, ribbed, vibrating surfaces. A coal-water slurry is fed in at one corner of the top of the table; as the slurry moves down across the table, the mixture fans out in a predictable pattern: the more-dense refuse moves toward the bottom of the table, the less-dense, clean coal remains nearer the top. Cleaning tables are relatively inexpensive cleaning devices, but, like the water cyclone, they are inefficient performers when faced with sizable amounts of near-gravity material.

Fine-coal cleaning

The most difficult of all coal fractions to clean are the fines. As coal particles get smaller, specific gravity differences become less and less significant. Many plants clean fines along with coarser sizes in gravity separation equipment, but since a fine-coal particle behaves much the same in solution as a fine-refuse particle, low fines-cleaning efficiencies are the result.

Froth flotation, which relies on surface properties rather than on specific gravities to make a separation, is a common method presently used on fines. In essence, coal attracts oil, repels water; refuse repels oil, attracts water. So raw fines are treated with an oil-based collecting agent that adheres to the coal particles rather than to the refuse. The fines slurry is then fed into a tank, or froth flotation cell. Mechanical agitation

induces air into the cell, and the small air bubbles attach themselves to the oil-coated coal. The bubbles rise to the surface in a froth, taking the clean coal with them. The refuse remains in the slurry, and is rejected as tailings. Unfortunately, froth flotation is not perfect: Fine pyrite particles tend to repel water, so a considerable percentage rises with the clean coal; fine tailings are a growing disposal problem; accurate instrumentation and control are needed.

Another means of cleaning fines (still under development) is oil agglomeration. An oil-based liquid is added to a mixture of fine raw coal. The coal surfaces absorb the oil; the refuse surfaces repel it. The mix is then violently agitated so that the oil-covered coal particles agglomerate into larger particles. These can then be collected by flotation or screening.

After cleanup

Once coal has been through the gamut of cleaning equipment at a preparation plant, it's soaking wet. Besides lowering fuel value and adding to shipping costs, this excess surface moisture may permit coal to freeze in stockpiles or railroad cars, creating handling problems. Plant operators use dewatering methods to remove much of this surface moisture. Vibrating screens are usually adequate for dewatering coarse coal; centrifuges and filters are used for intermediate and fine sizes. Occasionally, thermal dewatering with fluidized-bed dryers is necessary. However, neither mechanical nor thermal dewatering works well with fine coals, and improvements are needed.

Dry cleaning of coal is one way to get around dewatering problems. A number of dry cleaning methods are already in limited commercial use, including the air jig, which performs gravity separation by using pulsating currents of air. Others, such as magnetic separation, electrostatic separation, and the use of heavy organic liquids as heavy media, are still under development. However, dry systems generally suffer from poor efficiencies.

Instrumentation and automation of cleaning plants are needed to cut costs, increase output, and maintain product consistency. There is little instrumentation or automation at preparation plants today, according to Sehgal. Instead, most plant and unit process control is provided by the skill of individual operators. Equipment that could monitor the fluctuations of feed size, moisture, ash, and sulfur would contribute to improved plant efficiency.

Automation, including control of feed rates according to feed characteristics and control of reagent additions to froth flotation systems, would improve the situation further.

Another area that requires improvement is preparation plant design. Engineers must often rely on insufficient data when they design new plants: either exploratory coal samples are too small to represent actual mine conditions or the effects of mining are not properly simulated in trial washability tests. As a result, operators are frequently in for what Sehgal terms "many nasty surprises" when a new plant goes on-line, and better analysis and sampling techniques are needed to ensure plant efficiency.

The ultimate beneficiaries

The R&D necessary to achieve better ash and sulfur rejection and increased Btu yields is sizable, and not cheap. But if better ways to clean coal can be developed with only small increases in capital and operating costs, the potential benefits to utilities are no less sizable. Better ash and sulfur rejection leads to better fuel, lower shipping costs, improved boiler reliability and availability, and emission control alternatives. Increased Btu yields lead to lower mining costs, and because coal is sold on a highly competitive, buyer's market basis, asserts Ehrlich, these savings will be promptly reflected in lower coal prices. Utilities and utility customers are the ultimate beneficiaries of coal cleaning, and that, concludes Ehrlich, is why the industry must hone this art to a science.

EPRI STRATEGY

There's more than one way to clean coal, so EPRI is planning a coal cleaning test facility that offers more than one plant flowsheet. Splice in the appropriate cleaning units, diverters, and piping, and this unusual facility, the core of EPRI's coal-cleaning effort, will be able to simulate up to 50 different commercial flowsheets. Any unit operation, either an old standby that needs improvement or a new gadget that requires development, may be bolted into the plant structure. The result: an appraisal of not only how well each unit performs individually but also how well the unit integrates with the rest of the plant.

EPRI will use the facility to develop new coal-cleaning equipment beyond bench or test-stand results and to evaluate older equipment. The facility will also be available to test retrofit components—a utility's existing flowsheet could be duplicated, the retrofit component tacked on, and the results observed. A utility wanting to know how well a particular coal will respond to a specific cleaning scheme can also make use of this flexible arrangement quickly and at reasonable cost. Yet another utility benefit: the test facility can serve as a training ground for industry coal-preparation engineers.

The target of EPRI's test-facility work and complementary coal-cleaning contracts is improved ash and sulfur reduction and greater recovery of Btu-rich fines. Highlights include the following improvements.

▫ Mechanical comminution. EPRI is now contracting for a closer look at existing mechanical comminution techniques and the improvements needed to liberate more pyrites and ash. This is likely to increase the amount of fines even beyond the present high levels, thus making fines cleaning a major R&D focus.

▫ Froth flotation. EPRI is searching for organic chemicals that will selectively prevent fine pyrites from rising to the tops of froth flotation cells with the clean coal product.

▫ Heavy-media cyclones. Heavy-media cyclones are efficient separation devices. However, problems emerge when the feed includes fine coal. These problems include excessive magnetite loss, lowered efficiencies, and difficulties in system control. EPRI plans a major effort to improve the efficiency of heavy-media cyclone systems.

▫ Instrumentation and automation. EPRI will develop control techniques for preparation plants and establish engineering and control parameters for individual pieces of equipment. Part of this effort includes development of an on-line sensing device that will provide immediate feedback on such coal characteristics as sulfur content. Besides easing in-plant control, such a device could also be used by utilities to ascertain whether purchased coal meets agreed-upon specifications.

▫ Preparation plant design. A coal- and region-specific design manual is essential if engineers are to design optimal coal-cleaning plants. EPRI will develop just such a manual, as well as improved analysis and sampling techniques, and will evaluate the effects of mining methods on plant design.

Science and technology have continually relieved the limitations on man's ability to live in the circumstances provided by nature.

The Growth of Limits

by Chauncey Starr

Adapted from the keynote speech by Chauncey Starr, vice chairman, EPRI, at the Edison Centennial Symposium, San Francisco, California, April 2, 1979. The title was suggested by the study, "Humangrowth," by Harlan Cleveland and Thomas W. Wilson, Jr., Aspen Institute, 1978.

Science and technology have permitted enormous growth in the world population by improving man's ability to increase the food production of arable land; to increase the amount of productive land; to accommodate to harsh climates; to provide transportation and communication for the world's goods, services, and ideas; to increase available resources and use them more effectively; and to live longer in better health.

Thus, science and technology historically have opened new frontiers for mankind, not only permitting but also stimulating the "growth of limits." I do not accept the premise that constraints on such growth are in view or that our long-range planning horizons should be determined by today's perceptions of existing limits. I believe that a long future of expanding expectations continues to be an available option if we take advantage of the fact that technology is an unlimited resource of the human mind.

The real question we face is: Do we want to accept the idea of limits as a guide to human expectations and societal planning, or do we want to keep alive the idea of expanding expectations and new horizons? If we choose expansion, we need more science and technology applied to a spectrum of uses—some old, some new—and to the problems of dealing with the undesirable side effects of growth.

What about the poor?

The recently popular "limits to growth" theme was based on the assumption that natural resources and ecology impose a near-term limit on our ability to continue to derive materials from the earth and to safely handle residuals of growing industrial processes. For proponents of this theme, the obvious course would be to limit the personal economic expectations of those now alive and to sharply limit the growth in the world's population. This is a seductive dogma, because if it were socially and politically feasible to accept such limitations and thus reduce the worldwide demand for goods and services, it would seem to follow that we could simultaneously reduce the stress on our natural environment, on our political and social institutions, and on our problem-solving and decision-making mechanisms.

But is such a prescription acceptable from a social and political standpoint? Perhaps it is for the comparatively wealthy, some of whom idealistically yearn for a simpler life or implicitly presume a resulting stabilization of their present comfortable status. But what about the poor people of the world, both those within the industrialized nations and the vast numbers in countries that have not yet caught up with the modern world? For them, limits to growth would mean lives of hopelessness and despair.

The continuing debate on energy supply and demand epitomizes these issues. Those who press the view that manmade energy processes alter the natural ecology appear to forget that human society also has a complex energy ecology woven into its fabric. As with natural ecology, any change in this total system of relationships will affect all its components. Popular ignorance of this fact has led to many simplistic notions on the role of energy in the quality of life, ranging from the idyllic notion that the less energy used, the better the life, to the opposite extreme, the need for unlimited abundance. Neither extreme has sufficient evidence to support its validity. A grain of truth does not make a whole doctrine.

Lessons from history

When we examine social groups with very low energy supplements we find they are frequently on starvation's edge, ridden with malnutrition, endemic disease, and physical misery. There is no mass migration into such deprived societies. It has been estimated that one-fourth of the world now lives on this edge of survival. Given a free choice, such groups avidly seek more energy input. It is clear from history, as well as from the visible living patterns in the range of societies worldwide, that a significant level of inanimate energy to supplement human labor does improve the quality of life. The vehicle for such energy input is technology. And this is intuitively understood by the world's peoples.

Thus, if personal aspirations worldwide cannot be reduced, limiting economic growth might indeed reduce the strain on our natural environment, but it would also create major—and perhaps catastrophic—strains on our international political and social institutions.

I challenge the factual validity of the assumption that resources are limited, which is at the root of the doctrine of limited expectations. I believe that the resources available for use into the distant future are *not* generally limited because history testifies that advances in technology expand the availability of resources. Technology does this by providing increased efficiency in the conversion of resources to human uses (that is, less is needed to produce more) and in the extraction of traditional resources from the biosphere, as well as by providing methods for the conversion of dormant substances into new resources. So far, we have extracted only a small fraction of the store in the earth's crust.

History also tells us that the apparently limited resources available to mankind in any one period of time become just a small fraction of the resources available to later generations because of the intervening contribution of science and technology. A key example is the relation of world food production to the population it can support. The following appraisal given in the December 1922 *Scientific American* illustrates this point:

According to Eugene Davenport, Dean of the Illinois College of Agriculture, the greatest future need of American agriculture is a fundamental national policy. One of our leading statisticians estimates that a century from now our population will amount to more than 225,000,000 people. The prophecy is startling because it suggests possible hunger and even famine as our future. At present, with less than half of these numbers, our food production is only about equal to our domestic consumption. Unless we institute very revolutionary practices to enhance production, we may look for it to fall behind. Present indications are that we are rapidly slipping into the class of food-importing nations. This means that unless we are able to reverse the tide, we must readjust our social, economic, and industrial organizations to accord with this new condition.

Obviously, this catastrophe did not occur. Because of improved technology in the agricultural industry, we are a major exporter of food.

As another example, let's consider the availability of oil. If oil exploration and extraction had been restricted to the techniques that were current about 1900 we would have been out of oil generations ago. At the beginning of this century, available U.S. reserves were about one billion barrels—enough for a decade then but only about two months of our present use. What oil was available then was found by looking for signs of seepage at the surface and by drilling around salt springs. In that period we didn't have the sophisticated exploration, deep drilling, and extraction techniques available today. Technology has enabled us to discover oil repositories miles underground and to force that oil out, as well as to obtain it through artesian pressures. And we've been able to open up oil fields under the oceans. There is no possible way that anyone without high-technology engineering could develop a deep sea oil well. This is truly a frontier opened by technology.

This is a good example of how technology has kept increasing the available supply of all mineral resources and illustrates how science and technology are instrumental in expanding the limits of man's resources. This expansion of limits has not been just with minerals, but with food; with transportation; with communication; with health; and with extending livable space in unfriendly, harsh environments.

Technology and social development

There is ample stimulation today to reassess the role of science and technology in our social development, to explore what they have done for the world's nations, what they mean to the individual, and where they are likely to go in the future. Such an assessment is particularly timely for the electric utility industry. The major economic growth of the industrial nations has taken place in parallel with and has been supported by the development of new uses for electricity, so the electric industry recognizes its responsibility as a partner in this growth.

"History tells us that the apparently limited resources available to mankind in any one period of time become just a small fraction of the resources available to later generations."

Those of us pursuing the applications of science and technology believe that all progress in these fields is good for humanity generally and the developing nations in particular. Yet, we do recognize the serious negative impact that some of the by-products of these technical developments have had on individuals, on specific social trends, and on the environment in which we live. We are also conscious of the possibility such social costs might become quite large, and we must carefully examine what we are doing and perhaps better plan our activities.

There has been—particularly during this past decade—a growing attack by a portion of the intellectual community on the social merit of the industrial sector of our society. The electric utility industry is one such target, as are the automobile industry and the chemical industry. The natural-food movement is a popular reaction to the agricultural industry, which uses chemical fertilizers and pesticides heavily.

A segment of the intellectual community has suggested that we should somehow restructure our society to remove the heavy hand of technology. This has been one of the popular tenets of the environmental movement. The basic question being posed is: Are we the passive subjects of an uncontrollable technical system, or are we able to actively control this system to improve our destiny? I believe we must understand all aspects of such fundamental questions and assist our society in finding its balance.

Whether or not one pushes technological growth depends partly on individual philosophic beliefs and partly on the perceived prospects for technology. It's like sending your children to school, making a sacrifice to pay for the their education. There is no guarantee on the long-range outcome, and it is a matter of faith that their education is a valuable investment. For more than a hundred years most societies had unquestioned faith that technological growth was worthwhile. Our cultural conceptions of the role of science and technology are very fundamental to the average man. They affect his immediate activities, his future, and that of his children and grandchildren.

In the last few decades, our faith in technology has been questioned. And these doubts have created public issues bearing not only on the applications of science and technology but also on the creation of new knowledge. To some, the disapproval of the intended end use of a particular science or technology means that research to develop fundamental knowledge should be stopped. But to do so would inhibit the potential for its good use, as well as for its bad. The debate on genetic engineering is such a case.

In contrast, as an example of the stimulation fostered by an approved social objective, the continual search for military superiority has historically extended scientific and engineering frontiers. It is an interesting commentary on the priorities of nations that this search for military strength has focused resources on new technology as no other social goal has done. It is indeed regrettable that our peaceful objectives are not equally stimulating.

The intangible values

As we scan the diversified activities of science and technology, we must not only examine the measurable values and costs but also some of the humanistic intangibles. How have the developments of science and technology changed the perception of the individual as to his role in society and his aspirations for the future? The key to this question is whether a scientific and technological age is perceived as serving or as thwarting basic human needs and aspirations.

A fundamental issue is the appropriate assignment of priorities in national planning. We have, for example, slowed the expansion of basic science and technology in the United States, restricting the amount of resources available for them. Conversely, we have thrown more resources into the intangible values of our society, such as expanding our scenic forests and improving the physical environment. How should our priorities be balanced? If, as many of us believe, the energetic application of science and technology in the past has provided enough economic surplus for both tangible and intangible uses and could continue to do so in the future, does the development and use of science and technology demand a higher priority than it is now receiving?

It is not sufficient that these matters be phrased in abstract terms and discussed only among those in the scholarly professions. Decisions on these important and ethical issues clearly relate to the traditional values and objectives of the average man and to the common concerns of society, thus ultimately affecting the well-being of all. They concern the ability of society to provide abundantly for all human needs, material as well as spiritual, and to maintain a dynamism that leads to the development of new and improved useful products (as well as luxuries) over time.

Typical of the questions we are really asking when we plan our energy future are: Do we have the right to interfere with nature? Should we modify natural environments to suit our perceived needs—create coal mines and build hydraulic dams, for example? These are important ethical issues. They are no less central than such medical questions as whether it is desirable to develop an artificial heart and other technical aids to keep someone alive or to delay death. There is no one "truth" that will resolve such questions; rather, we must seek a socially acceptable compromise.

> "Those who press the view that man-made energy processes alter the natural ecology appear to forget that human society also has a complex energy ecology woven into its fabric."

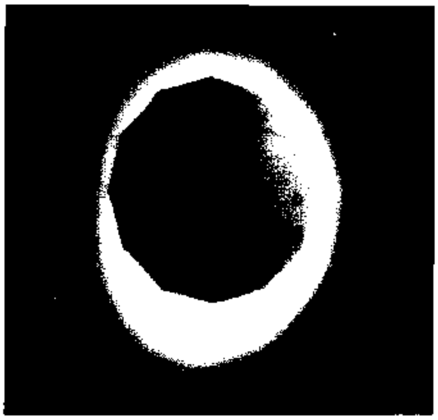
My own compromise is to strive for the greatest number of available options society can balance effectively. If someone wants to live in the redwoods and even if needed, wants to do without an artificial heart, I believe that should be an available individual choice. But if someone wants to live in the middle of San Francisco and wants to use an artificial heart so he can live there for ten more years, that option should also be available.

Freedom of choice

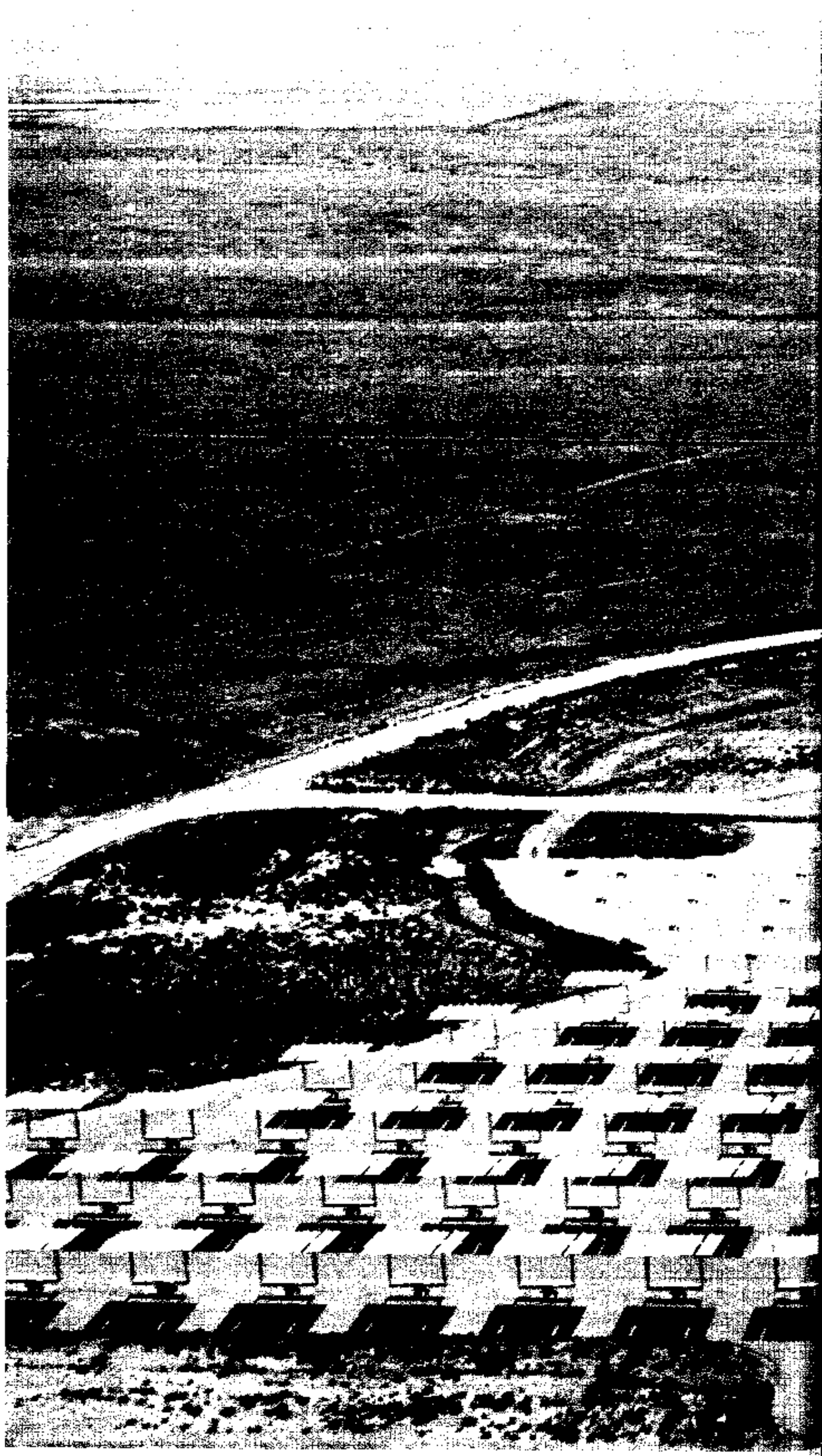
We are all exposed to propaganda urging particular views intended to modify our behavior. Perhaps all social systems require such indoctrination for internal self-discipline. However, there is a distinction between persuasion in an effort to achieve behavior modification and the restriction of options by prohibiting choice. I believe they are separable issues —persuasion versus coercion. For me, this is a matter of social ethics: should society attempt to provide freedom of choice, or should it restrict options? It sounds very academic, but it isn't. Everyone's daily life is affected by such philosophies—indeed, they underlie most popular political debates.

These issues are common to all societies—both those that are dominated by the competition of individual economic incentives and those that are described as centrally planned economies. Only the social and political institutional mechanisms are substantially different among nations, and such differences importantly affect the daily lives of the peoples involved. But in the long term, the role of science and technology is universal in all economies.

I would like to reemphasize my personal belief that science and technology are powerful and unlimited resources for bettering man's condition; that the undesirable by-products of their applications are also susceptible to reduction by these same arts; that science and technology are the key to the "growth of limits" for resources and to the application of these resources for useful purposes, as well as to the breaking of constraints on human expectations and aspirations; and finally, my own faith that future generations will be able to competently manage the world they will inherit—one that I believe will be better than the world my generation inherited. I believe this can, and will, happen, provided our sociologic and cultural structures do not inhibit their intrinsically fruitful activities—whether from fear of future uncertainties or from paranoid anxieties created by the doomsday syndrome. ■



Turning to the Sun for Power



One key to economical solar-thermal power is an efficient receiver. EPRI has two promising designs under test.

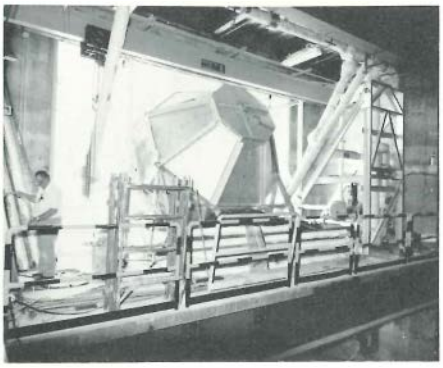
Sunlight is free, but the process of gathering its energy to expand a working fluid and drive a turbine generator is neither cheap nor easy. The fuel is free of such familiar expenses as mining and transportation, but on the other hand, it is not free-flowing—supply is interrupted each night and often during the daytime, too.

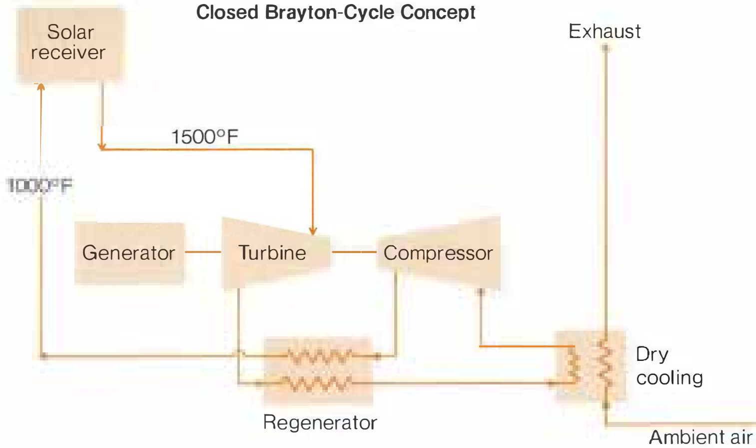
These problems of supply and collection are some that are faced by utilities and industries as they look toward solar-thermal conversion concepts as viable alternatives to conventional resources. By the mid-1980s a number of solar-thermal conversion systems are expected to be undergoing pilot-scale tests and demonstrations. Dual goals of these tests will be to demonstrate the technical capabilities of the concepts under actual operating conditions and to give a clearer picture of the hardware cost-reduction potential.

The state of the art

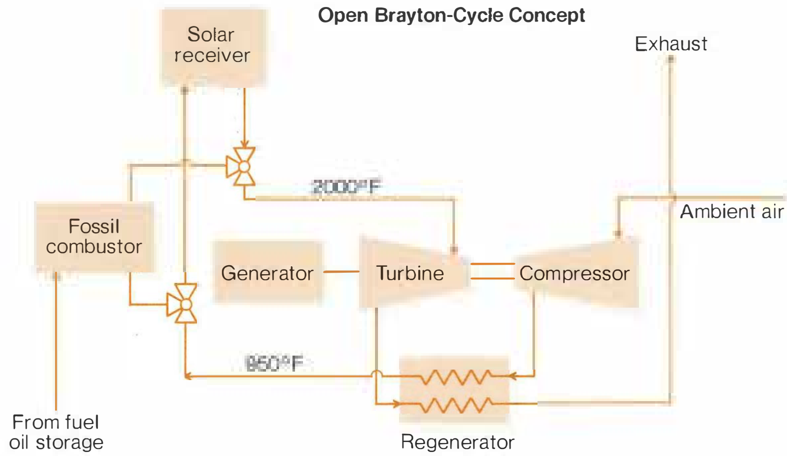
Since 1974 Boeing Engineering & Construction has been developing a solar-thermal power plant concept for EPRI that incorporates a closed Brayton-cycle (gas turbine) system (RP377).

The Brayton cycle was chosen for its potential benefit in electric utility applications. For example, the reduced need





The key component in the closed Brayton-cycle concept (above) is the Boeing metal tube receiver, which was recently demonstrated capable of heating air in a controlled manner to 1500°F (815°C) with solar energy. In the open Brayton-cycle concept (below), the Black & Veatch ceramic tube receiver will demonstrate its capability to heat air to 2000°F (1100°C). The first concept achieves its efficiency with smaller, high-pressure components; the second, with a higher operating temperature.



for cooling water increases siting flexibility, so plants can be built in sunny, arid regions of the southwestern United States. Also, the closed Brayton cycle operates efficiently by recycling hot exhaust air back to the receiver; the system may thus require fewer heliostats (collecting mirrors) and so reduce land requirements in individual power plants.

After completing the design of a commercial-scale solar-thermal plant, Boeing designed and fabricated a model-size 1-MW (th) solar receiver. When operated in the solar environment, the model performs in a similar manner to its future commercial-size counterpart. The receiver is shaped like a deep octagonal dish, standing 15 ft high (4.5 m) and weighing 10,000 lb (4550 kg). It is fitted with eight heat-exchanger panels, each of which consists of 54 superalloy (Inconel 617) U-tubes. These tubes are welded to inlet and outlet headers, and the working fluid, air, flows through the tubes. The temperature of the air when it passes through the receiver tubes rises from 1000°F (535°C) to the design temperature of 1500°F (815°C).

In September 1978 Boeing began a series of tests on the receiver at DOE's central receiver test facility outside Albuquerque, New Mexico, in a cooperative program between DOE and EPRI. (It was the first receiver to be tested at the newly built facility.) The test objectives were to expose the receiver to operating and environmental conditions expected at future solar-thermal plants and to verify the capability of Boeing's design and performance computer models to predict the receiver's performance.

The receiver was installed at the 140-ft

(43-m) level of the facility's tower by the Sandia Laboratory team that operates the test facility. After all systems—the test facility, air supply system, and receiver system—went through a series of checks, the heliostats were positioned for reflecting sunlight into the receiver. On October 27, 1978, solar testing began.

A series of equilibrium tests were conducted to determine the heat balance, operating characteristics, and performance under a number of controlled conditions. This test series confirmed the predicted receiver performance and accuracy of the thermal simulation models used in the design.

Two series of tests were held to determine the dynamic response characteristics of the receiver to solar energy input and airflow changes. To begin with, the level of solar energy reflected into the receiver was varied at predetermined rates. Then, the portion of the heliostat field that supplied the energy was changed.

Next, to simulate abnormal and emergency conditions, the airflow in one heat-exchanger panel was restricted, and then the total airflow was blocked completely. Total airflow blockage automatically activated emergency shutdown procedures for both the receiver and the heliostat field.

The last series of tests simulated normal solar power plant operations with a number of sun-following runs starting in the early morning and continuing all day under varying degrees of cloud cover and solar intensity.

By March of this year, all test program objectives were met. The receiver had fulfilled expectations and achieved rated design capability of 1-MW (th) energy input and an outlet air temperature of 1500°F (815°C).

This inaugural test at the facility also provided EPRI, DOE, Boeing, and Sandia with new information from this first-hand experience. One significant finding was that a solar-thermal conversion plant may experience a greater number of thermal cycles in its lifetime than was previously estimated. Thermal cycles are made up not only of the diurnal cycle but also of cycles within each day that are caused by intermittent cloud conditions.

Boeing is consolidating and evaluating the data collected and analyzing samples of receiver material, such as insulation material and the Inconel superalloy used for the heat-exchanger tubes.

Pushing the state of the art

In mid-1975 Black & Veatch Consulting Engineers led a team to develop an open Brayton-cycle, central-receiver concept (RP475). This concept is designed to heat air to 2000°F (1100°C) to achieve higher thermal efficiency. To withstand this temperature, the heat-exchanger tubes are made of ceramic material (silicon carbide), which up to now has been used primarily in industrial applications. The tubes are 1.5 in (3.8 cm) in diameter and 8 ft (2.4 m) long. A 1-MW (th) model receiver to demonstrate this concept is being built and will arrive at DOE's test facility this summer.

Because the rates of thermal expansion in ceramic and metal are different, the interface between these materials was a critical research area in this project. In fact, the processes of designing, testing, and successfully qualifying ceramic-to-ceramic and ceramic-to-metal mechanical joints represented significant achievements in themselves, even before the receiver was built. Black & Veatch was assisted in developing the ceramic joints by Atlantic Research Corp. To qualify for use in the receiver, the candidate ceramic-to-ceramic joints were cycled under mechanically induced stresses, while air heated to 2150°F (1175°C) was flowing through them. Despite these severe conditions, the joints maintained leak-tight integrity. The ceramic-to-metal joints were also successfully cycled while air heated to 1550°F (845°C) was flowing through them.

Assisting the sun

Because the arrival of clouds and the advent of night interrupt the supply of sunlight, a backup source of energy is needed to ensure the reliable production of electricity from a solar-thermal plant built for utility applications. In another project funded by EPRI, Solar Turbines International will modify a commercially available 2.5-MW (e) gas turbine to demonstrate solar-fossil hybrid operation (RP1270). Design and development of new combustors for the turbine began earlier this year. Bench-scale testing the new combustors will start this summer.

Contrary to what might be expected, a solar-fossil hybrid power plant does not burn large amounts of fossil fuel. In a recent study by Westinghouse Electric Corp., it was found that the major portion of energy produced by the plant comes from the sun (RP648). The backup fuel allows the plant to provide dependable capacity, constant levels of energy, and flexibility of operation for the utility dispatcher.

Where are we headed?

Besides the Brayton-cycle concepts, various studies, experiments, and demonstrations to develop an array of other solar-thermal concepts for utility and industrial applications are under way. The majority are funded by DOE and include solar stand-alone power plants with thermal storage, repowering units at existing oil- and gas-fueled power plants, and plants designed to provide industrial process heat.

The successful test of the EPRI–Boeing 1-MW (th) receiver marks the achievement of a major milestone in the EPRI Solar Program—the demonstrated capability to convert the sun's energy, with all its vagaries, to high-quality heat in a controlled manner. The program is moving forward toward one of its goals, that of developing another viable electric power generation option.

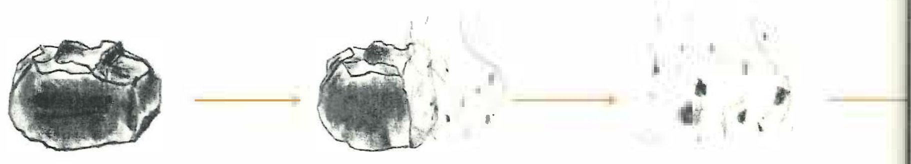
With further testing and operating experience, solar-thermal systems may prove they can provide the utility industry with an alternative means of generating electricity and may help to present the United States with another way to become more energy self-reliant. ■

Controlling Oxides of Nitrogen

by J. Edward Cichanowicz

Nitrogen's traditional fate is giving way to a controlled destiny through advances in coal combustion chemistry, burner and furnace design, and flue gas treatment.

Two categories of emissions generated from the combustion of coal have come under scrutiny, which has led to the development of control technologies. Electrostatic precipitators are well established in dealing with particulate matter, and scrubbers are coming into wider use for controlling sulfur dioxide. New developments are improving the performance and reliability of both. As emissions of these two pollutants are reduced to required levels, it appears that more regulatory attention will be directed to controlling oxides of nitrogen (NO_x).



Raw coal at the burner contains many complex nitrogen compounds . . . that volatilize as the coal temperature rises steeply toward its combustion point . . . yielding NO, HCN, NH_3, and other gases, plus nitrogen-bearing fuel fragments.

Emission standards

The health effects and public welfare issues of NO_x emissions aren't yet clear. Nevertheless, while they are being defined, New Source Performance Standards (NSPS, which set limits on pollutant emissions from new power plants) are becoming more stringent. The requirement has been that no more than 0.7 lb of NO_x be emitted for every million Btu of heat released; the new maximum issued late in May is 0.6 lb or 0.5 lb, depending on coal properties. The latter figure represents a significant (about 60%) reduction from uncontrolled levels.

Furthermore, NSPS are expected to be tightened in future years. An Environmental Protection Agency (EPA) report concludes that reduction to 0.2 lb/10^6 Btu would be required to maintain nationwide mass emissions at current levels. But even NSPS are not the sole NO_x emission criteria. Still lower values may now be specified if the ambient nitrogen dioxide (NO_2) concentration exceeds local air quality standards. Also, federal legislation is being considered for certain unspoiled areas that would permit essentially no deterioration of their present air quality—that is, today's concentrations of NO_2 and other defined pollutants. Concern over other phenomena, such as secondary particulate formation and acid rain, may further influence NO_x standards. Taken together, these factors could lead to regulatory definition of control technology beyond the capability of any that has been demonstrated to date. The potential for NO_x control and its attendant economic implications are therefore under urgent investigation.

J. Edward Cichanowicz is an air quality control project manager in the Fossil Fuel Power Plants Department of EPRI's Fossil Fuel and Advanced Systems Division.

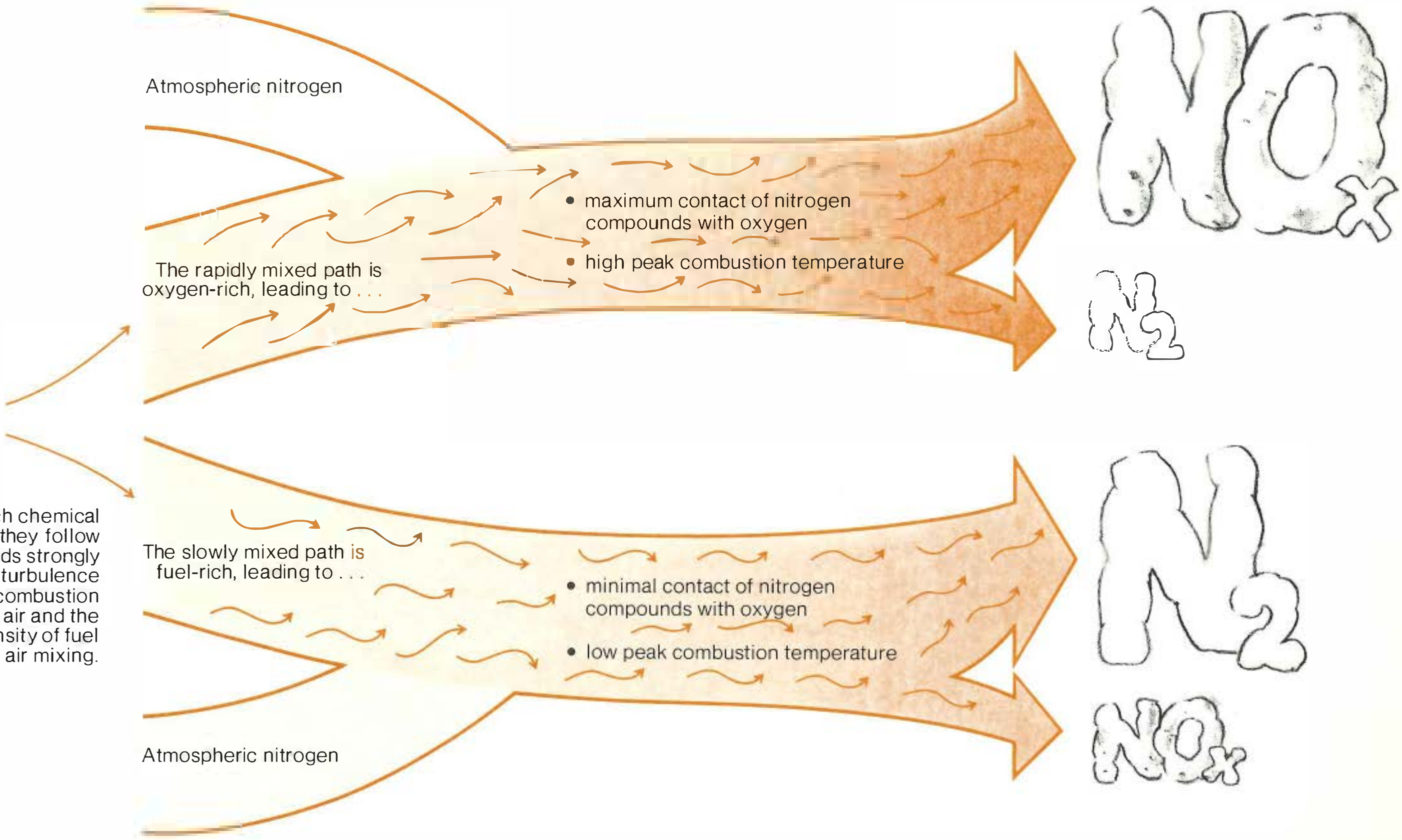
Formation of NO_x

NO_x refers to the sum of nitric oxide (NO) and NO_2. Coal combustion produces these from two sources: molecular nitrogen in the combustion air, and complex nitrogen compounds in the fuel itself. The NO and NO_2 that evolve from nitrogen in the combustion air are called thermal NO_x because the net rate of their formation depends strongly on combustion temperature. Oxides evolved from fuel nitrogen are called fuel NO_x. Their formation is influenced most by the chemical environment of the combustion reaction zone.

In addition to this flame-zone environment, the formation of fuel NO_x depends on fuel properties. Most coals contain relatively significant quantities of nitrogen, usually between 1.0 and 1.4 weight percent of the fuel. Typically, as a result, between 60% and 80% of all NO_x generated from the combustion of coal is attributable to fuel nitrogen. Although the task of reducing NO_x emissions requires attention to both thermal and fuel sources, most of the effort is directed at controlling fuel NO_x.

Combustion practice

For firing in a utility boiler, coal is first pulverized to a size range of about 0.003–0.05 in, then injected into the furnace



Vhich chemical ath they follow pends strongly the turbulence he combustion air and the ntensity of fuel and air mixing.

by a high-velocity air stream. The pulverized coal is injected at several locations, along with the remainder of the air required for combustion. The coal is subsequently burned in what is referred to as a *turbulent diffusion flame,* which governs the mixing and burning of coal and air; thermal energy radiates to the walls of the furnace. Combustion products, still at about 1090°C (2000°F), then exit the furnace and pass through a series of heat exchangers, where additional energy is extracted by convection.

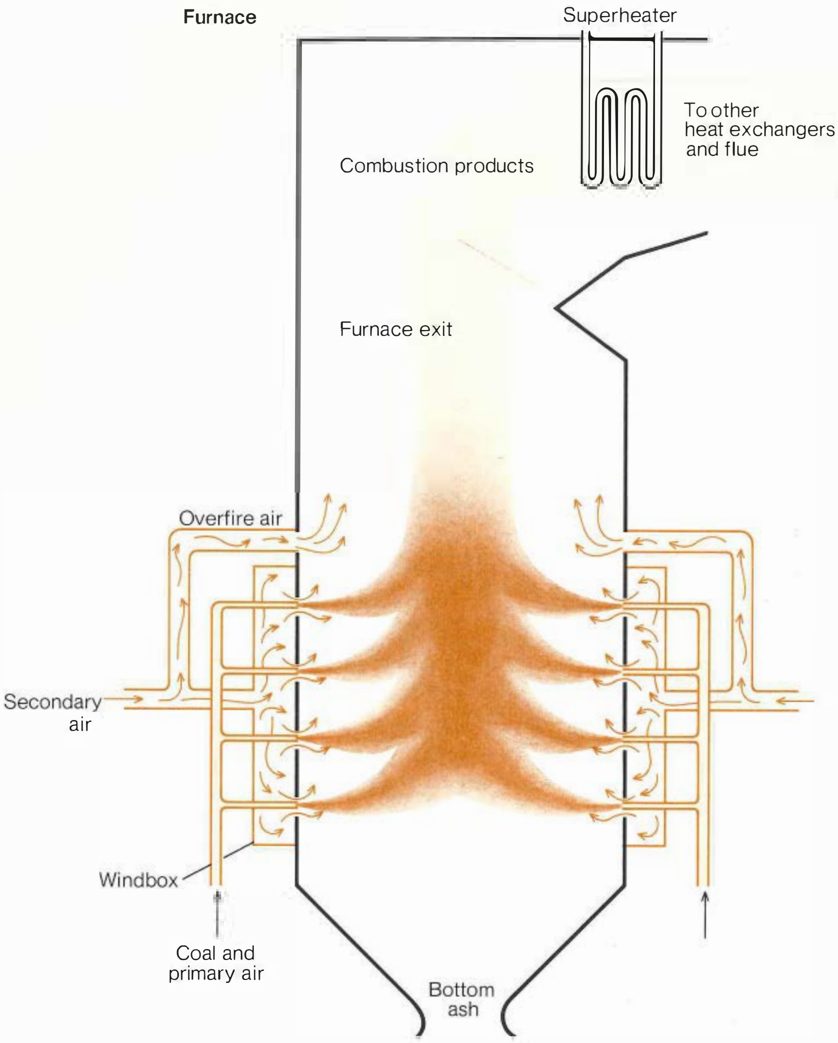
Before NO_x emissions became a factor, burner and furnace design called for the coal and combustion air to react as completely and quickly as possible—so long as temperatures were low enough to avoid slagging or fouling by coal ash. This practice provided the most efficient and economical steam generation.

Emergence of NO_x controls

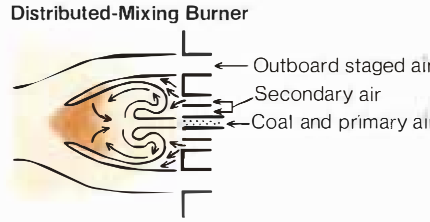
Burner design criteria are now quite different. Because it is known that rapid fuel-air mixing and high peak flame temperatures produce high NO_x levels, modern practice dictates a slowly mixed, less intense, and thus cooler flame.

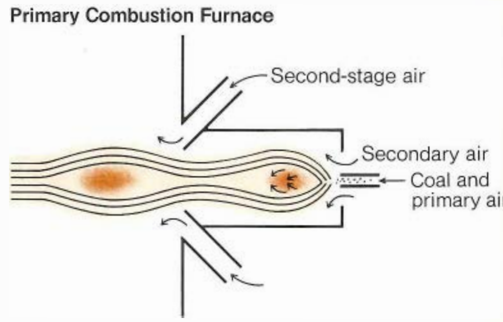
Controlling thermal NO_x is mainly a matter of manipulating combustion conditions to suppress flame temperature. This is achieved with burner designs that delay the mixing of coal particles in the combustion air. Since complete combustion takes longer, more thermal energy is lost to the furnace walls from the flame zone and the ultimate combustion temperature is lower.

The control of fuel NO_x also relies on delayed mixing. The ultimate fate of nitrogen-containing fuel fragments—to be oxidized to unwanted NO_x or to be reduced to molecular nitrogen (N_2)—depends on the abundance or deficiency of oxygen encountered in the combustion zone, where the parent fuel particles



Today's opposed-firing utility furnace may have four tiers of burners, with turbulent diffusion of coal and air induced by the flow of secondary air through an annulus surrounding each burner tip. The relatively smooth flow pattern delays fuel-air mixing and extends the time for combustion so that the peak temperature is reduced. This necessitates a somewhat larger furnace wall area for thorough heat transfer, but it also suppresses NO_x formation. Overfire air, injected closer to the furnace exit, further encourages fuel-rich combustion and controls peak temperature. Carbon burnout is essentially complete as gases leave the furnace.





Delaying, or staging, coal combustion to suppress NO_x formation is achieved quite differently in these two advanced burner designs now under development. Fuel and air mixing patterns and the general shape of the heat-release zones are shown as they are presently thought to occur.

In the Distributed-Mixing Burner, primary air injects the coal into the flame zone, where secondary air progressively contacts the eddying fuel particles. Outboard staged air leads to complete burnout and envelops the flame zone to protect furnace surfaces from interim combustion products that are corrosive.

The Primary Combustion Furnace physically confines the initial, fuel-rich flame zone of each burner to a chamber outside the main furnace. Two distinct heat-release zones result, and special lining materials for the primary furnace resist corrosion attack there.

first break down to produce a variety of intermediate species. If the environment is fuel-rich (oxygen-deficient), these species are mainly hydrogen cyanide (HCN), ammonia (NH_3), and NO_x. If not overly exposed to oxygen, these will subsequently reduce to N_2 and other byproducts. However, if sufficient oxygen is encountered, they will oxidize to (or remain as) NO_x.

Minimizing fuel NO_x emissions thus requires minimizing the amount of fuel and fuel-rich intermediate species that rapidly mix with oxygen. This is achieved by burner design schemes that delay the contact of fuel and air. Mixing can be even further retarded by modifying furnace design to permit injecting a portion of the combustion air (about 20%) above the burners, closer to the furnace exit. Injecting this "overfire air" also tends to reduce NO_x emission levels.

The state of the art

How effective have these design refinements been in reducing NO_x emissions? Uncontrolled NO_x emissions were once as high as 1.0–1.3 lb/10^6 Btu. Now, in units designed for NSPS compliance, emissions are in the range 0.5–0.7 lb/10^6 Btu, depending on furnace design and coal properties.

What have been the penalties? Increased burner complexity is reflected in higher capital costs for steam generators and in operating and maintenance requirements. However, costs attributable to NO_x controls have been a relatively small percentage of steam generation costs. NO_x reduction measures to date can therefore be judged as relatively cost-effective.

Can the technique of delayed fuel-air mixing be used for even greater NO_x suppression? Not without the development of radically different hardware, it appears. Fuel utilization becomes poor as combustion temperatures are lowered beyond those required for adequate fuel burnout. In addition, a new problem arises: the potential for corrosion of furnace walls due to exposure to combustion products.

Advanced control concepts

Two current equipment developments provide the potential for emissions as low as 0.2 lb/10^6 Btu, without efficiency penalties or corrosion problems. These innovations rely on the same physical and chemical principles as commercial designs. One option is called the Distributed-Mixing Burner, under investigation by Energy and Environmental Research Corp. (EERC). This option has federal sponsorship through EPA. The other is the Primary Combustion Furnace, under development by Babcock & Wilcox (B&W), and cosponsored by B&W and EPRI.

In EERC's design the coal is initially fired in an extremely fuel-rich mixture—essentially, no free oxygen. Very high turbulence is created by the burner configuration, so that incoming coal particles are rapidly and thoroughly mixed with partially burned nitrogen-bearing fuel fragments. This environment favors chemical reduction of nitrogen compounds to molecular N_2. Combustion is completed only as gases leave the fuel-rich zone and mix relatively slowly with the remainder of the combustion air that is injected through ports distributed around the burner. Air flow patterns are designed to provide a protective envelope that isolates the corrosive fuel-rich zone from the furnace walls.

Tests at the pilot scale under well-controlled laboratory conditions are encouraging; EPA reports potential NO_x levels of less than 0.2 lb/10^6 Btu. Conclusive results await full-scale tests in an operating utility boiler. These tests are currently being planned and are expected to begin in 1980.

B&W's Primary Combustion Furnace is a parallel effort that employs a physically separate first stage to produce the fuel-rich conditions essential for reducing the nitrogen-containing fuel fragments to N_2. Only at the entrance to the second stage is more air added, thereby permitting complete carbon burnout while maintaining the physical and chemical conditions for minimal NO_x formation. Corrosion potential in this furnace configuration is managed by confining the fuel-rich zone to the first stage, where corrosion-resistant materials can be used without adding significantly to overall furnace cost.

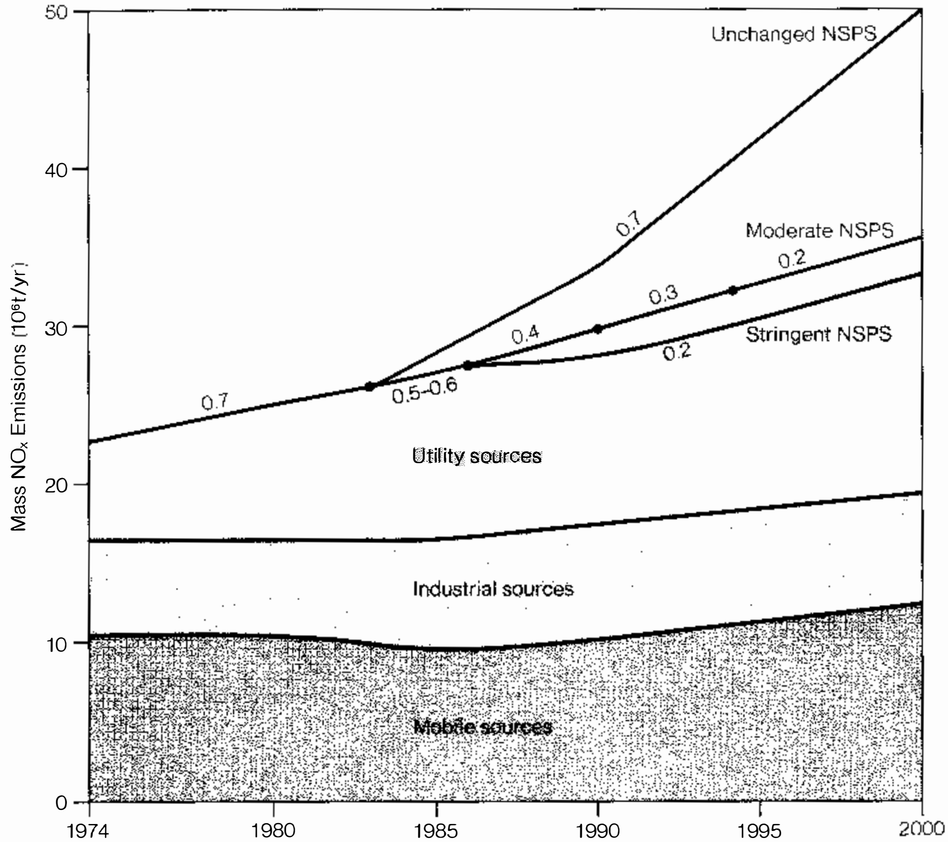
Pilot-scale results from B&W's Research Center are comparable to those for EERC's Distributed-Mixing Burner. In this case also, greater certainty awaits the results of scale-up of the Primary Combustion Furnace, first to a larger pilot unit (now being tested) and then to a utility boiler demonstration. Both approaches are likely to be more expensive than today's combustion NO_x controls. Assessment of the utility-scale demonstrations will define the overall economics and allow the cost-effectiveness of these control concepts to be determined.

NO_x removal from flue gas

Will it become necessary to lower NO_x emission levels below 0.2 lb/10^6 Btu? The rationale for more stringent emissions standards has been noted. In fact, NO_x control equivalent to levels as low as about 0.10 lb/10^6 Btu has been promulgated for California's South Coast Air Basin, to be implemented in the early 1980s. From what is known about combustion control approaches today, it appears unlikely that they alone are feasible for the purpose. In response to more stringent standards, postcombustion flue gas treatment (FGT) has come under study.

More than 50 FGT processes for NO_x control have been identified. "Dry" processes employ a gaseous reagent that selectively reduces flue gas NO_x to molecular N_2. "Wet" processes, on the other hand, employ an aqueous reagent that first absorbs and then reduces NO_x for disposal in liquid form. Several generalizations can be made about the relative merits of the two kinds of processes.

Dry processes tend to require less complex equipment, partly because there is no liquid waste stream for disposal. Costs therefore appear to be lower, for both initial capital requirements and subsequent operation and maintenance. And



The total tonnage of NO_x emitted by three major U.S. categories of combustion will be heavily influenced by growth in utility generation, the fuels chosen to achieve it, and the unit emission standards applied. These curves illustrate futures in which utility steam-electric generation rises 6% annually, with three-fourths of the new and replacement capacity fueled by coal (the rest by nuclear energy).

Evolution of New Source Performance Standards is assumed, as indicated by the unit values for NO_x emission (lb/10^6 Btu) shown with each curve. The moderate NSPS curve reflects the NO_x standard issued in May 1979 and its possible effect on mass emissions between 1983 and 1986.

denitrification efficiency (the percentage reduction of NO_x entering the process) appears to be superior, because of the relative simplicity of uniformly dispersing a gaseous reducing agent in the flue gas. Dry FGT processes have therefore had the most R&D attention, initially in Japan and mainly for dealing with NO_x from low-sulfur fuel oil and natural gas, which are widely used in that country. The major problem is to adapt these processes to coal-fired applications, where higher levels of sulfur dioxide (SO_2) and particulate matter can easily impair their performance. (Because these processes require a temperature range of 290–430°C [550–800°F] for optimal performance, FGT equipment for NO_x removal must be located upstream from air preheaters, precipitators, and SO_2 scrubbers in the exhaust gas duct.)

Selective catalytic reduction

Of most interest and potential commercial feasibility are several dry-process FGT approaches that use NH_3 as the reducing agent. These processes employ catalysts to speed the reactions, so that selective NO_x reduction can occur throughout the range of flue temperatures encountered under practical operating conditions, and are termed selective catalytic reduction (SCR) processes. These processes differ in catalyst composition and physical characteristics, but most developers claim denitrification efficiencies of 90%. Exact figures depend on catalyst design, process temperature, the ratio of NH_3 to NO_x, and other factors in boiler operation. Although these findings encourage the view that SCR is technically feasible, there are unresolved problems that could limit its practical performance and degrade its cost-effectiveness, which, even at optimistic levels, is poor.

Excess NH_3 carryover appears to be the foremost problem; NH_3 that does not participate in the reduction process is emitted, possibly constituting a separate environmental hazard. Sulfur trioxide (SO_3) is another problem; it is easily formed from SO_2, which is at high levels in the flue duct where the FGT equipment is located. This, too, can have environmental implications. Furthermore, SO_3 can lead to severe corrosion—by itself, or through combination with water to make an acid mist, or in reactions with NH_3 to produce several corrosive compounds (ammonium sulfate and ammonium bisulfate). Air preheaters, for example, would suffer from corrosion or from plugging by these compounds.

NH_3 demand is an important consideration in assessing the feasibility of SCR processes. For a single 500-MW plant, assuming 90% NO_x reduction from an initial level of 0.6 lb/10^6 Btu by an SCR process, the annual NH_3 requirement could be almost 6000 tons. The production of NH_3 requires a methane supply on a one-for-one molecular basis. And since methane must be derived from either natural gas or coal gasification, the energy and economic implications of NH_3 requirements can't be ignored. Catalyst life is another factor. For most SCR processes, it is about one year; so this raises additional problems of supply and disposal—and their costs.

In sum, FGT for NO_x control is characterized by many unanswered questions and unresolved issues. System costs are therefore hard to assess. Current estimates place them in the range of \$75–\$200 per kilowatt of plant capacity, several times the cost of even advanced combustion NO_x controls and thereby a significant portion of total plant costs.

FGT at pilot scale

The reality is that FGT may be required in regions that mandate stringent NO_x emissions standards. Decisions whether to promulgate such standards can best be made in the light of accurate and detailed assessments of the relative benefits and burdens of FGT systems. To provide such information for use in the decision-making process, three studies will soon be under way that will carefully examine all aspects of FGT technology.

The largest pilot facility to be tested, and for the longest evaluation period, will involve a commercial dry SCR process developed jointly by Kawasaki Heavy Industries and Japan's Electric Power Development Corp. Sponsored by EPRI, these tests will be initiated in January of 1980 at EPRI's Advanced Emissions Control and Test Facility at Denver, Colorado. The facility draws flue gas from the adjacent coal-fired Arapahoe station operated by Public Service Co. of Colorado. In this test a gas flow equivalent to that from 2.5 MW of generating capacity will be treated in studies of denitrification efficiency under authentic plant conditions. Extending over a year, the test program will provide detailed measurements of NH_3 emissions, SO_3 concentrations, corrosive compounds, catalyst degradation, and other factors in an attempt to define total system impact and costs.

Concurrently, EPA will sponsor field tests of two commercially available SCR processes. The Hitachi-Zosen process is to be installed at Georgia Power Co.'s Plant Mitchell; and the Universal Oil Products process will be installed at Tampa Electric Co.'s Big Bend station. Both will be used to treat flue gas streams equivalent to those from about 1 MW of capacity during a 6–9-month study that should begin late this year.

Toward conclusive knowledge

The conventional and prospective NO_x control technologies discussed here differ in their ability to restrict power plant NO_x emissions and in their foreseeable cost-effectiveness. With today's level of understanding, it appears that the greatest promise for effective NO_x control lies in preventing NO_x formation in the furnace. If further reductions that are beyond the reach of this strategy alone are necessary in some air quality regions, FGT will also be needed.

Efforts that are now under way to define the environmental benefits and cost impacts of NO_x controls will provide the necessary information in the next several years to enable utilities and national and local legislative bodies to work toward the best solutions regarding NO_x emissions and public health and welfare.

R&D Benefits: Getting Down to Cases

What sort of yardstick do electric utilities use to measure the benefits they gain from membership in EPRI? It's a knotty question, and its importance wasn't evident when the Institute was first formed.

Two utility chief executives spoke about this point at an EEI conference on research early this year. What they said was important to their companies—Utah Power & Light Co. and Pennsylvania Electric Co.—for its own sake and also for an unexpected fact it revealed. E. A. Hunter and William Verrochi were the spokesmen. Their summaries both showed (as UPL's director of R&D, Val Finlayson, later underscored) "that R&D expenditures can be justified after only 5 years or so. I had thought," he added, "that 10 or 15 years would be needed."

Hunter and Verrochi shared the EEI platform with Ellis Cox, executive vice president of Potomac Electric Power Co. and chairman of EPRI's Research Advisory Committee. Cox touched on the industrywide cost savings potential of EPRI research, citing pollution control technologies for coal combustion, especially, in light of projections for coal-fired capacity growth in the next 20 years. But he acknowledged that the findings of individual companies are the real-world proof that goes beyond theory in cost-benefit evaluation of R&D.

Meeting a regulatory challenge

Hunter faced the problem squarely: "We've been questioned by our regulatory commissions about the amount of money that we were spending on research and development and its payoff to our customers. For example, early last year we were told by the commission in Idaho (where we receive 20% of our revenue) that they were going to scrutinize our R&D expenditures very carefully. If we were to have their approval to continue including such costs above the line, we would have to provide complete justification at a hearing later in the year.

"We immediately began studies to determine what short-term benefits had definitely resulted from our five-year R&D expenditures. We selected six projects—two local and four EPRI—that could easily be quantified to determine benefits accruing to our ratepayers. Both annual savings in 1978 dollars and present worth over the project lifetime were calculated.

"For a research expenditure averaging about $990,000 annually (escalated for computation) over the five years from 1973 to 1977, UPL realized a saving of $7.4 million in 1978 alone—a benefit-cost ratio of 7.5:1. The present worth of the six projects over their lifetime is $106 million, which yields a benefit-cost ratio of 21.5:1."

Detailing three cases

Hunter put this conclusion into context by describing three of the UPL problems and citing the cost comparisons developed with and without recognition of solutions based on R&D. "Our two newest plants are subject to zero discharge requirements for waste water, most of it from evaporative cooling towers and thus highly saline. If we had used today's conventional technology for disposing of this water, we would have installed lime softeners and either evaporating ponds or flash distillation equipment. Such hardware for the three generating units now operating at the two plants would have cost over $19 million. We're adding three more units, which would increase the cost of waste water–processing equipment to $36 million.

"As it was, two years' work on our experimental farm indicated that the waste water can be used for agriculture without further treatment. The capital cost of the farm equipment was only $250,000. The present-worth savings over the lifetime of all six units will therefore be in excess of $76 million, and this R&D expenditure will have a benefit-cost ratio of 304:1.

"The second project involves a helicopter-borne washing system for transmission line insulators. Some of our lines are subject to heavy contamination during windstorms; we've spent considerable money to clean the insulators.

"Our local R&D people developed a system that uses equipment installed in a helicopter. The development cost was only a little over $3000, but the annual saving will be some $55,000."

Applying EPRI findings

Hunter's third example was a compact transmission line. "UPL encouraged EPRI to develop such a design for 115–138 kV to allow increased power transmission over existing rights-of-way and to provide more environmentally acceptable facilities in congested areas.

"We were the first utility to use such a design. In 1978 we constructed 13 miles, and during the next 10 years we will build some 70 miles more. Our saving in 1978 was about $4500 per mile. The present worth of the annual savings in fixed annual costs for the 83 miles of line is $740,000."

Citing three other EPRI-sponsored projects—a high-intensity ionizer for electrostatic precipitators, ceramic oxide surge arresters for lightning protection, and ice-release coatings for air-break switches—Hunter reported that the present worth of their annual savings in fixed annual costs had been estimated to be $26 million. "For comparison," he added, "our total expenditures for R&D during the 1973–1977 period were $4 million."

How was the information received by the Idaho regulatory commission? "Very favorably," Hunter concluded. "Extensive hearings began in August and continued intermittently during the next two months. They went into the propriety of R&D spending by all the utilities that operate in Idaho. The final outcome was an order that allows UPL to participate in the EPRI program in the same manner as in the past. Frankly, we were somewhat

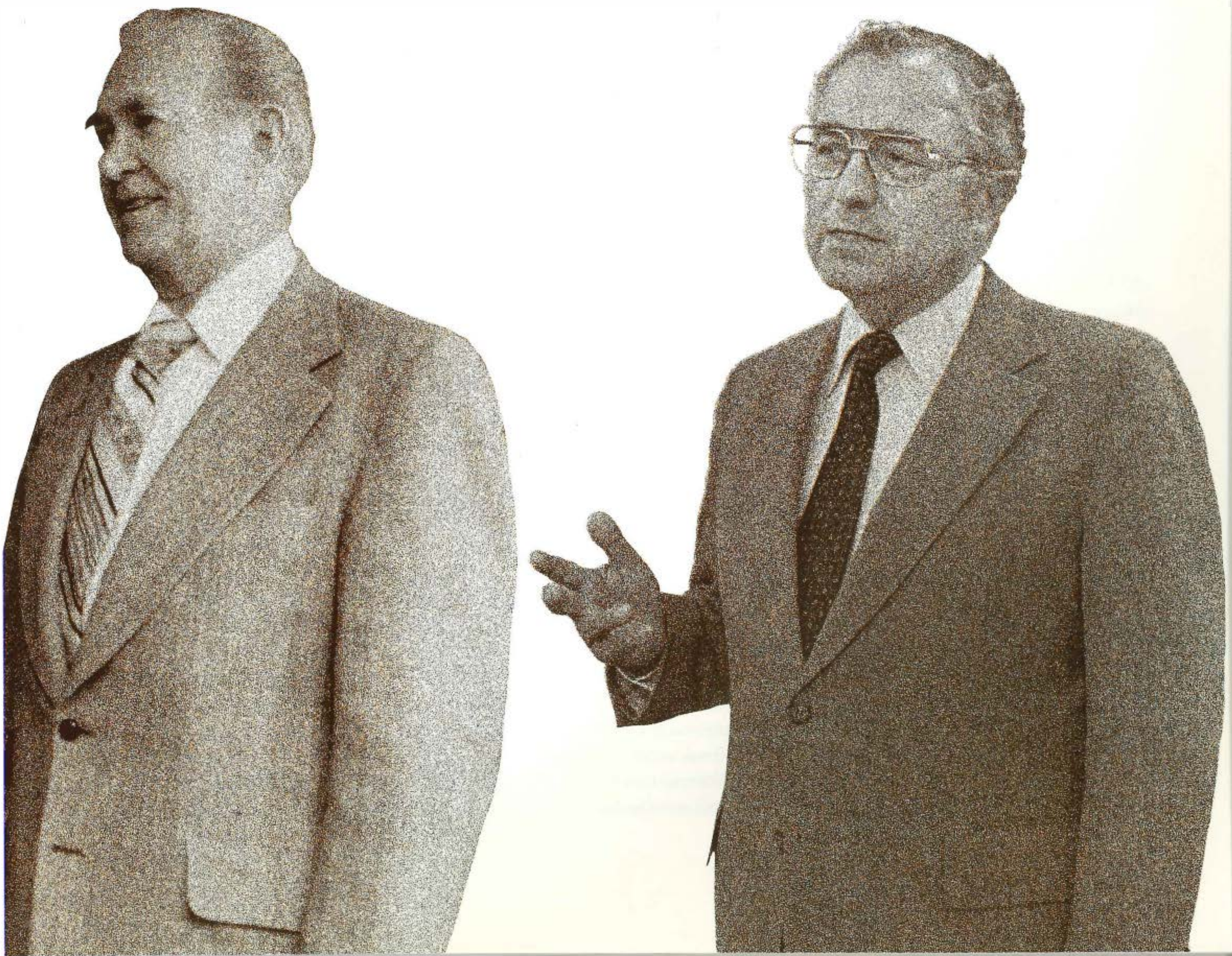
Different in scope, different in method, the evaluations made by two electric utilities prove equally useful in justifying the cost of research that underlies newly adopted technologies.

Just six projects: "For research averaging $990,000 annually over the preceding five years, we realized a saving of $7.4 million in 1978 alone."

ALLAN HUNTER,
Chairman
Utah Power & Light

Coal cleaning: "One benefit will be at least a 6% improvement in plant capacity factor. At Homer City, a 1% improvement is worth $1.2 million per year."

WILLIAM VERROCHI,
President
Pennsylvania Electric



surprised that such a relatively small amount of analytic work could so clearly communicate the benefit of R&D."

Answering a commissioner's question

Pennsylvania Electric's analyses had a different motivation, according to William Verrochi. Here, a utility commissioner called on the company to develop summary information for regulatory personnel. "And one example," said Verrochi, "related to the substantial dollars in support of EPRI: What had it done for our customers?

"Just a month later, EPRI's July 1978 executive summary of research accomplishments arrived, and I asked several company officers to identify the research results we had put to use. Brief comments were made on nine items, ranging from research on transmission line longitudinal loading to development of the high-intensity ionizer. These were pasted into copies of the EPRI booklet, highlighted in yellow, and sent to the public utility commissioners and their key staff people with a cover letter that offered more information. I'll come back to what happened next, but let me describe just three items."

Adapting transmission research

"Compact transmission has been of interest to us for a long time," commented Verrochi. "We were pleased to hear that UPL has built 13 miles of compact line, but let me explain what I believe is a major benefit from this type of research.

"Because of the mountains around Johnstown, we've had to build many circuits with minimum clearances. The compact transmission research would enable us to reduce our clearances even further, but our engineers wondered if we couldn't do still better by applying to our transmission design some concepts that we've used successfully on our distribution system. The open-cable principles we use at 15 and 34 kV seemed to be a natural.

"Therefore, at our Johnstown substation a couple of years ago, we started tests on covered conductors to see if they would work at 115 kV. EPRI has now taken the results of our work and is expanding the research on conductors to include insulators and pole-top design. This illustrates the synergism of the research process: A good idea is adapted to a local need by stretching a proven technology, and from that spring new concepts that may have broad industry application."

Cutting turbine outage

"The second example," continued Verrochi, "involves research on a major utility problem. Steam turbine blade erosion is a major source of outage on large units of our system. It's caused by scale that flakes off the steam side of superheater and reheater tubes. Throughout the General Public Utilities [the parent company] system we've tabulated the costs of this scale exfoliation for 12 units that total 5600 MW. Outages cost from $44,000 to $500,000 per unit annually. Repairs every 5 to 10 years run from $250,000 to over $1 million per unit. And the reduced thermal efficiency means more than $2.5 million per year in higher fuel costs.

"EPRI-sponsored research has identified two methods for reducing this steam-side exfoliation from high-temperature heat exchanger tubing, but full-scale boiler tests are needed for validation. These tests are scheduled for 1979, and if they're successful, the process should soon become commercially available. The benefits to GPU will be significant. Here we're betting on the outcome, but the stakes are quite high."

Cleaning up raw coal

"The third example," said Verrochi, "is research in which GPU is participating along with EPRI and EPA. This is the multistream coal-cleaning system at our Homer City station. Since a major part of Pennsylvania Electric generation is from coal-fired units, clean coal research is vitally important to us. The objective is to demonstrate the technical and economic benefits of cleaning coal before burning it, as a means of meeting New Source Performance Standards.

"A three-year testing program is now in progress. Boiler tests of run-of-mine coal have been completed. We're now preparing to test deep-cleaned coal. We estimate that one benefit will be at least a 6% improvement in plant capacity factor. At Homer City, a 1% improvement is worth $1.2 million per year, so the reason for our research participation is apparent.

"Now, to wrap up my exchange with the commissioner whose request was responsible for our capsule highlighting of these research benefits. After receiving our marked-up booklet, he called me to ask for six more copies. He wanted them to go to the other major utilities in Pennsylvania, with the suggestion that they do something similar."

Going one step further

Not only may other utilities soon begin to document their own short-term R&D benefits in concise form for quick assimilation and understanding, but EPRI also is beginning an analysis of several projects whose results are being put to use by individual utilities. The objective is to assess the role of R&D as an anti-inflation measure—that is, the extent to which its application can offset future increases in utility capital investment and O&M expense.

Some 25 or 30 projects are under consideration for study with selected utilities. Among the candidate topics are fabric filters, boiler feed pump outage, mitigation of BWR pipe cracking, corrosion of copper concentric neutral wires, compact transmission lines, transformer hot spot detection, control of biological deterioration in wood, and UHV transmission.

The hard criteria for project selection are that the R&D results be in use at a specific plant (or depending on the subject, on a utility system) and that their benefits can be expressed definitively in monetary savings over a 5- to 10-year span.

At the Institute

Lewis Elected Chairman of EPRI Board

Lewis

Austin

Hauspurg

McDonald

Nichols

Floyd W. Lewis, president and chief executive officer of Middle South Utilities, Inc., was recently elected chairman of the EPRI Board of Directors.

Lewis, 54, is also chairman of the board of Middle South Services, Inc., which is the technical and advisory subsidiary of Middle South Utilities. He became president and chief executive officer of Middle South Utilities in 1972 and chairman of the board of Middle South Services in 1975.

Lewis began his career with New Orleans Public Service Inc. in 1949 and has held several senior management positions within the electric utility industry.

The operating electric utilities that constitute the Middle South Utilities system are Arkansas-Missouri Power Co., Arkansas Power & Light Co., Louisiana Power & Light Co., Mississippi Power & Light Co., and New Orleans Public Service Inc.

Lewis will serve as EPRI chairman for a one-year term, replacing Frank M. Warren, chairman and chief executive officer of Portland General Electric Co.

In addition to Lewis, four directors were elected to the EPRI Board. They are T. Louis Austin, Jr., chairman of the board and chief executive officer, Texas Utilities Co.; Arthur Hauspurg, president and chief operating officer, Consolidated Edison Co. of New York, Inc.; Marshall McDonald, chairman of the board, Florida Power & Light Co.; and Guy W. Nichols, chairman, president, and chief executive officer, New England Electric System.

Predicting Power Pole Life

How long power poles last, how fast they decay, and their differences in strength are important questions to the electric utility industry. So says an EPRI project manager, Phillip Landers, in announcing the start of a two-year research effort to help answer these types of questions.

Electric utilities in this country replace approximately two million wood power poles a year at an average cost of $500 each. Because of these costs, Landers says utilities need better methods of determining changes in the structural strength of the poles as they age.

"Even if poles are of the same kind of wood, their structural strength may vary, depending on where the trees were grown or where the poles are placed," states Landers, a project manager in the Overhead Transmission Lines Program of the EPRI Electrical Systems Division. "For example, in Utah a wood pole may last 50 years, while in humid Florida the same pole may last only 10 years."

Landers notes that some wood now being used for utility poles comes from trees whose growth has been stimulated by chemicals, and there is evidence that wood from these trees is not as strong as wood from trees maturing naturally.

Working under an EPRI contract, researchers at Colorado State University

Research Institute will use sonic testing to send waves through poles of various ages and will also perform laboratory tests. The results will provide utilities with improved methods for predicting the lifetime and strength of wood poles.

Several utilities will be contributing poles for testing, including Fort Collins Light & Power Department, City of Fort Collins, Colorado; The Kansas Power and Light Co., Topeka, Kansas; Minnesota Power & Light Co., Duluth, Minnesota; Public Service Co. of Colorado, Denver, Colorado; and Tri-State Generation and Transmission Association, Inc., Denver, Colorado.

Reference Book Available

The *Transmission Line Reference Book—345 kV and Above,* which was out of print, is available again. A 1000-copy, soft-cover reprint has been completed in response to industry demand.

First published in 1975, the reference book covers most electric considerations of transmission design through the 345–1500-kV range. It goes beyond the results of EPRI Project UHV and has the latest data from research projects throughout the world. Under EPRI contract; General Electric Co. is now updating the current edition. Publication of the revision is expected in late 1980.

The soft-cover version is available for $15 through Research Reports Center, P.O. Box 10090, Palo Alto, California 94303, (415) 961-9043.

Balzhiser Testifies on Fuel Cells

At a recent hearing before the House Subcommittee on Energy Development and Applications in Washington, D.C., Fossil Fuel and Advanced Systems Division Director Richard Balzhiser outlined a $40–$50 million program that EPRI believes is necessary to move fuel cell technology closer toward commercial availability. Balzhiser stressed that at least 75% of the funding would be required from DOE if fuel cells are to be commercially available by the mid-1980s.

A three-to-four-year program would include improving fuel cell stack technology to reduce manufacturing cost and increase operating life; developing the commercial prototype power plant design and specification; defining power plant characteristics when operating on a variety of coal-derived fuels; defining mass production techniques and costs; and projecting likely market penetration scenarios.

Fuel cells offer an attractive new generating option for electric utilities. Current interest in fuel cells stems largely from their favorable environmental characteristics—they have very low emissions, operate quietly, and conserve water.

Fuel cells convert the chemical energy in liquid and gaseous hydrocarbon fuels directly into electricity. They could be sited close to the power load in urban and other environmentally constrained areas.

Power Plant Emissions Studied

Determining to what extent emissions from fossil fuel power plants contribute to reductions in visibility is the purpose of a new EPRI study.

EPRI has contracted with Dames & Moore of Phoenix, Arizona, to identify daily visibility changes in Blythe, California. Aerovironment, Inc., of Pasadena, California, will do a similar study for EPRI in Duncan Falls, Ohio, and Scranton, Pennsylvania.

The Ohio and Pennsylvania sites were selected because they are in heavy industrial areas and are near fossil fuel power plants; the California site was selected because it is relatively free of pollution and has several good reference points, such as mountain ranges, that are useful in visibility comparisons. These differences in air pollution and surrounding conditions will help researchers determine the contribution of fossil fuel emissions to visibility reduction.

The experiments call for an observer at each site to record visibility changes. Observations will be supplemented by data from sophisticated measuring and camera equipment, such as a telephotometer (which measures the brightness of objects against a background) and a nephelometer (which measures the light-scattering properties of particles).

"The growing air quality issue of visibility or haze makes this research very important," states Glenn Hilst, a project manager in EPRI's Environmental Assessment Department. Hilst says this issue is of special concern in the western United States because of the many parks, high mountains, rugged terrain, and exceptional views.

The subject of restricted visibility from industrial pollution gained national attention with the Clean Air Act Amendments of 1977, which stated that visibility could not be degraded in so-called Class 1 areas (national parks, wilderness areas, and other pristine regions).

According to Hilst, the study's results will be useful to utilities in determining the extent of emission controls necessary in fossil fuel power plants to prevent further visibility degradation in Class 1 areas and in other areas of the country.

Reducing Energy Losses

A new amorphous metal alloy for power transformer cores, developed by Allied Chemical Corp., could someday save utilities as much as $200 million each year by cutting energy losses.

The alloy, Metglas, has the potential of reducing transformer core losses by at least 60%. EPRI is funding a $4.4 million, four-year project with Allied Chemical to develop scaled-up, continuous production techniques for making strips of this material suitable for transformer cores. A separate, $1.2 million contract has been signed with Westinghouse Electric Corp. to design, build, and evaluate transformer cores made with Metglas alloys, according to E. T. Norton, EPRI project manager for this effort.

Washington Report

NRC officials look to the Steam Generator Project Office for broad-based research to solve the tube-denting problem.

Problems with steam generators in PWRs are many and complicated, but the one that has received the most attention is tube denting. The Virginia Electric and Power Co., for example, has embarked on a program to replace the steam generators at its two Surry nuclear units. It is anticipated that other nuclear reactors may need such replacements in the near future, and more may follow unless the problem can be corrected.

A major utility program to understand and solve the problem of tube denting is under way. The Steam Generator Owners Group, composed of utility operators of Babcock & Wilcox Co., Combustion Engineering, Inc., and Westinghouse Electric Corp. nuclear steam supply systems, has funded a $40 million, five-year program at EPRI, managed by the Steam Generator Project Office.

"We are looking for ways to prevent or correct denting in operating plants and to preclude it from new plants," said a spokesman for the Steam Generator Project Office.

The problem has been the subject of concern at the U.S. Nuclear Regulatory Commission because replacing steam generators results in high worker exposure to radiation. If the generators are not replaced, some plants could be derated because of the reduced heat transfer area. (Severely dented tubes, which are detected by periodic in-service inspections, are plugged and taken out of service to prevent leakage, thus reducing the heat transfer area.) NRC officials cite the EPRI research as one of the significant efforts aimed at solving problems with steam generators.

The corrosion problem

The nuclear steam generators in PWRs are substantially different from the steam generators used in fossil plants. In fossil plants, the steam is generated inside tubes that are exposed to the burning fuel. In PWRs, heated water from the reactor core is circulated inside tubes housed in tall, cylindrical vessels. In a typical reactor, such as the Westinghouse design, there are about 3500 tubes in each steam generator. In a Surry unit, for example, there are three steam generators. Feedwater is introduced into the generator and flashes to steam. That steam is used to drive the turbine.

Problems associated with the hot, wet environment are not new. In the earlier years of commercial LWR operation, sodium phosphate was introduced into steam generators to reduce corrosion. The phosphate acted as a buffer, which maintained the alkalinity of the fluid. But the concentrated phosphate corroded the metal (Inconel 600) from which the tubes were made. This corrosion thinned the walls of the tubes and led to leaks of the radioactive water in the primary coolant pipes into the steam generator. One plant where this so-called wastage took place has had to plug (remove from service) some 22% of its steam generator tubes. Only three U.S. commercial plants still use the sodium phosphate treatment.

To solve the problem, most plant operators began using an all-volatile water chemistry treatment to minimize steam generator corrosion. The drawback to the all-volatile treatment is that it doesn't buffer the impurities in the steam generator water, which tend to concentrate in the small crevices formed between the tubes and carbon steel support plates. The impurities are believed to act as catalysts in the corrosion of the carbon steel supports and lead to the formation of iron oxide between the tubes and the supports. Since the iron oxide is twice the volume of the original steel, it begins to push against the tubes and dents them. The results can be a weakening of the tubes and subsequent leakage. The current procedure is to plug the affected tubes and remove them from service prior to leakage, when possible. This practice has been effective in minimizing in-service leakage.

If the denting process isn't halted, the percentage of plugged tubes in a steam generator can become high enough to require the derating of the plant because the heat is not removed from the reactor fast enough. Right now, it is judged that the crucial point is about 30%, although a firm percentage will depend on more detailed analysis.

Fourteen U.S. plants had some degree of steam generator tube denting as of October 1978. Wastage had been identified in 12 plants, many of which also had evidence of denting. Seven plants had evidence of caustic stress corrosion cracking.

Research avenues

What, then, is EPRI research doing about this problem? EPRI's effort is focused on six major factors: diagnostics (including nondestructive evaluation), chemistry, materials, thermohydraulics, wear and vibration, and design evaluation and testing. It is believed that an acid chloride is the cause of denting. This impurity in the steam generator feedwater is concentrated by boiling and is then present to do its damage. New reactors will use metals and designs in the steam generator supports that are more resistant to the accumulation of iron oxide and have a reduced tendency to concentrate the corrosive chemicals in the crevice. Stainless steel supports, for example, will replace carbon steel in the new steam generators being installed at Surry-2 this year.

Another promising avenue is to try to reduce the impurities that find their way into the feedwater. In most plants, the feedwater is recycled. Once it flashes to steam and passes through the generator, it is condensed. In the condenser, a vacuum is created as the steam becomes water. The tubes over which the steam passes in the condenser are cooled by seawater or freshwater. This condenser cooling water is at atmospheric pressure, so any leaks in the tubes tend to pull this cooling water into the feedwater leading back to the steam generators. Impurities can then get into the generators, increasing the acid buildup.

Research, therefore, is concentrating on ways to reduce contamination of the condenser water being returned to the steam generators. Nondestructive testing techniques to check the soundness of the tubes are promising. Additionally, demineralizers can be added to the steam generator feedwater system. Research is being conducted in this area, and several utilities' units will include a demineralizer, which will help to demonstrate the practical application of this technology.

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

GEOTHERMAL ENERGY

EPRI's Geothermal Program includes three elements. Two are oriented to hydrothermal and geopressured resource development, and the third concentrates on generic research and technology development. A portion of the hydrothermal effort has been aimed at removing some of the development uncertainty by sharing with utilities the risk of a commercial-size, binary-cycle hydrothermal demonstration plant project. Other efforts in this area are aimed at reducing the effects of resource temperature and fluid chemistry variations by developing the technology that will allow maximum standardization of equipment and by adapting current technology for near-term commercial development. The emphasis in the development of geopressured resources is on defining their energy and economic potential and determining when and how they may be used to generate electricity. The program is continuing to assess technical issues and to develop key technology that will apply to a broad range of geothermal resource types.

Geothermal power development is not keeping pace with resource discovery. Construction of hydrothermal plants is planned for only about 5% of the discoveries that have been confirmed by deep drilling. This trend indicates that by the year 2000 only about 15% of the hydrothermal potential will have been developed, unless key technical and economic issues are resolved soon. One of the main obstacles to development is the lack of precedent, or proved methods, for evaluating elements that involve long-term fluid supply, reservoir temperature, and fluid chemistry. The rate of fluid supply from new reservoirs can be proved only after significant production time. Bottom-hole reservoir temperature strongly affects production capability, choice of conversion technology, and ultimate conversion efficiency. The chemistry of geothermal fluids, especially mineral content, may also have secondary effects on busbar energy cost.

While interest in geopressured resources is high because the energy potential may be large, it is also cautious because little work has been done to confirm producibility.

Hydrothermal development

The Heber binary-cycle, moderate-temperature hydrothermal demonstration plant project had to be terminated in November 1978 (RP582-2). The project was stopped after DOE announced in July that federal funding would not be available and subsequent efforts by EPRI and the other participants to find alternative sources of funding were unsuccessful. Cancellation does not diminish the importance of the objective of the project. It continues to have high priority because successful development of the binary cycle will increase the percentage of the resource that can be converted to electric power by reducing the cost of power production from moderate-temperature resources. For this reason, attempts to develop a suitable substitute project to meet the industry's need will continue. Meanwhile, all the documentation on the project will be preserved for possible use in other projects by EPRI and by utilities that become involved in binary-cycle power plant design. The plant optimization studies, such as cycle selection, selection of secondary working fluids, and the choice between pumped wells and spontaneous flow, are expected to be particularly useful to others involved in geothermal projects. The contractor was San Diego Gas & Electric Co. *Program Manager: Vasel Roberts*

A 6-MW (th) binary-loop heat exchanger module is being tested to establish design and performance data on a unit of scalable size and representative configuration. The test of a supercritical boiling cycle will develop data for both isobutane and a mixture of isobutane and isopentane as the secondary working fluids. These tests will also yield important data on overall heat transfer coefficients, fouling, heat transfer coefficients of the hydrocarbon working-fluid film, and phase-change characteristics of hydrocarbon mixtures. Phase-change characteristics are important in both the boiling and condensing parts of the cycle, but especially near the critical point because system and turbine design parameters hinge about this point, particularly in axial-flow turbines.

The equipment for the test has been fabricated and calibrated (at Lawrence Berkeley Laboratory) with water on both the tube and the shell sides. Installation of the equipment at the field-test site has begun, and the tests will have begun by the time this report is published. Equipment arriving at the field is shown in Figure 1. The geothermal brine will come from Magma Power Co.'s East Mesa wells; its temperature will be about 188°C (370°F). The brine flow rate through the system will be about 0.012 m^3/s (200 gal/min). Turbine operation in the isobutane loop will be simulated with a throttle valve. The contractors are Colley Engineers & Constructors, Inc., and Raly Schilling, consultant.

The performance and busbar energy costs associated with the first hydrothermal power plants will be of great interest to utilities. The first such facility to be built in the United States will be Magma Power's 10-MW (e) net, binary-cycle experimental plant, which is near completion at the East Mesa geothermal field. EPRI will participate with Magma in collecting and analyzing the data from the plant and in assessing the system's performance (RP1195-3). The plant uses a subcritical boiling cycle, two secondary-working-fluid loops (a 10-MW [e] isobutane loop and a 1.2-MW [e] propane loop), and a propane turbine–driven pump. Contractor for the project is PFR Engineering Systems, Inc. *Program Manager: Vasel Roberts*

Figure 1 Heat exchangers and condensers being installed by Colley Engineers & Constructors, Inc., at the East Mesa geothermal field.

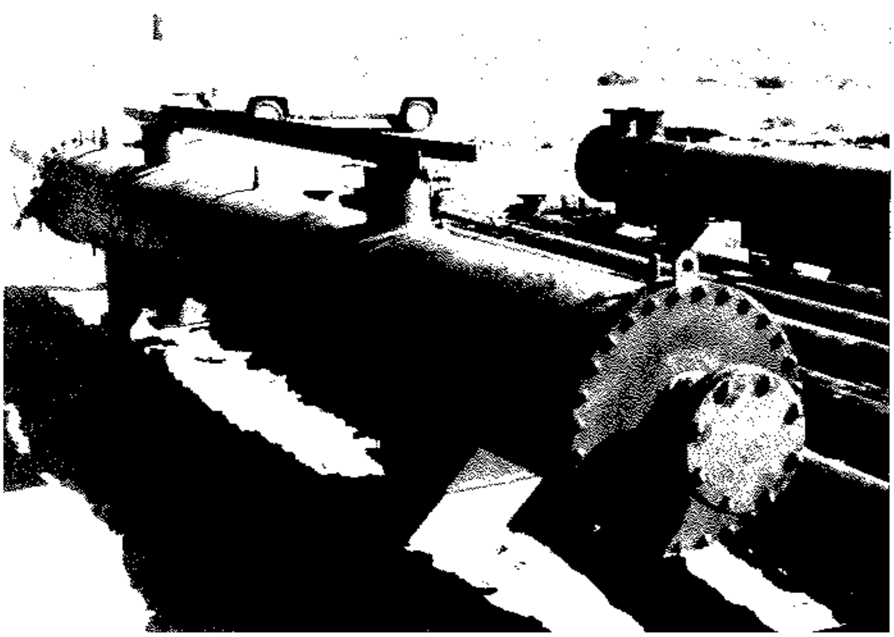


Table 1
ESTIMATES OF RESERVOIR SIZE FOR GEOPRESSURED PROSPECTS

Prospect	Total Size (km^2)	(mi^2)	Net Sand Thickness (m)	(ft)	Sand Volume (km^3)	(mi^3)
Hidalgo	1295	500	91	300	117	28.0
Armstrong	130	50	91	300	12	2.8
Corpus Christi	518	200	107	350	55	13.3
Matagorda	259	100	9	30	2.5	0.6
Brazoria	41	16	91	300	4	0.9
Southeast Pecan Island	174	67	213	700	38	9.0
Rockefeller Refuge	174	67	245	800	40	9.5
Johnson's Bayou	142	55	402	1320	48	11.4
Atchafalaya	329	127	101	330	25	5.9
La Fourche Rossignol	101	39	91	300	6	1.5

Geopressured resources

Immense pressure, geothermal heat, trapped water, and organic matter have combined at depths of 1500–7600 m (5000–25,000 ft) in large sedimentary basins to form geopressured resources. The potential of resources in the Gulf Coast states of Texas and Louisiana is being studied. Although the thermal energy of geopressured resources is important, the main economic consideration is expected to be the amount of associate methane dissolved in the fluids. Geopressured resources have long been known to exist in Texas and Louisiana, but they have been of little commercial interest because of their low quality. For example, one would expect only about 1.13 m^3 (40 ft^3) of methane to be produced per barrel of brine, assuming the brine in the reservoir is saturated with methane. The limited supply of natural gas, and of energy from any source, has stimulated the present interest in geopressured resources.

EPRI awarded its first contract for research on geopressured resources to the Southwest Research Institute (SWRI) in December 1978 (RP1272-1). The project was designed to assess the technical and economic issues of geopressured resource development and to determine the potential of the resource for the purpose of near- and intermediate-term utility planning. SWRI has two major subcontractors: Bechtel National, Inc., which will study energy conversion and utilization; and Intercomp Resource Development and Engineering, Inc., which will address the issue of fluid disposal.

Progress has been made in estimates of energy in place, analysis of geopressured reservoirs, and surveys of drilling costs. The energy-in-place estimates are not yet complete, but a review of several prospects (five in Texas and five in Louisiana) covered a total area of over 3100 km^2 (1200 mi^2), a total net reservoir sand volume of about 354 km^3 (85 mi^3), and a fluid volume of about 75 km^3 (18 mi^3). Table 1 lists the resource sites and some of the reservoir dimensions. At 1.13 m^3 (40 ft^3) of methane per barrel of brine, this amount of fluid would contain 0.6×10^{12} m^3 (21×10^{12} ft^3) of natural gas. Assuming a disposal temperature of 65°C (150°F), which is realistic for binary-cycle development, the useful heat content would be about 4.2×10^{19} J (4×10^{16} Btu). This represents energy in place, not recoverable energy; the study of recoverability and conversion has begun, but results are not yet available.

In the area of reservoir analysis, a simplified computer model, based on an analytic solution to fluid flow under transient and steady-state conditions, has been programmed for both constant surface pressure and constant flow rate. Also, a probability model using Monte Carlo simulation has been written, permitting probable flow rates over the lifetime of a reservoir to be calculated. Typical costs for deep-well production are $3.6 million for a 4267-m (14,000-ft) well and about $4.9 million for a 5486-m (18,000-ft) well. Experience with brine disposal has been extensive. For example, in the Houston area, more than 250 million barrels of brine have been injected into shallow aquifers over the past 30 years; however, present disposal costs are high, that is, they are estimated to be in the range of 3.5–4.5¢/bbl. *Program Manager: Vasel Roberts*

Research and technology development

Development of a geothermal scale-simulation computer program is now complete (RP653-1). The four computer programs developed were programmed to be used either individually or in combination. The first is an equilibrium chemistry code, EQUILIB, that calculates changes in chemical species present in solid, liquid, and gaseous phases as geothermal fluids change temperature, pressure, and acidity. The code allows prediction of mineral precipitation, taking into account over 350 aqueous-phase and solubility-product equilibria for about 175 minerals and 8 gases, at temperatures ranging from 0°C (32°F) to nearly 300°C (572°F).

The scale prediction code, FLOSCAL, calculates chemical kinetics, including the rate of mineral deposition on the surfaces of geothermal fluid systems and the formation of the products of corrosion. The computer code is capable of predicting scale deposition rates for quartz, amorphous silica, calcium carbonate, and sulfides.

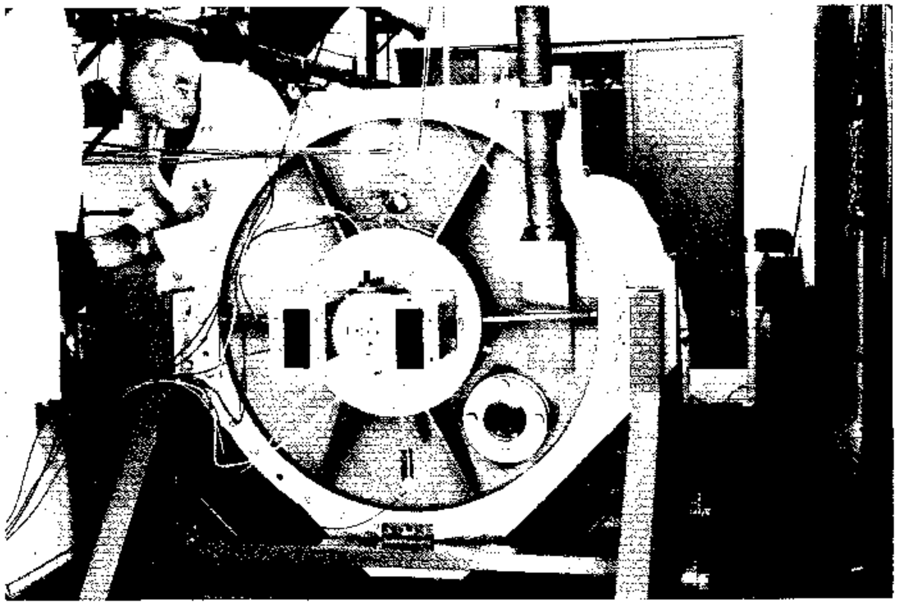
The PLANT code simulates thermodynamic and hydrodynamic conditions. As coded, it simulates flashed-steam and binary-cycle plants and calculates steady-state hydrodynamic and thermodynamic conditions for all fluid flow streams at key locations in a power system.

A fourth code, GEOSCALE, is used when all the preceding codes are combined. It controls the other programs and calculates scale accumulation at key locations and system performance effects of scale deposition, as a function of time. The contractor is Battelle, Pacific Northwest Laboratories. The objective of the follow-on phase of the project, now in progress, is to apply the computer codes in the analysis of actual plant designs and facilities.

A bench model of a rotary separator–turbine, fabricated by Biphase Energy Systems, Inc., is being field-tested at the East Mesa geothermal test site (RP1196-1) (Figure 2). The test unit consists of a rotary steam separator integrated with a hydraulic turbine that has a 20-kW (e) capacity. When used in combination with flashed-steam conversion cycles, the rotary separator–turbine was estimated to have the potential for adding about 20% to the total power output, given the same brine flow. The objective of this project is to measure the performance of such a rotary separator–turbine with geothermal brines to determine the extent of possible improvement in performance. Prior to design and fabrication of the bench model, Barber-Nichols Engineering, Inc., analyzed the concept and concluded that the increased performance estimated by Biphase Energy Systems was somewhat optimistic but that a substantial increase in performance is possible.

Figure 2 Biphase Energy Systems, Inc., fabricated a test unit consisting of a rotary steam separator integrated with a hydraulic turbine that has a 20-kW (e) capacity **(a)**. This unit, being tested in the East Mesa geothermal field, is mounted inside a trailer **(b)**, from which the separated steam is exhausted to the atmosphere (top right). The power generated by the hydraulic turbine is dissipated by three banks of tungsten halide arc lamps, seen glowing on the side of the trailer.

a



b

Results of bench tests with a chemically clean mixture of steam and water show the measured performance to be 75–80% of theoretical values. The first field test is being conducted at the East Mesa geothermal field. Preliminary indications are that the performance is close to that achieved during the bench tests. However, calcium carbonate scaling, which occurs with East Mesa brine, limited the early test runs to about 12 hours each. This problem has been temporarily solved by retrofitting the test apparatus with a chemical additive system to inhibit the scaling, thereby permitting longer test runs. Steam purity in the system separator during the bench tests was about 99.85–99.96%. The field measurements of steam purity are not yet available for comparison. *Project Manager: Evan Hughes*

R. W. Beck and Associates has completed a waste heat rejection project (RP927). The objective of the study was to assess water consumption in geothermal power plants, methods of reducing cooling-water consumption, and the cost penalties associated with such reductions. Cooling towers, ranging from all wet to all dry, were studied. All-dry cooling does not appear feasible for use in geothermal power plants because of high capital cost and restriction on resource utilization. The feasibility of wet-dry cooling will depend greatly on the cost of water. For example, if water is moderately priced at 3¢/m³ (10¢/1000 gal, or $32/acre-ft), the penalty for wet-dry cooling would be in the range of 10–20%. However, if the price of water is 68¢/m³ ($2.50/1000 gal, or $814/acre-ft), the cost penalty for wet-dry cooling would drop below 10%, even as low as 1%. One of the reasons is that costs of busbar electricity from geothermal power plants depend more on resource temperature and costs of geothermal wells than on costs of cooling water or cooling systems.

Another project with high priority is the development of the technology necessary to remove hydrogen sulfide from geothermal steam upstream from the power plant. Hydrogen sulfide emissions, which must be controlled, are expected to be present with the steam at some hydrothermal sites following flash and separation of the steam. Upstream removal is attractive for several reasons: It would not interfere with plant operations; it would remove boron and ammonia; and it would permit treatment of the vented steam during plant outages.

Pacific Gas and Electric Co. (PG&E) is testing a pilot version of EIC Corp.'s copper sulfate upstream-removal process (RP1197-3). At least 90% of the hydrogen sulfide and other noncondensable gases could be removed from geothermal steam with a process of condensation and reevaporation in a single heat exchanger unit. Tests of a small-scale version of the unit began in March at The Geysers, where PG&E is providing the site, a steam supply, and supporting labor and equipment at Unit 7. The advantage seen for the heat exchanger is that hydrogen sulfide and all suspended solid particles would be removed from the steam before it enters the turbine. For new power plants, there could also be a cost advantage in incorporating this system. However, though operation would be simple, some disadvantages exist. The system would reduce the energy available for conversion, and noncondensable gases may have to be treated in a conventional sulfur-reducing plant, although in some cases it may be possible to reinject the vent gases with the cooling-tower blowdown. Coury and Associates, Inc., is the contractor for development and testing of the heat exchanger process (RP1172-2). *Program Manager: Vasel Roberts; Project Manager: Evan Hughes*

SOLIDS BY-PRODUCTS AND HAZARDOUS WASTE DISPOSAL

*One of the newest of EPRI's 130 research areas is solids by-products and hazardous waste disposal in the Water Quality Control and Heat Rejection Program. This and the activities in four programs of the Environmental Assessment Department and the Advanced Fossil Power Systems Department are the components of the interdepartmental Solid Waste Disposal Program (*EPRI Journal, *October 1978, p. 41). The main objectives of the waste disposal program are to define the physical and chemical nature of solid waste; to develop an economic and environmentally sensitive method for assessing the hazard potential of utility wastes; to develop resource recovery processes and utilization systems; to develop safe solid-waste disposal systems; and to respond to socioeconomic concerns facing the industry.*

One major question the utility industry faces is which power plant wastes will be classified as hazardous under the screening-test procedures proposed by the Environmental Protection Agency on December 18, 1978, pursuant to the Resource Conservation and Recovery Act. An EPRI data study published in September 1978 indicated that ash, scrubber sludge, metal cleaning wastes, boiler blowdown, and several other power plant wastes might approach or exceed certain of the draft EPA limits, particularly in the areas of toxicity, corrosiveness, or radioactivity (FP-878).

EPRI was one of several cofunders of the American Society of Testing Materials (ASTM) Collaborative Test Program, in which two ASTM-devised leachate extraction procedures were compared with the EPA procedure. A number of utility wastes were included in the test program. The results of the test program analysis indicated wide variation among laboratories (±100% in some cases) for all three test procedures. ASTM has recommended its procedures for adoption as ASTM standards, and a modified extraction procedure was proposed by EPA in the regulations of December 18, 1978. It should be noted that an evaluation of the EPA extraction procedure variability is under way in the Physical Factors Program in the Environmental Assessment Department (RP1487).

Waste characterization

The long-term stability of the solid-waste products of flue gas cleaning is being investigated (RP1260-1). The four major tasks in this laboratory study, which is being conducted by Radian Corp., are the evaluation of long-term strength behavior, long-term permeability studies, the evaluation of long-term leachate potential, and further study of the mechanisms responsible for the development or loss of strength over time.

As part of the program, 250 test cylinders of sludge-ash mixtures were analyzed after 500 days and after 700 days. These test cylinders are made of approximately 70 different batch mixtures. In general, the results of the 500-day test place the cylinders into two groups: those with strengths in excess of 1000 psi (6.89×10^6 Pa) and those with strengths less than 100 psi (6.89×10^5 Pa). Very few had strengths between 100 and 1000 psi. The 56-day strength, a measurement used in a previous EPRI test, was indicative of future trends in the strength of the stabilized sludges: if above 1000 psi (6.89×10^6 Pa), the strength continues to increase; if below 100 psi (6.89×10^5 Pa), the strength deteriorates. The strength of cylinders with 17% ash typically decreased, whereas the strength of those with 90% ash increased. Mixed results were observed at the 50% ash level. Further analysis of the data from the 500-day and 700-day tests will be made by using statistical methods for the final report, which is expected to be issued in September 1979.

PCB disposal

The objective of the EPRI research on the disposal of polychlorinated biphenyls (PCBs) was to develop guidelines for the evaluation of acceptable alternative disposal methods for wastes containing PCBs (RP1263). Electric utilities have produced and stored more than half the PCBs manufactured between 1929 and 1977 (when production ceased).

The EPRI guidelines to be provided in Volume 1 of the final report on PCB disposal will be presented in the form of a data base, including relevant information on PCB production and use, PCB-disposal regulations (present and proposed), projected regional PCB-disposal requirements, available PCB-incineration technology and proposed commercial facilities, and PCB-landfill design and available commercial facilities. The general conclusions are discussed below.

On the basis of service-life data for industry equipment and the distribution of PCB equipment by region, significant PCB-disposal capacity will be required in all parts of the United States for the next 40 years. Landfill capacity for PCB solid waste, which is insufficient at present, may be adequate by next year.

The incineration capacity for PCB solids does not now exist and, though about to be developed, will not be sufficient by the deadline of January 1, 1980. The lack of commercial PCB incineration capacity is due to stringent design criteria that cannot be met by existing facilities, to the lack of demonstrated demand for this capacity (until the effective date of the incineration regulations), and most important, to public opposition to the siting of new facilities.

The technology for PCB incineration is available—utility boilers, cement kilns, and several incinerator configurations apparently meet the EPA-specified criteria. Environmentally acceptable disposal of PCB wastes necessitates the consideration of several factors not usually encountered in chemical-waste incineration. As a result of the high stability of the PCB molecule, relatively high temperatures and residence times are required for complete destruction. In addition, the chlorine present in PCBs can form extremely corrosive substances in the exhaust gas. On the basis of full-scale test burns in utility boilers, cement kilns, and solids-liquids incinerators, it has been demonstrated that adequate destruction of PCB materials can be achieved.

The PCB project includes the development of conceptual designs for the systems required to incinerate PCB solids-liquids mixtures, along with cost estimates. In general, the unit costs for disposal of PCB solids and liquids in a cement kiln are less than half those of a utility boiler disposal system because of the different feed rates allowed.

The recommended actions for utilities to ensure adequate disposal capacity include:

- Utility development of new integrated incinerator systems specifically for PCB combustion
- Adaptation of existing boilers for PCBs
- Use of utility-owned cement kilns both for PCB disposal and for cement production incorporating other solid-waste by-products, such as fly ash and gypsum
- Establishment of utility-owned hazardous-waste landfills
- Use of existing commercial facilities in those regions having sufficient capacity

The most important consideration in evaluating the alternative PCB-disposal options is the cost of transport to the disposal facility. The cost of PCB transport is approximately 15¢/t-mi (10¢/t-km).

Volumes II and III of the PCB project report will relate to the development of spill prevention and control plans to ensure that the risks associated with PCB activities are minimal. Included will be model operation plans that address assembly and servicing techniques for PCB-filled components, spill-free use of equipment, and containment procedures for preventing accidental releases.

Volumes IV and V will document the test incineration of PCB solids and liquids in an integrated commercial incinerator and the incineration of PCB-contaminated mineral oil in an oil-fired utility boiler.

Solid-waste by-product disposal

Because of different performance standards, the unfolding EPA regulations that specify what constitutes nonhazardous, hazardous, or special waste create considerable uncertainty for those who are designing a research program in by-product disposal.

An early product of the EPRI research program was the *Flue Gas Desulfurization (FGD) Sludge Disposal Manual* (FP-977, developed under RP786-1) issued in February 1979. The manual discusses the disposal of the wastes from lime, limestone, alkaline fly ash, and double-alkali throwaway scrubbing systems designed primarily for FGD on utility boilers. The objective of the manual is to provide to utilities information that can be used to select and design FGD by-product disposal systems and components. The manual includes chapters on current disposal practices, the procedure for estimating waste composition and quantities, disposal alternatives, site selection, leachate, disposal-area design, sludge processing, forced oxidation, thickening and dewatering, fixation/stabilization, transportation, costs, and utilization.

The manual reviews the components of sludge and their effects on processing and disposal. Three distinct methods are presented for estimating the quantities of sludge that will be produced under sets of assumed conditions. The options available for processing and disposal, and the question of fixation versus stabilization, are considered in light of the current regulations and the requirements that may yet be established under the Resource Conservation and Recovery Act (RCRA). The various factors affecting cost are reviewed, and procedures are recommended for estimating the components of total cost under various assumptions.

In order to extend the usefulness of this sludge disposal manual, EPRI will update it at frequent intervals (at least annually for the next three years) to incorporate the latest technology that is responsive to regulations. Users of the manual are therefore encouraged to provide the EPRI staff with comments on the usefulness or shortcomings of the first edition, so that later editions can benefit from these suggestions.

Although the manual includes sections on the disposal of fly ash, either when it is collected in the scrubber and becomes a part of the sludge or when it directly relates to sludge disposal, the manual does not address the collection and disposal of fly ash as a separate by-product.

A separate ash disposal manual is being prepared (under RP1404-1) and will be available in summer 1979. This manual will provide detailed information on fly ash disposal as a guide for utility design staff who evaluate the technical and economic factors that govern the selection of optimal disposal systems and locations. This manual will include:

- Detailed site-selection information, including physical, engineering, regulatory, environmental, and economic considerations
- Information on the physical, chemical, and engineering properties of ash and its leachate
- A summary of disposal practices and an assessment of the areas in which they may be deficient
- Details of the design features, equipment selection, licensing, and specific procedures necessary for the construction of new facilities
- Information to facilitate the prediction of such factors as waste quantity, waste characteristics, and system costs
- Explanations of monitoring-well systems, including their costs
- Information on site-reclamation procedures for ash-disposal areas
- Cost estimates and cost curves or tables for making preliminary general cost estimates

Since both the sludge and ash disposal manuals emphasize the construction of new facilities, their usefulness for designing disposal facilities for retrofit at existing waste-disposal sites is limited. To assist utilities in the design of upgraded disposal facilities, a new design manual for upgrading existing disposal facilities will be started in fall 1979, to be completed by September 1980.

A major project in the by-product disposal subprogram is the sludge-disposal demonstration at a 20-MW(e) limestone dual-alkali scrubber (RP1405). This project at the Scholz power plant of Gulf Power Co. is being conducted in conjunction with the EPA process-evaluation demonstration. The demonstration and monitoring of sludge disposal at this experimental facility will provide a documented technical basis for the future design of full-scale disposal facilities. The project provides an opportunity to identify and solve, on an experimental facility of tractable size, the potential engineering, operational, and environmental problems associated with the disposal of high-sodium, high-sulfur sludges. The 20-MW (e) demonstration size is sufficient for scale-up to a full-sized facility. During the project, particular attention will be given to the following issues: the effects, if any, of the mixing of sludge and ash on dewatering, handling, stability, and leachability; the techniques and costs for fixation and stabilization; the site-preparation requirements; the composition of leachate, supernatant, and runoff; the rate of contaminant leaching; the identification of potential problems arising from recycling runoff and drainage from the landfill to the scrubber (as makeup water); the problems, if any, associated with the high-sodium, high-sulfate composition that is characteristic of these sludges; and the long-term maintenance requirements and site-reclamation criteria.

The project, which began in April 1979, will last 31 months, although most of the demonstration will be completed during 1979. Each of the three landfill disposal areas will be filled with a different mixture of fly ash, FGD waste, and lime. In later years the study will evaluate the chemical and physical fate of the waste materials in the disposal site.

Monitoring and model development are the subjects of a three-year project at the Conesville Station of the Columbus and Southern Ohio Electric Co., which is the first full-scale system to use the I.U. Conversion System proprietary process for the disposal of sludge (RP1406). This unique operation will determine whether full-scale application of this proprietary fixation process reflects the laboratory and test-pond results claimed by the proprietor, provides an environmentally acceptable disposal method, creates no new operating problems for the utility, and meets criteria established by regulatory agencies.

Battelle, Pacific Northwest Laboratories, is developing a model for predicting the quality and quantity of leachate and its migration path in the disposal area. The monitoring program will serve to verify the predictive model because the monitoring-well locations were based on the model.

Most utility-industry solid-waste disposal sites are lined with native soils rather than synthetic membranes. This may change in view of the proposed stringent federal regulations (Section 3004 of RCRA). Soil containment may still remain the prevalent design for utility waste disposal, but admixed materials and synthetic membranes may increasingly be used as a leachate-control technique. In environmentally sensitive areas, such as floodplains and wetlands (where most power plants are located), the use of lining material may be the rule rather than the exception.

In view of this need, a new EPRI project was initiated in March 1979 to evaluate the effects of exposure to nine types of potentially hazardous utility wastes, over an extended period, on a selected group of 14 liner materials (RP1457). The objectives of this laboratory study are to determine the durability and cost-effectiveness of using synthetic membranes, admixed materials, and natural soils as liners for waste storage and disposal areas; to estimate the effective lives of liner materials exposed to different types of utility wastes under conditions that simulate those encountered in holding ponds, lagoons, and landfills; and to develop a method for assessing the relative merits of the various liner materials for specific applications.

In another part of this project, a state-of-the-art investigation will be made of the groundwater monitoring systems to review current practices and provide guidelines for the proper design, location, construction, and maintenance of these systems. A report on this phase will be published in early 1980.

By-product utilization research

In a two-year project begun in December 1978, methods are being studied for extraction of the trace metals in fly ash (RP1404-2). Because these are the same trace metals that can cause an ash to be categorized as hazardous, their removal prior to disposal may have important environmental and economic advantages. Many of the metals recovered have a significant commodity value. The project will result in the identification of the most promising removal process, including process flow sheets and detailed designs for a demonstration plant, as well as cost estimates and expected benefits from the recovered resources.

Regulatory-impact assessment research

Occasionally a law has such a cost impact on utility operations (e.g., environmental requirements) that extensive research studies are justified. RCRA is significant in its impact on power plant design and operation. As part of its solid-waste disposal program, EPRI published a study entitled *The Impact of RCRA (PL94-580) on Utility Solid Wastes* (FP-878). During 1979, additional studies are planned to assess some of the implications of the regulations being issued pursuant to RCRA, as well as those issued under the Surface Mining and Reclamation Act of 1977. *Subprogram Manager: Dean Golden*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

NONDESTRUCTIVE EVALUATION CENTER

EPRI is proceeding with plans to implement a nondestructive evaluation (NDE) center dedicated to serving the needs of the electric utility industry. The objective of the center is to employ EPRI-funded R&D results in the development of equipment and procedures for use in the field in the shortest time possible. The center will also offer programs to train utility personnel for in-service inspection (ISI).

EPRI plans to implement a nondestructive evaluation center that will provide NDE capability for the electric utility industry. The center will be a contractor-operated facility for:

- Evaluation of current ISI technology
- Development of improved ISI procedures
- Research and development
- Promotion of technology transfer
- Encouragement of NDE education programs within the academic community to alleviate growing manpower shortages
- Training of ISI crews, using full-scale component mock-ups before work in actual plants

An important reason for establishing such a facility is that the commercial nuclear industry is the only industry in the United States that is legally required to perform periodic in-service inspections. Thus the prescribed methods and procedures are spelled out in much greater detail than those that are merely recommended for other industries. It is anticipated that the improved technology developed and qualified to meet these requirements can easily be transferred to other types of generating systems. Because of the diversity in the U.S. electric utility industry, no one institution is responsible for evaluating NDE capabilities and for representing the industry with regard to proposed inspection requirements.

In addition, EPRI's experience has indicated that contracting research is not always the most efficient means for quick transfer of results to field applications. Although there are several reasons for this shortcoming, the primary one is the difficulty of forming a team with the appropriate variety of skills. There is a limited amount of NDE technology available in the United States. Forming liaison teams between research groups and application groups to effectively implement technology transfer often places too many demands on the limited manpower (Figure 1). The NDE Center will be staffed with people who have the necessary and somewhat unique abilities to bridge the gap between understanding and using research results, to apply necessary engineering modifications, and to demonstrate and qualify the resultant hardware or new procedures in the field.

EPRI is moving rapidly to implement the NDE Center. After the five-year operating contract is negotiated, specific work scopes for the technical direction of the center will be set up. The target date for startup is October 1, 1979. EPRI's Research Advisory Committee has specified that the overall operation be reviewed in the fifth year of the initial contract to assess the usefulness of the center's activities to utilities. A positive review and a satisfactory assessment of the contractor's performance will be essential conditions for renewing the operating contract for another five-year period.

It is anticipated that the NDE Center will

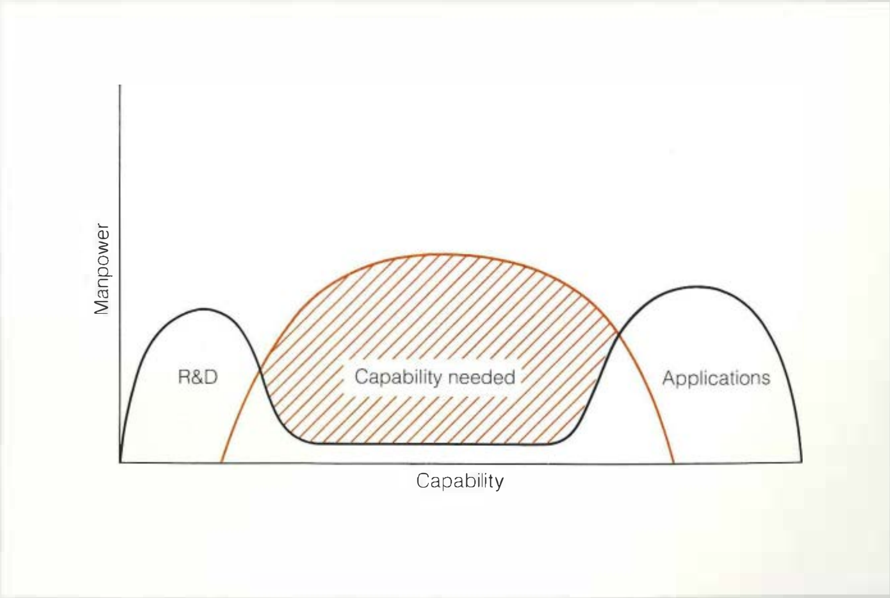


Figure 1 Comparison of available NDE capability with that needed to efficiently serve the U.S. utility industry. The challenge to the NDE Center's success will be to recruit and train the needed staff.

provide a means for rapid response to new and unexpected problems in the ISI area within the utility community. In this role the center is expected to work closely with EPRI and the utilities to evaluate and develop recommended remedial courses of action for generic problem solving. The center is expected to have about 20 to 25 professional staff members, who will be housed in facilities to be leased by EPRI. *Project Manager: Gary Dau*

RETRAN CODE DEVELOPMENT

The object of the RETRAN project (RP889) was to provide the nuclear utility industry with a verified system analysis simulator. The RETRAN computer code was developed in the first phase of this project. During the second phase, the EPRI–Utility System Analysis Working Group was organized. This group, in conjunction with the contractor, performed extensive verification and qualification analysis with RETRAN.

RETRAN, a thermal-hydraulic computer program for analyzing LWR system transients, was developed primarily for use by utilities to evaluate and improve system design and operation, to evaluate safety considerations, and to support licensing submittals. In addition, EPRI and its contractors can use RETRAN to interpret safety- and operations-related experiments and analyses, and to make generic evaluations of safety issues, proposed regulations, and new concepts.

The magnitude and importance of the RETRAN verification effort first became apparent to EPRI in late 1976. It was estimated that a minimum of 500 hours of CDC-6600 time would be required to verify this code package, as well as an extensive amount of manpower to set up and perform the analysis. It was also apparent that when the verification phase was complete there would be an additional delay in implementing RETRAN on utility computers and in training utility personnel in the use of this rather sophisticated computer code package. The EPRI–Utility System Analysis Working Group was established during the second phase of the project to combine these tasks and to shorten the overall time between development and application of RETRAN through a series of prerelease activities. The activities of this phase, including analyses of many different operational transients, as well as comparisons of RETRAN results with data from test facilities and reactor operational tests and incidents, are documented in Volume 4 of the RETRAN computer code manuals. Below is a summary of the overall intent of these RETRAN prerelease activities:

- To provide participating utilities with RETRAN so they can become familiar with and competent in its use
- To obtain, through utility participation, a much more thorough debugging of RETRAN than EPRI can provide under conventional project effort
- To use RETRAN in a wide series of problems typical of utility application
- To qualify RETRAN against existing plant data and other analyses
- To reduce the confusion associated with implementing a large computer program by inexperienced users
- To accumulate results of RETRAN analyses from a wide-based application effort

The following utilities are participants in the working group: Consolidated Edison Co. of New York, Inc., Consumers Power Co., The Detroit Edison Co., Florida Power & Light Co., General Public Utilities Service Corp., Long Island Lighting Co., Northeast Utilities Service Co., Pacific Gas and Electric Co., Philadelphia Electric Co., Portland General Electric Co., Power Authority of the State of New York, Public Service Electric and Gas Co., Southern California Edison Co., Tennessee Valley Authority, Washington Public Power Supply System, Virginia Electric and Power Co., and Yankee Atomic Electric Co.

The initial phase of this part of the project is complete; the RETRAN code was released in December 1978. Additional development and qualification will be performed this year.

The main features of the current version of RETRAN are (1) one-dimensional, homogeneous-equilibrium, thermal-hydraulic models for the reactor cooling system; (2) a point-kinetic model for the neutronics in the reactor core; and (3) a simulation model of the entire control system. This level of sophistication permits analysis of most incidents required in the NRC Safety Analysis Report, Chapter 15, for both PWRs and BWRs. The use of a single computer program for such a wide range of applications is possible because RETRAN provides a best-estimate solution to accident and operational transient problems. Any desired safety margin may be added to the best-estimate RETRAN solution or be incorporated through conservative initial conditions supplied by the user. In contrast, most other accident analysis codes contain various conservative assumptions and provide so-called conservative solutions for only a limited group of accidents.

RETRAN was developed from the RELAP-4 series of codes and reference data based on extensive analytic and experimental work for describing the thermal-hydraulic behavior of LWRs under postulated accident and operational transient conditions. RETRAN thus includes proven thermal-hydraulic models obtained from current accident and operational transient analysis codes, as well as other improved and newly developed models. RETRAN is constructed in a semimodular and dynamic-dimensioned form. By using the semimodular structure, new models may be tried and proved before they are inserted into the code. The gradual progression of incorporating new models and improvements is much easier within the RETRAN code structure. RETRAN contains the same basic homogeneous-equilibrium flow equations found in RELAP-4.

New models and improvements in RETRAN include:

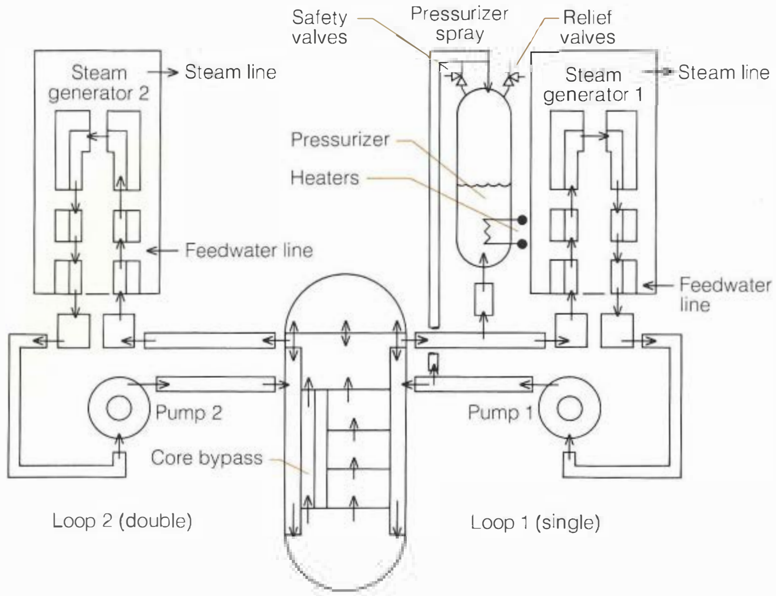
- Improved numerics
- Iterative steady-state initialization
- Trip logic models
- Control system models
- Transport delay model
- Nonequilibrium pressurizer models
- Auxiliary models for departure from nucleate boiling

One of the original goals in developing RETRAN was to provide an effective analytic tool that is flexible and user-oriented. RETRAN offers the user the flexibility of adding to or subtracting from the number of system volumes and junctions used in the input model without reconstruction of the entire input. RETRAN has been used to analyze the Peach Bottom BWR turbine trip tests; the results of that analysis follow this report. Another example of RETRAN's modeling ability is seen in Florida Power & Light's representation of its Turkey Point PWR units 3 and 4. This plant was modeled in considerable detail (Figure 2), with 37 control volumes and 46 flow paths in the hydraulic network. The RETRAN model was used to analyze a series of preoperational pump tests.

Figure 3 shows the comparison of RETRAN results with measured data for the test in which two of the three pumps were tripped.

The first version of the RETRAN code has been used to analyze separate effect experi-

Figure 2 Turkey Point, units 3 and 4, RETRAN base model.



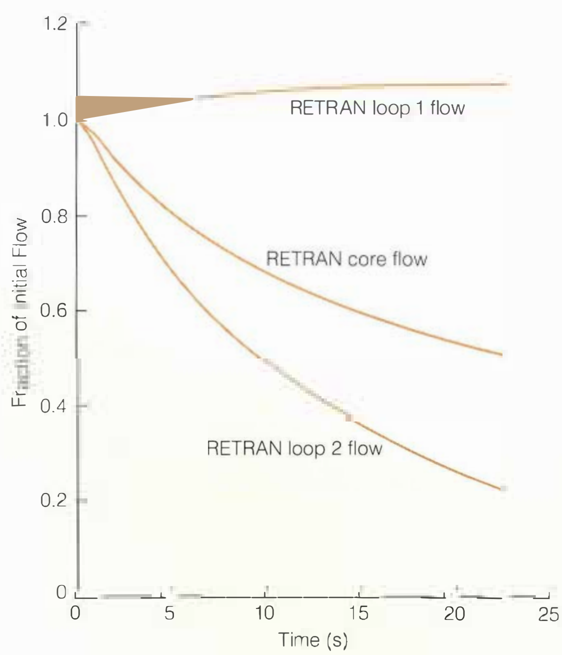


Figure 3 Comparison of RETRAN results with preoperational test data on two pumps in a three-flow coastdown at Turkey Point, units 3 and 4.

ments, small-scale system effects, operational transients, and PWR LOCAs. Additional analyses will be performed in the next year.

The RETRAN program is described in a four-volume manual (EPRI CCM-5) entitled *RETRAN—A Program for One-Dimensional Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems.* Volume 1, *Equations and Numerics,* gives a detailed description of the theory and numerics used in RETRAN. Volume 2, *Programmer's Manual,* contains the code logic and detailed programming descriptions. Volume 3, *User's Manual,* describes code input and output and offers a series of sample problems to assist the user. Volume 4, *Applications,* gives details of the verification and qualification process.

EPRI has formally released the first version of the RETRAN computer program and is now licensing interested users. The code is available from the Electric Power Software Center, 155 Moffett Park Drive, Sunnyvale, California 94086, (408) 734-5500, for a distribution charge of $200.00. Versions are available for either IBM or CDC computers. *Project Manager: Lance Agee*

RETRAN ANALYSIS OF THE THREE PEACH BOTTOM–2 TURBINE TRIP TESTS

An analytic model has been developed for RETRAN analysis of the three turbine trip tests performed at the Peach Bottom Atomic Power Station, Unit 2, during April 1977. The results of the analysis of all three tests compare favorably with the actual measurements. Extensive sensitivity studies were also performed to explore uncertainties in both the input parameters and modeling options. This work has been a significant part of the RETRAN code qualification effort, has helped point out areas of needed code improvement, and will be an important aid in the proper use of the code.

Safe and economic operation of nuclear power plants depends on the ability to predict their behavior under both routine and abnormal conditions. Because the plant systems are so complex, description of their performance is facilitated with highly sophisticated computer codes. Preparation of the input to such codes requires a great deal of insight into the actual system and understanding of the principles on which the code is based, as well as the numerical techniques used to obtain solutions for specific conditions. The ultimate test of the model lies in its comparison with actual measurements taken at the plant.

The analysis of transients caused by planned turbine trips in a BWR (*1*) showed that the special conditions provided at Peach Bottom-2 proved to be a stringent test for a reactor dynamics code. This stringent test is due to the phenomena inherent in BWRs under turbine trip conditions (such as the strong correlation between pressure, core void, and reactivity; the dominance of acoustic phenomena during the early part of the transient; and the significance of heat transfer and pressure drop characteristics during later stages when the system begins to depressurize).

The turbine trip tests at Peach Bottom-2 during April 1977 are described in detail elsewhere (2). Basically, there were three turbine trip tests with bypass (TT1, TT2, TT3); the initial test conditions are given in Table 1.

In order to enhance the effect of pressure-void-power feedback, the anticipatory scram signal from the turbine stop valve had a significant time delay inserted into the signal channels for the purposes of these tests. At the same time, the flux-level scram clamps were lowered appropriately for each test to limit the amount of power peaking that otherwise might have resulted from the delay of the anticipatory scram. This procedure was followed to keep the linear heat generation rate of the fuel within the preconditioning envelope and to guarantee a minimum critical power ratio at all times during the transient, while still obtaining a significant flux spike from the pressure-void-power feedback.

The RETRAN code (*3*) offers a variety of modeling options in virtually all areas necessary to represent a nuclear power system. These options can be linked in various ways, providing a set of building blocks to construct a model of the system to be simulated. The model used to simulate Peach Bottom-2 in this study is shown in Figure 4. The input data for this model were prepared to obtain a best-estimate solution because comparison with the actual measurements was the primary objective. The RETRAN steady-state self-initialization feature was used for the analysis of all three tests and for approximately 100 associated sensitivity calculations. This important feature of the code saved a considerable amount of work.

The results of the analysis of TT1 are shown in Figures 5 and 6. Figure 5 presents the calculated normalized reactor power, together with the normalized core average local power range monitor signal. The calculated reactivity components (also shown in Figure 5) indicate that the power peaks out before the scram becomes effective. The reactivity decreases because of a drop in the reactivity associated with the moderator density and the Doppler effect. The causes for the former are (1) the pressure in the core reaches its first peak, after which there is a brief pressure decrease, allowing the core moderator voids to increase; (2) the effect of heat delivered directly to the moderator at the higher power increases the voids; and (3) the heat conducted from the fuel at the higher power creates additional voids. The same result is seen in TT2 but not in TT3, where the scram occurs much sooner because of the decreased difference between the initial power level and the scram level setting.

Figure 6 shows both the calculated steam dome pressure transient and the measured transient. The curves compare well in both the locations and the magnitude of the pres-

Table 1
TURBINE TRIP INITIAL CONDITIONS

	Power Level		Core Flow			Scram Setting
Test	MW (th)	% Rated	10 kg/s	(10^6 lb/h)	% Rated	% Rated Power
TT1	1562	47.4	12.76	(101.3)	98.8	85
TT2	2030	61.6	10.45	(82.9)	80.9	95
TT3	2275	69.1	12.84	(101.9)	99.4	77

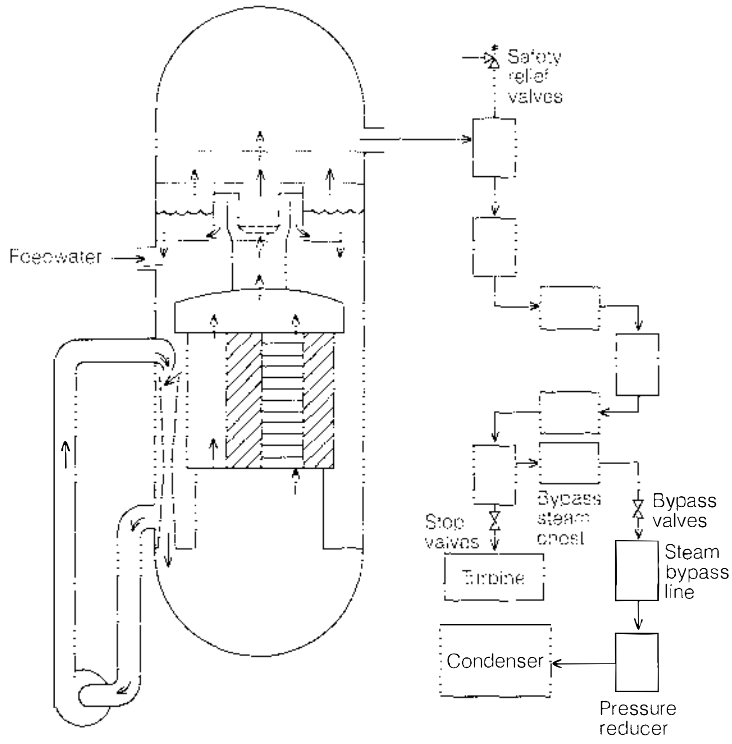
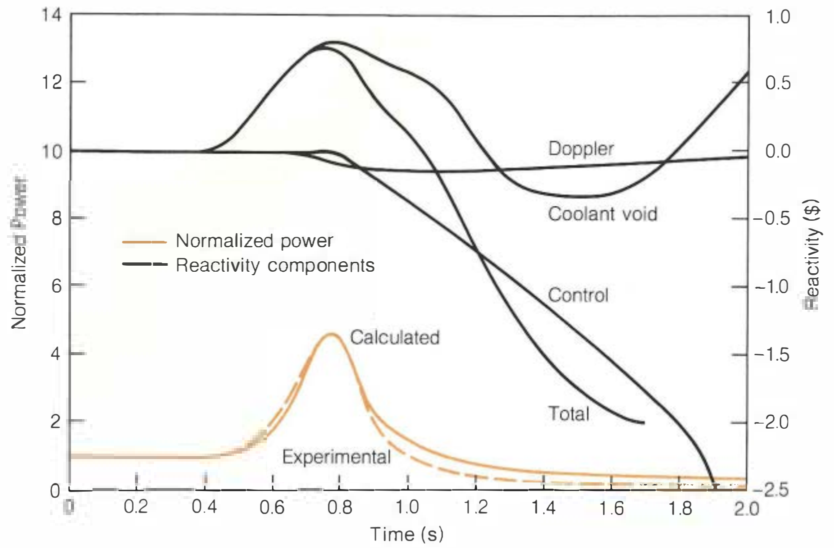


Figure 4 RETRAN simulation model for Peach Bottom-2 for the turbine trip tests.

Figure 5 Comparison of the experimentally measured and RETRAN-calculated normalized power for turbine trip test 1. Included are the RETRAN-calculated reactivity components for the transient.



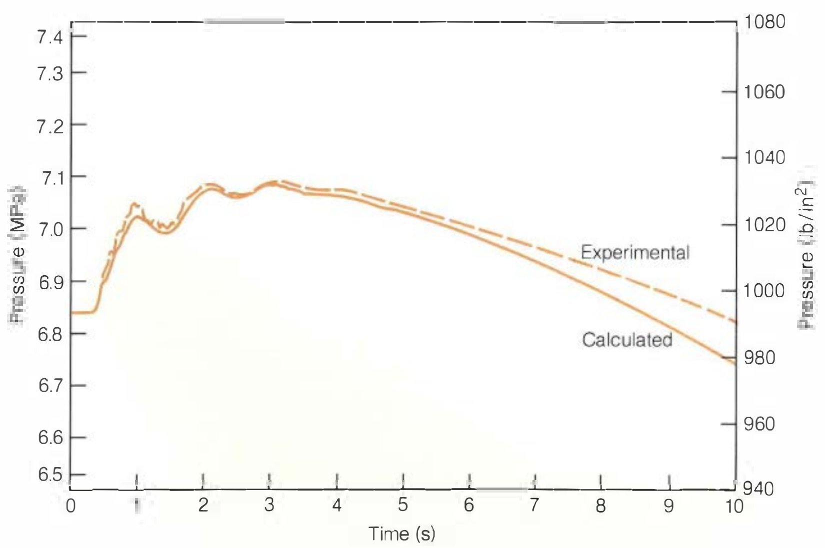


Figure 6 Comparison of the experimentally measured and RETRAN-calculated steam dome pressures for turbine trip test 1.

sure peaks. The pressure fluctuations seen in both measured and calculated curves in the early part of the transient are due to the damped pressure-flow oscillations in the steam lines. The high-frequency oscillations seen only in the measured curve are caused by acoustic ringing in the sensor lines. The depressurization rate in the later part of the transient is determined basically by the amount of flow through the bypass valve and the amount of heat released to the moderator from the solid components. Comparisons between calculated and measured pressures for the upper plenum, the steam line, and the region in front of the turbine stop valve were also made. In all cases the comparisons were good in terms of magnitude and timing of the peaks.

An extensive study of the effects of model and input parameter variation on the transients was carried out. Some of the input data values were uncertain; a variation of the numerical values will help evaluate the significance of the uncertainty with regard to the characteristics of the response. The uncertainty may derive from a lack of information (e.g., precise geometric data and event timing) or from the need to correlate the parameters of simplistic models used in the code with the more complex reality (e.g., equivalent characteristics of simple volumes and junctions representing complex flow paths). A related problem is that of the choice of various modeling options (e.g., critical flow models and integration methods) and the proper choice of nodelization of the system.

Sensitivity studies have helped resolve the following issues: the need for improved input data, the need for better models (and identification of modeling and coding errors), the determination of which phenomena are the most important in the type of transient being modeled, and the minimum modeling requirements for producing a solution within certain accuracy limits.

The analysis of the three turbine trip tests at Peach Bottom-2 with the RETRAN system analysis code has produced good comparisons with the measured data. This analysis and its associate sensitivity studies have been an important part of the qualification effort for the RETRAN code. They have also demonstrated the need for some code improvements in certain areas. The experience gained will provide a valuable guide for using RETRAN. *Project Manager: Joseph Naser*

References

1. *RETRAN Analysis of the Turbine Trip Tests at Peach Bottom Atomic Power Station Unit 2 at End*

of Cycle 2. Prepared by Karl Hornyik, Oregon State University, and Joseph Naser, EPRI, April 1979. EPRI NP-1076-SR.

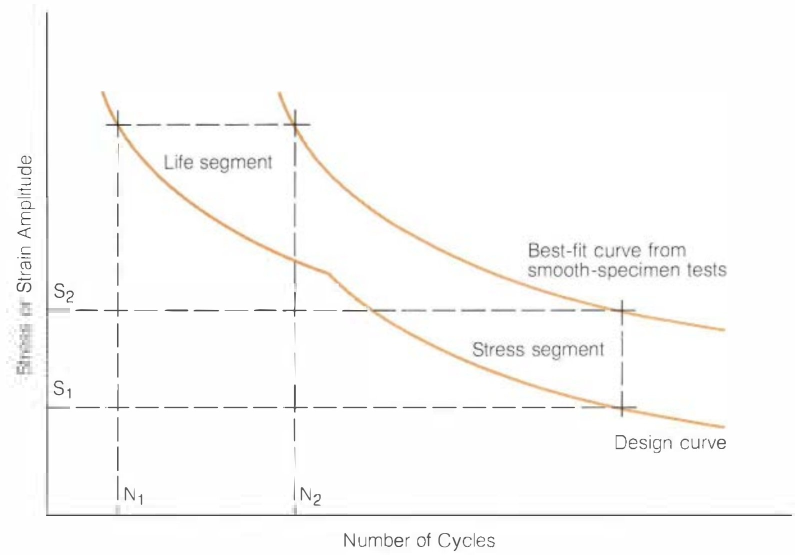
2. *Transient and Stability Tests at Peach Bottom Atomic Power Station Unit 2 at End of Cycle 2.* Final report for RP1020-1, prepared by General Electric Co., July 1978. EPRI NP-564.

3. *RETRAN—A Program for One-Dimensional Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems.* Final report for RP342 and RP889, prepared by Energy Incorporated, December 1978. EPRI CCM-5.

ENGINEERING TREATMENTS OF MULTIAXIAL FATIGUE

Nuclear power plant components are often exposed in service to loading in which two or more principal stresses vary with time (multiaxial fatigue). Fatigue design curves were developed for, and are properly applied to, uniaxial stress situations. Procedures have been developed to use uniaxial fatigue design curves to predict component life under multiaxial fatigue conditions. However, these procedures lack a sound fundamental basis, and the accuracy of their predictions is uncertain. Theories and engineering treatments of multiaxial fatigue are being evaluated by EPRI to provide a basis for the development of improved procedures for component design (RP1123-1).

Figure 7 The fatigue design curves in the ASME Boiler and Pressure Vessel Code are obtained from the best-fit life curves for uniaxially loaded smooth specimens by applying a safety factor of 2 on stress or of 20 on life, whichever is the more conservative at each point. The design curve therefore consists of two segments.



Many components in nuclear power plants are subjected in service to cyclic loading that can lead to fatigue failure at stress levels well below those required for failure under monotonic loading. For assurance against fatigue failure, design curves are provided in Section III of the ASME Boiler and Pressure Vessel Code. These curves describe allowable combinations of cyclic stress (or strain) and number of cycles during component life for a variety of materials and service temperatures. As shown in Figure 7, the curves are based on data obtained in uniaxial fatigue tests on smooth specimens. They include safety margins experience has shown are adequate to ensure acceptably small failure probabilities for components that are subjected to predominantly uniaxial, fully reversed loading.

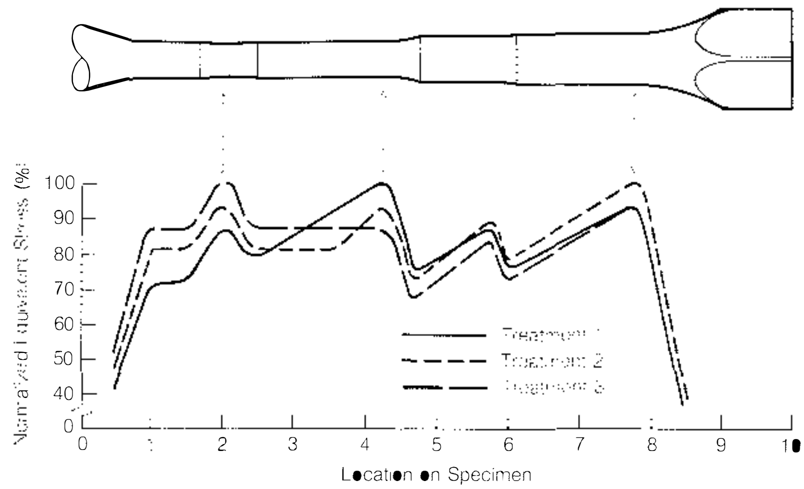
However, the service loading for pressure vessels, piping, vessel supports, and many rotating machinery components is typically neither uniaxial nor fully reversed. Such components often experience biaxial or triaxial loading, in which the average cyclic stress is not zero and in which two or more principal stresses vary with time (multiaxial fatigue). In some instances, the ratios of the principal stresses and their directions also vary with time (complex multiaxial fatigue). A number of theories of multiaxial fatigue have been proposed, and two engineering treatments are included in the ASME code. These treatments attempt to bridge the gap between the idealized laboratory tests on which the fatigue design curves are based and the practical conditions to which they must be applied. Because these treatments are largely empirical, it is not certain whether their use alters the safety margin provided by the design curves. This problem is being studied by faculty and students at Stanford University's Mechanical Engineering Department (RP1123-1).

The two code-specified treatments of multiaxial fatigue were compared with each other and with a number of other multiaxial fatigue models from the technical literature. The evaluation involved comparative assessments of the bases of the models, the main parameters included, and the ease and range of application. An analytic investigation of the divergence between the predictions of the various models was also performed. These studies indicated that the two code procedures are good first approximations and are much more conveniently and widely applicable than most of the other models. The difference between the equivalent uniaxial stresses calculated using the two code methods never exceeded 15%. Therefore cost and simplicity considerations suggest that it is generally preferable to use a procedure of the kind given in ASME code case 1592 rather than the treatment included in Section III of the code.

In the concurrent experimental studies, specimens that discriminated between multiaxial theories for completely reversed, 90° out-of-phase twisting and bending were designed and tested. The concept underlying these experiments is illustrated in Figure 8. In tests on a group of nine AISI type-304 stainless steel specimens, the peak equivalent stresses according to the two code treatments and a new empirical treatment based on literature data occurred at different locations. All nine specimens failed at the location predicted by the new treatment, that is, at a location of less-than-maximum equivalent stress according to the code procedures. However, the fatigue lives fell well above the ASME design curve for type-304 stainless steel, indicating that the procedure illustrated in Figure 7 provides an adequate safety margin against fatigue under this type of multiaxial loading.

The failure of the ASME code procedures

Figure 8 A test specimen designed to discriminate among three engineering treatments of multiaxial fatigue. The peak equivalent stress for each treatment occurs in a different location; the actual location of crack initiation is the indicator for the most successful treatment.



to correctly predict the location of fatigue cracking indicates that current procedures somewhat underestimate the likelihood of fatigue caused by out-of-phase twisting and bending, supporting the need for an improved treatment. A candidate procedure has been identified and will be developed during the rest of the project, along with improved methods of modeling the influence of nonzero average cyclic stresses on multiaxial fatigue life. *Project Manager: Robin Jones*

BWR PIPING REMEDIES

A program is in progress to develop and qualify piping remedies that will eliminate intergranular stress corrosion cracking of welded type-304 stainless steel (304 SS) piping in BWRs (RP701-1). These piping remedies include solution heat treatment of shop-welded pipes, application of corrosion-resistant cladding, and use of heat-sink welding. These remedies apply to existing plants for repairs and replacement of pipes and to plants under construction that are committed to the use of 304 SS piping. The qualification of the remedies is based on the capability of successful operation over the plant lifetime, as demonstrated by statistical testing of full-size welded pipes. A special pipe test laboratory has been constructed to accommodate the large number of pipe test specimens. Qualification of the solution heat treatment and shop corrosion-resistant cladding has been demonstrated, and these remedies are now being implemented.

Over the past several years a small number of intergranular stress corrosion cracks (IGSCC) have occurred in the heat-affected zones of welded 304 SS pipes in certain lines of BWRs. While these incidents have not presented a safety problem, they have resulted in costly reductions in plant availability.

The key factors that contribute to the IGSCC in welded 304 SS have been identified (*1*). These factors are the coincidence of weld sensitization, tensile stresses, and environment at the same location. The degree to which any given factor must be present for IGSCC to occur depends on the level of intensity and overlap with the other factors. Therefore, in order to prevent the IGSCC in welded 304 SS, the simultaneous occurrence of the three factors must be avoided.

According to this premise, the most direct approach for an engineering solution to the IGSCC problem would be to focus on the sensitization and stress contributors. Three potentially practical remedies that are attractive from the standpoints of cost and ease of implementation have been identified.

- Solution heat treatment (SHT) of pipe welds. This remedy eliminates the sensitized microstructure and weld residual stresses. Its application is limited to shop welds.
- Corrosion-resistant cladding (CRC). This remedy consists of applying a layer of weld metal on the inside surface of the pipe. The weld metal is essentially immune to IGSCC and protects the sensitive area of the pipe weldment from the environment. This remedy can be applied to both shop and field welds. In the shop CRC a solution heat treatment is performed to eliminate the weld sensitization at the interface between cladding and base-pipe material, but in the field CRC this treatment is not practical.
- Heat-sink welding (HSW). In this remedy, water cooling of the inner surface of the pipe after the first few root welding passes are made results in favorable compressive residual stresses on the inside surface, thereby enhancing the resistance to initiation of IGSCC. While the remedy is suitable for both shop and field welds, the prime application is for field welding.

To demonstrate that these remedies could prevent IGSCC for the plant design lifetime, a statistical qualification test program was formulated. This involved the testing of full-size welded pipes to provide results that could be scaled to reactor service (*2*).

Many tests had to be made of the three pipe remedies and of reference 304 SS to satisfy the statistical requirements. By testing both reference 304 SS and the pipe remedies, a factor of improvement, due to the pipe remedies, over the original reference material was determined. To reduce the test times, high stresses, cyclic loading, postweld grinding, and high levels of dissolved oxygen in the 288°C (550°F) water were used as accelerators. The criterion for qualification was improvement by a factor of 20 in the time to first failure of the pipe remedy over the mean time to failure of the reference 304 SS. The factor of 20 translates to a conservative improvement that is equivalent to the plant design lifetime.

To satisfy the pipe test needs of the statistical qualification test program, General Electric Co. constructed a special pipe test laboratory that is capable of testing seventy-two 10.16-cm (4-in) and one 25.4–40.6-cm

Table 2
RESULTS OF STATISTICAL PIPE TESTS

Pipe Remedy	Factor of Improvement	Remarks
SHT	46	No failures
CRC shop	48	No failures
CRC field	6	Failure*
HSW	9.3	Failure*

*Heat of 304 SS sensitized in as-received condition.

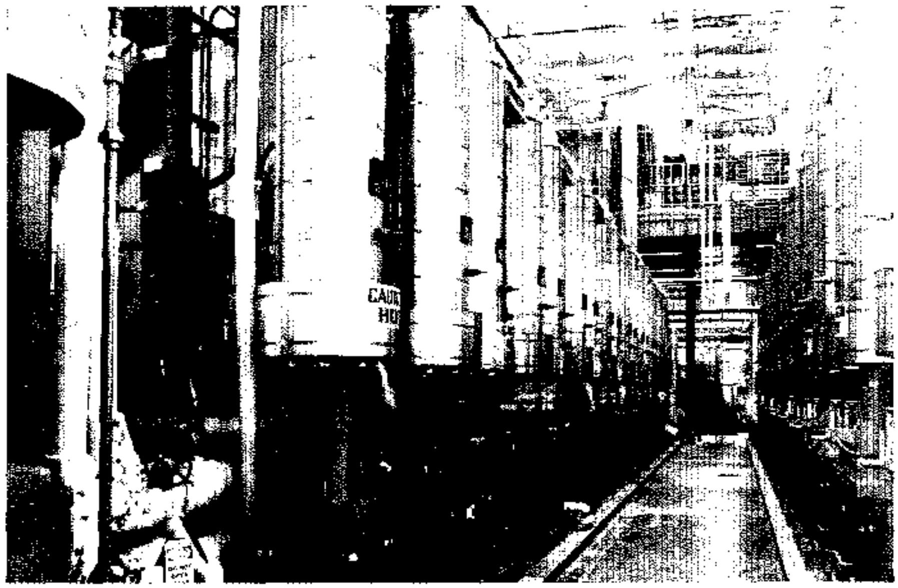


Figure 9 View of pipe test stands in General Electric's Pipe Test Laboratory.

(10–16-in) pipe specimens (Figure 9). The laboratory is also used to test alternative pipe materials (RP968).

The results of the statistical pipe-testing qualification project are tabulated in Table 2. The SHT and the shop CRC pipe remedies far exceed the test criterion of improvement by a factor of 20. However, the field CRC and HSW did not achieve the desired factor-of-20 improvement over the reference 304 SS. Their failure may be attributed to the heat of 304 SS that was sensitized in the as-received condition. Tests on the other heats not sensitized in the as-received condition are continuing. The SHT and shop CRC remedies are currently being implemented in domestic and foreign BWRs, both in the repair of existing plants and in plants under construction.

Since the field CRC and HSW represent a considerable improvement over reference 304 SS, they are being considered for limited applications in pipes that cannot be treated by the remedies qualified for at least a factor of 20. *Project Manager: Joseph Danko*

References

1. *Studies on the AISI Type-304 Stainless Steel Piping Weldments for Use in BWR Application.* Final Report for RP449-2, prepared by General Electric Co., December 1978. EPRI NP944.

2. J. C. Danko et al. "A Pipe Test Method for Evaluating the Stress Corrosion Cracking Behavior of Welded Type-304 Stainless Steel Pipes." In *Properties of Steel Weldments for Elevated Temperature Pressure Containment Applications.* December 1978. ASME MPC-9.

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

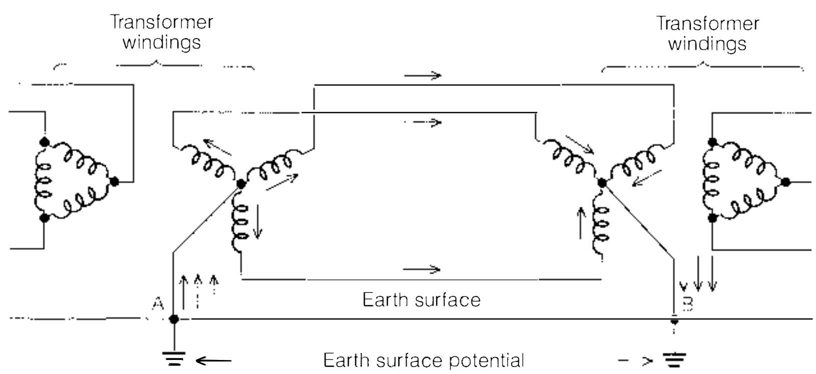
John J. Dougherty, Director

OVERHEAD TRANSMISSION

Geomagnetically induced currents

Voltage differences between various points on the earth's surface can be induced by solar activity. Geomagnetic field fluctuations can cause quasi-dc voltage differences of 6 V/km or higher after severe magnetic storms. These differences in the earth's surface voltage produce sporadic quasi-dc currents to flow through system grounding points that are remote from each other (Figure 1). Currents in the range of 50–100 A can be induced in grounded neutral points that are separated by several hundred kilometers. These geomagnetically induced currents flow into the neutral points and into each phase, thereby causing the iron in power, current, and voltage transformers to saturate. This, in turn, causes unusual real and reactive power flows, undesirable harmonics, misoperation of protective relays, and localized heating of transformers.

Figure 1 Mechanism for geomagnetically induced currents to enter an electric power system. Differences in the earth's surface potential produce sporadic, quasi-dc currents, which flow through system grounding points that are remote from each other (A, B). Since this flow is through the neutral points of power, current, and potential transformers, it can cause the iron to saturate and result in unusual real and reactive power flows.



Geomagnetically induced currents have been reported over a wide range of the earth's surface. However, areas of the earth that are nearest to the paths of auroral currents and that have high ground resistivity produce the highest values of geomagnetically induced current. High ground resistance causes the power lines to be the preferred path. EPRI and Minnesota Power & Light Co. are sponsoring research at the University of Minnesota to study the effects of these currents. Specifically, the research will examine their effects on a 500-kV line that will be built from Winnipeg, Manitoba, to Duluth to Minneapolis–St. Paul, Minnesota (RP1205). Other agencies involved in this study are Manitoba Hydro and Northern States Power Co. A fluxgate magnetometer to measure magnetic field variations, as well as earth surface potential measuring equipment, has been installed and is collecting data at a site northwest of Duluth. The geomagnetic field and earth surface potential are being measured and correlated with measurements of geomagnetically induced currents obtained from a number of sites in the area. This endeavor, together with field tests and measurements on the power system, will contribute to an understanding of the phenomenon and increase the ability to predict and control the effects such currents have on power systems. *Project Manager: Joseph Porter*

UNDERGROUND TRANSMISSION

Waltz Mill Facility

The Waltz Mill Underground Cable Test Facility was originally established by the Electric Research Council in 1969 as a proving ground for new cable designs and components for underground transmission cable systems and accessories. The principal objective was to provide a test area where new cable designs could be installed and operated under realistic field conditions and proved in service.

Results obtained at this facility provide proof testing of cable systems to meet the need for higher voltage transmission, improved reliability, increased transmission efficiency, and suitability for utility installation. The laboratory also facilitates early rejection of defective designs, preventing in-service failures (which may cause potential customer service interruptions) and the expense of failure location and repair.

Waltz Mill is essentially an EPRI facility, as EPRI has leased the property and test equipment for 10 years and a resident EPRI project manager is responsible for the testing and research. Day-to-day operation and maintenance are covered by an operating contract, currently with Westinghouse Electric Corp.

Use of the facility has changed from one

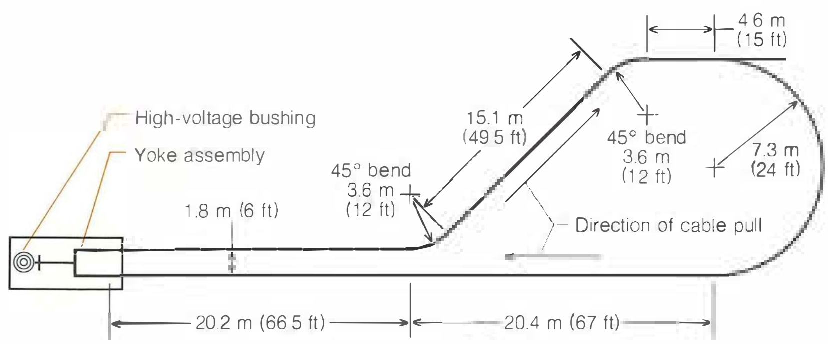


Figure 2 Diagram of test trench (1.2-m deep, 0.9-m wide; 4 × 3 ft) at Waltz Mill Underground Cable Test Facility. A realistically severe test of the manageability of a test section of flexible, gas-insulated cable was provided by this trench, through which the cable was pulled.

Figure 3 Flexible, gas-insulated cable on reel, shown at the start of the pulling operation at the Waltz Mill facility.

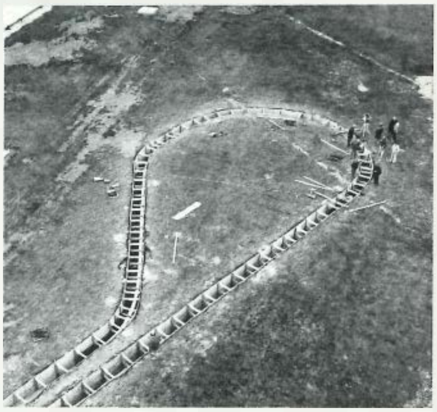


Figure 4 Aerial view of the Waltz Mill trench and pulling operation just after the cable had been pulled past the first severe bend on left. (The cable progressed around the loop from left to right.)

Figure 5 Obstructions, such as might be encountered in urban trenches, are represented in this test of the trench shoring in which the horizontal members (located 0.45 m [18 in] from the bottom of the trench) can be bypassed without difficulty.

of multisample, accelerated-life testing of conventional cable systems to multifaceted testing of less-traditional cable systems. This testing includes gas-insulated cable research and research on specific system problems, for example, the determination of hydraulic and thermal variables in forced-cooled cable systems. Use of Waltz Mill for other research, such as studying biological effects of electric fields, is planned in order to maximize use of the excellent multipurpose test facility.

A recent installation of a gas-insulated transmission cable illustrates the change in site-use philosophy. Development of flexible gas-insulated EHV cable had progressed to the stage where installation problems needed to be examined. Flexibility is a relative term. From a utility point of view, a cable is flexible if it can be pulled into a trench, around reasonable bends, and under, over, and around typical field obstructions, such as intersecting pipes and conduit. It must be able to withstand this without sustaining damage or change in its electric integrity.

To determine the degree of flexibility and the handling characteristics of this new, flexible, gas-insulated cable system, an installation test was proposed. To create a realistic, severe test, a trench 0.9 m (3 ft) wide and 1.2 m (4 ft) deep was dug, in the configuration sketched in Figure 2. Though not required by usual construction codes for trenches this shallow, wood shoring and cross bracing were used along the walls of the trench to prevent the wall from collapsing during the several months the trench remained open.

The first two lateral bends in the cable run were 45° in opposite directions at approximately twice the radius of the shipping reel (2 × 1.8 m = 3.6 m [12 ft]). Not shown in the figure are the slight vertical bends required as the cable was pulled from ground level into the trench. The cable was pulled into the trench, through the two 45° reverse bends, around the 7.3-m (24-ft) radius (a 180° bend), and then was pulled straight back to the termination assembly and out of the trench.

This layout was designed to demonstrate that the cable could be pulled into a trench and under and around obstructions without any bending jigs or other special apparatus.

Consistent with the overall objectives of this project, the cable pulling was planned according to traditional concepts of setup and handling. These concepts include a cable reel, with brake, mounted on a reel stand at one trench end and a cable with a pulling eye; a pulling line threading the trench with appropriately placed snatch blocks for curved runs; suitably sized and spaced rollers or sheaves under the cable and on the inside of trench bends; and a capstan or winch to provide pulling-line tension (Figures 3 and 4).

The installation test at Waltz Mill demonstrated clearly that the flexible gas-insulated cable can easily be pulled into a trench, under and around obstructions, and through sharp radius bends. The cable followed the trench contour vertically and horizontally without the use of special rollers or guides. Even in these unrealistically severe bends (an S bend followed by a 180° bend), pulling tension was less than 26.7 MN (3 ton-force) and therefore only conventional pulling equipment was required.

Obstructions similar to those encountered in urban trenches (represented by horizontal shoring members about 0.45 m [18 in] from the bottom of the trench) can be bypassed with no difficulty (Figure 5). In its final form the flexible cable will have a relatively smooth-contoured, corrosion-protective jacket, with the valleys of the corrugations filled. These features should further improve pulling characteristics.

X-ray examinations, leak tests, and voltage tests revealed no damage to the cable. A series of thermal-cycling tests with simultaneous overvoltage is under way. X-rays will be taken at various points in the test to detect possible interior displacement of the conductor and insulators. The primary goal of this testing at Waltz Mill is to gather information on the mechanical aspects of the cable under extreme thermal-cycling conditions. *Project Manager: John Shimshock*

Three-conductor, gas-insulated cable

Where a buried or aboveground link of compact, high-power transmission is required, compressed-gas-insulated transmission (CGIT) lines have become an accepted and important part of high-voltage transmission systems. All CGIT systems in service are of isolated-phase design, with an aluminum conductor supported concentrically inside a grounded aluminum enclosure on insulating spacers. The insulation is provided by sulfur hexafluoride (SF_6) gas at a nominal pressure of 344.75 kPa (50 psig). Isolated-phase CGIT lines are now in service for voltage ratings 145–550 kV.

CGIT links can also be in a three-conductor configuration, in which the three conductors are mounted in a single, grounded enclosure. A three-conductor CGIT system has several significant economic advantages over the isolated-phase system: The total installed cost is typically 10% to 15% lower; the power losses are 15% lower; the design offers a more compact installation, with fewer joints to make in the field. To realize these advantages, EPRI funded a three-stage research program with Westinghouse Electric Corp. for the development of an optimized, three-conductor CGIT system (RP7840).

The first two stages of the research achieved the basic design, testing, and optimization of three-conductor CGIT systems. The object of the third stage of the development program is to manufacture, install, test, and operate a 183-m (600-ft) test loop of the optimized three-conductor CGIT system, connected as an integral part of a utility system (in this case, that of the Detroit Edison Co.).

Westinghouse has a seven-task program for the design, manufacture, test, and shipment of the three-conductor sections, trifurcations, and auxiliary equipment. The basic design is that of the 362-kV, three-conductor CGIT, developed under RP7840-1. An important new part of the program is the development of automatic welding and a nondestructive test system for the longitudinal welded joints on the aluminum enclosure.

Detroit Edison has a program for the test loop design, site preparation, CGIT field installation, instrumentation, and operation. The test program for the CGIT loop includes operation on the transmission system, with high-current runs, staged switching-surge tests, and carrier-wave measurements. Site preparation should begin late this summer, with installation scheduled for the spring of 1980. *Project Manager: John Shimshock*

Measuring thermal resistivity and soil stability

One of the limitations of installing and operating underground cables is that little is known about the thermal properties of soil. Because these properties ultimately determine the emergency loading criteria for any buried circuit, utilities need better tools to help them make accurate assessments of underground conditions.

The object of a study with Ontario Hydro is to develop instruments that will enable utilities to improve their knowledge of thermal profiles of soil around cable and to help them assign more accurate emergency loading criteria (RP7861). To provide this knowledge, many thermal properties of backfill and native soils must be measured with advanced equipment. In characterizing in situ soil, utilities face problems of:

- Time-consuming measurements of thermal resistivity
- Lack of variable heat flux on probes to determine critical moisture levels
- Lack of understanding of the forces affecting moisture movement
- Lack of an expeditious means of deter-

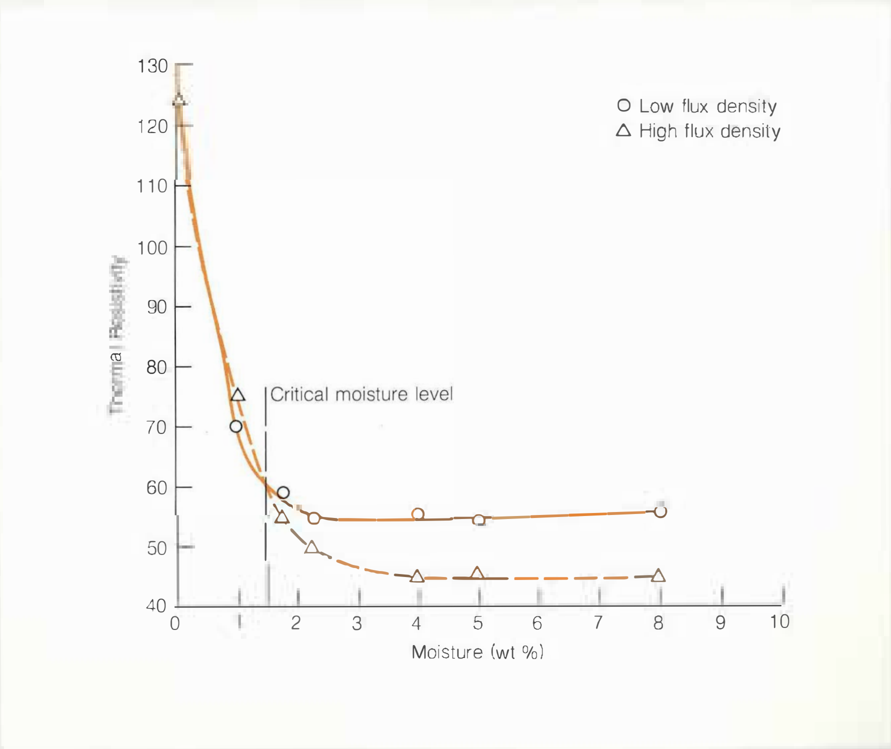


Figure 6 Plot of thermal resistivity as a function of moisture for a stable thermal backfill at two very different heat flux densities. At ~1.5% moisture, the thermal resistivity for both heat fluxes increases rapidly, indicating that this is the critical moisture level for this soil.

mining thermal resistivity versus moisture percentage

- Error introduced into thermal resistivity values by probe insertion methods
- Uneven application of probes by utilities
- Problems of grain-size analysis in the field

Many tasks are being pursued that should improve thermal resistivity probes, in situ moisture-measuring probes, and laboratory instruments. A microprocessor-controlled thermal property analyzer has been developed that can be connected to a data bank for characterizing soils.

This thermal analyzer will be connected to the probes (1.8-m-long [6-ft] thermal needles) when they are inserted in the ground. The processor will acquire the input of readings from the probes, determine accuracy, and proceed to display thermal resistivity, degree of thermal diffusion, and change in thermal resistivity with heat flux, thus yielding the temperature and the critical moisture level for stability (Figure 6). Inherent in the available data base for fully characterizing soil types will be information on dielectric constants, electric conductivity versus frequency, thermal resistivity versus percentage of moisture, and heat flux versus thermal resistivity curves.

By comparing the known data in the data bank with the field measurements, the soil type can be determined (Figure 7). The microprocessor also can suppress erroneous data caused by contact resistances and by poor probe insertion. Because thermal resistivity is determined by the slope of temperature (probe) versus log time curves for needle probes, contact resistance between probe surface and adjacent soil can yield a major error in readings if not detected (Figure 8).

In the time remaining under contract, Ontario Hydro will add and classify more soils for the data bank and will finish fabrication of the prototype instrument. This prototype will be field-tested during summer 1979, and two more instruments will be delivered to EPRI at the end of tests. These instruments may be loaned to utilities in a later demonstration phase. *Project Manager: Thomas Rodenbaugh*

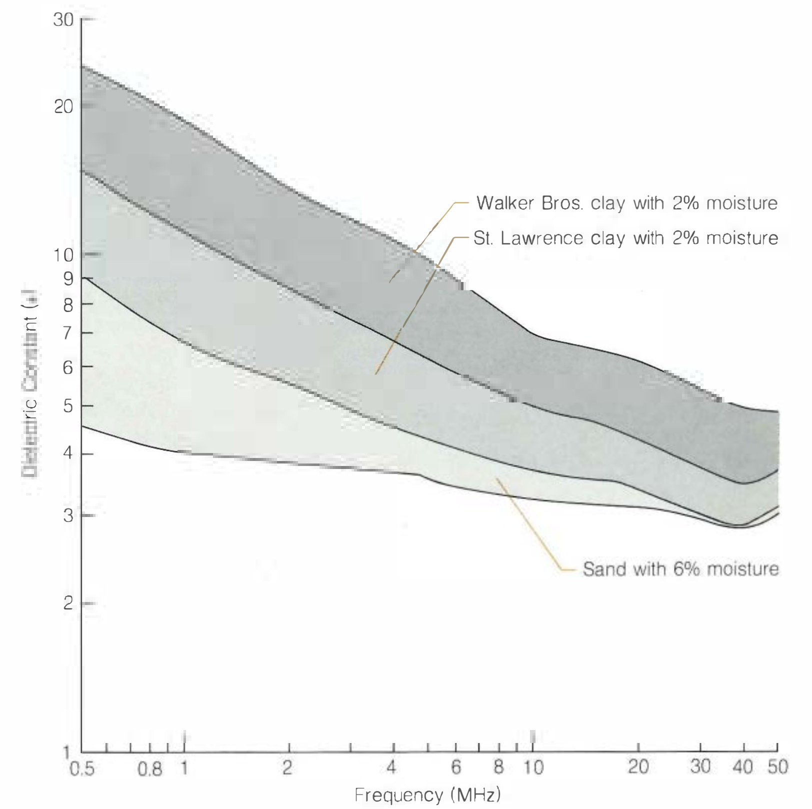


Figure 7 To help in characterizing type of soil and approximate moisture content, the complex dielectric constant versus frequency can be measured. Three distinct regions are shown: sand with 6% moisture, St. Lawrence clay with 2% moisture, and Walker Bros. clay with 2% moisture. Regions (rather than specific curves) are necessary because these measurements were taken at many different soil temperatures.

SUBSTATIONS

Combustible gas-in-oil detector

For many years the analysis of the gases present in the oil of a transformer has been used as the earliest possible indication of an incipient fault because the presence of certain gases is the result of electric discharge or overheating. With the lack of accurate field analyzers, however, considerable time elapsed between the taking of the oil in the field and the analysis of the gases in the laboratory.

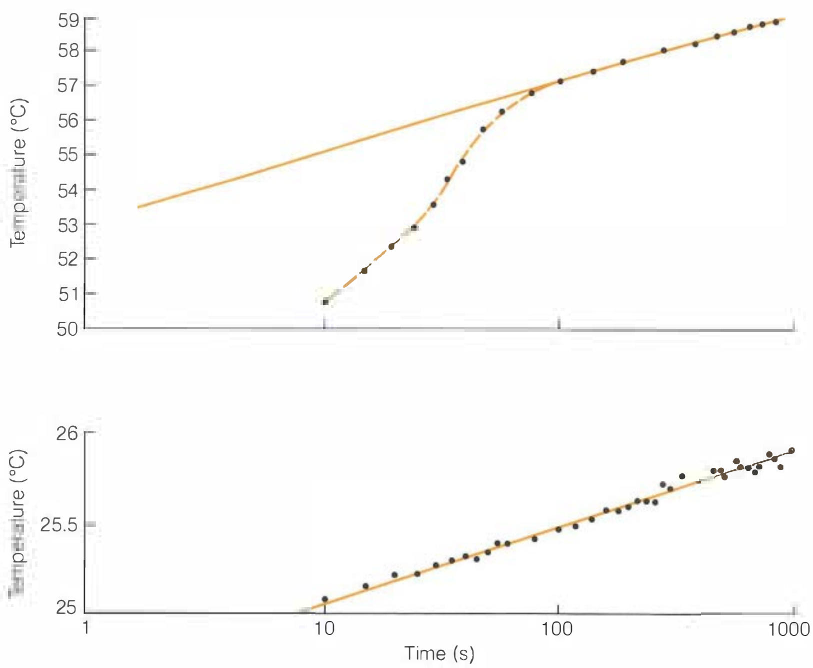
An instrument developed under EPRI contract overcomes this time-delay problem by continuously monitoring the transformer oil, with analyses occurring automatically every 24 hours on site (RP748).

Oil continually moves by thermosiphon flow through a permeation cell, which is connected by conventional piping to the transformer's upper filter press valve and to the drain valve. (A diagram of the cell and detection system appeared on p. 52 of the June 1978 *EPRI Journal*.) Any gases present in the oil diffuse through a fluorosilicone membrane in the cell into a collection cavity. Automatically, every 24 hours, a measured portion of the collected gas is chromatographically analyzed for the presence of hydrogen and carbon dioxide. The presence of hydrogen is of interest because it is formed in almost every case of an electric disturbance or an overheating. The presence of carbon dioxide is an indication that cellulose is involved in the disturbance. Alarms are activated when the levels of hydrogen and/or carbon dioxide exceed preset levels.

The high sensitivity of the instrument allows detection of 50 ppm hydrogen in the oil. Because the sensitivity of the instrument to carbon dioxide is not as high, greater amounts of carbon dioxide are usually allowed—a level of 4000 ppm is adequate.

Two prototype detectors have been built. One of these units will be installed on a 572-MVA auto transformer at the Staten

Figure 8 A temperature versus log time curve gives the thermal resistance by the slope of the line. This should be fairly constant when no moisture movement occurs. The lower curve is steady, showing good contact with the soil by the probe. The upper curve indicates a probe in poor contact that would give erroneous thermal resistivity readings for the entire test, as evidenced by the change in slope within the first 100 s. The microprocessor will tell the operator when poor contact occurs. (It is important to note that even after 100 s the reading is high.)



Island Goethals substation of Consolidated Edison Co. of New York. The other prototype will monitor an 880-MVA step-up transformer at the Shippingport power-generating station of Pennsylvania Power Co.

During this one-year follow-on program, the detector responses will be compared with load data and ambient and oil temperatures. The relationships of the analyses of the gas in the permeation cell relative to changes of these parameters will be determined. *Project Manager: Ed Norton*

Amorphous-metal low-loss transformer cores

With the sponsorship of EPRI, Allied Chemical Corp. is developing production technology for the manufacture of a new form of low-loss transformer core material (RP1290). The technology is based on Metglas amorphous metal alloys, invented by scientists at Allied Chemical's Corporate Development Center.

Metglas amorphous metals, a new class of engineering materials, are produced by cooling certain molten metal alloys so rapidly that no crystallization occurs during solidification. The resultant metal retains a random atomic structure similar to that of glass.

However, unlike ordinary glass, Metglas metallic alloys are not brittle. Being noncrystalline, Metglas does not have the grain boundaries that tend to weaken crystalline metals. As a result, Metglas materials exhibit exceptional strength, hardness, and ductility, as well as unusual magnetic properties.

The Metglas alloys typically contain base metals, such as iron, nickel, and chromium, which are alloyed with relatively inexpensive metalloids, such as carbon, phosphorus, boron, and silicon.

Complementing the metallurgy of the new class of materials, Allied Chemical researchers invented and developed new processes for economically spinning Metglas alloys into wires, ribbons, and strips. These processes operate at high speeds and require relatively simple equipment. The ribbon is cast directly from the melt to a finished width and thickness. In this new method, a number of costly time- and energy-consuming steps needed for conventional processing of metals are eliminated (e.g., rolling and rerolling billets and slabs to thin sheet).

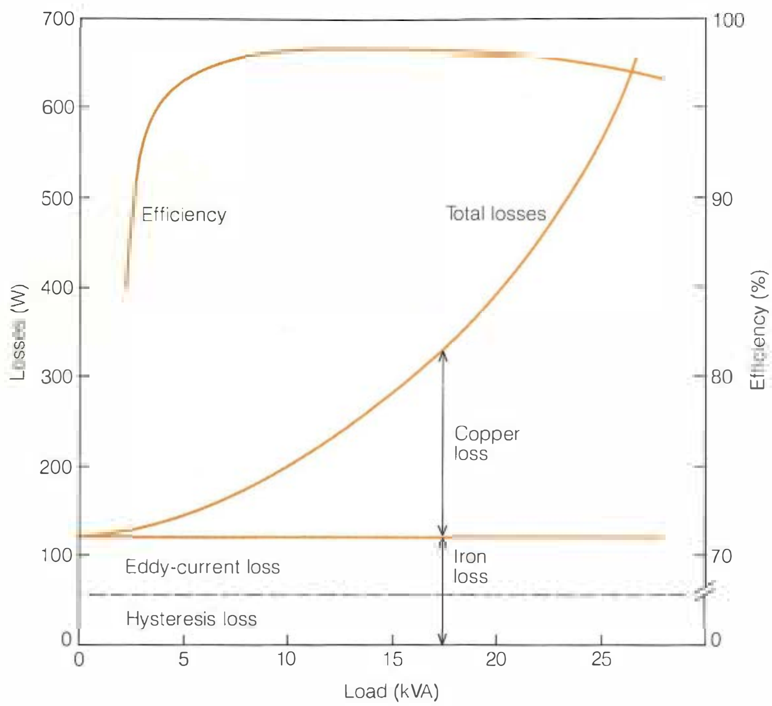
Allied Chemical has made a variety of Metglas alloy products commercially viable, including the production of brazing foils, which are used in fabricating parts of turbines, heat exchangers, honeycombs, and related machinery.

Recently Metglas alloys have been developed that combine relatively high saturation induction levels with low hysteresis and eddy-current losses. This unique combination makes it possible to produce transformer cores with energy losses that are substantially lower than those attained by the best silicon iron presently used for this purpose. If core losses in conventional distribution and power transformers purchased in any given year could be reduced by 60% with the use of Metglas materials, utilities could realize a savings of $200 million per year. This possibility is based on the most conservative of estimates. A typical 25-kVA distribution transformer has continuous (no load) core losses of 120 W (Figure 9), which some utilities evaluate on purchase of transformers at $1–$3/W. The target material of this program would result in core losses of only 45 W.

The joint EPRI–Allied Chemical goal is to develop scaled-up, continuous production techniques to make Metglas alloy strips that are suitable for transformer cores. In the first phase, which will take about 15 months, a pilot plant will be set up to melt, alloy, cast, and wind a Metglas strip 2 in wide under controlled conditions of width, thickness, and flatness. During the second phase, the system will be upgraded to produce at high rates full-width transformer core material (7 in) from raw materials that are relatively inexpensive. The Metglas alloy core project is anticipated to cost $6 million over a period of four years.

A separate $1.2 million contract has been signed with Westinghouse Electric Corp. to design, build, and evaluate transformer cores made of Metglas materials. This project is cofunded by EPRI's Substation and Distribution programs. *Project Manager: Ed Norton*

Figure 9 The constant core loss, even at no load, for a conventional 25-kVA distribution transformer could be reduced to 45 W (or 60%) by using Metglas, an amorphous metal alloy.



Heat-pipe-cooled epoxy bushing

Application of high-power electric bushings during overload conditions has been hazardous because of either thermal runaway or the limited space available for oil expansion.

A 41-month research program has resulted in the development of prototype epoxy bushings that can be made at a price competitive with existing oil-impregnated paper bushings (RP565). The design of a 242-kV, 4-kA, heat-pipe-cooled epoxy bushing is conservative in both voltage and continuous current rating.

The insulating structure is a duplex cast-epoxy system that eliminates all need for insulating oil and cellulosics. A capacitively graded, rigid, bisphenol-epoxy composition core provides strength and low dielectric losses. A flexible cycloaliphatic-epoxy composition weathercase is cast as an integral part of the outer, exposed end of the core to provide excellent track resistance and resistance to weather. This system simplifies the structure of the bushing by eliminating such characteristic features of former designs as the oil reservoir, oil-level gage, gasket seals, clamping springs, and oil-sampling valve. Also, the exposed epoxy weathercase is superior to porcelain in impact resistance and has a self-cleaning chalking action that rids itself of contaminating deposits.

The ultimate tests of a design are its feasibility for manufacture and its performance. The manufacture of the heat-pipe-cooled epoxy bushing is a delicate process in the epoxy-casting phases but otherwise poses no great problems. Research indicates that in quantity production, with a well-manned and experienced production line, the manufacturing process would flow smoothly and would be virtually problem-free.

The manufacture of the nest of tubular, voltage-grading foils and the assembly of the core mold are delicate operations better suited to a clean-room environment than to the epoxy-casting aisle exposure. The pouring of the bisphenol-epoxy core is hypersensitive because contamination at this point can spoil the electric performance of the product in a way that is irreparable. Although the weathercase casting is more tolerant of small impurities, close control must be exercised in the formulation, the casting, and the curing of the mix in order to create a completely satisfactory product.

The extruded aluminum alloy, finned heat exchanger proved satisfactory both as a component for press assembly onto the lead and in weathering studies that were run in parallel with the project. The extrusion was designed for another application, and its bore was bushed to bring it down to size. A greater production volume would be better served with a similar extrusion, custom-tooled to the specific requirement.

The mass production of cast-epoxy-insulated bushings of this size in quantities of 500 or more per year would dictate an order of magnitude expansion of the facility's production line. Together, these changes would improve productivity and, consequently, would lower costs.

The use of a heat-pipe to dispose of energy losses augurs well for low-cost modifications that will permit even higher continuous-current ratings (e.g., forced-air circulation and/or an oversized heat exchanger).

The technique developed with the particular 242-kV design is adaptable to other voltage ratings (e.g., upward to 362 kV, and possibly higher, and downward to cover intermediate voltage classes).

Two prototype bushings are available for installation on new 3-kA or 4-kA breaker bushings. *Project Manager: Ed Norton*

Transformer life characteristics

Two projects in progress are designed to develop a better understanding of the life of transformers via functional testing (RP 1289). General Electric Co. (Pittsfield, Massachusetts) and Westinghouse Electric Corp. (Sharon, Pennsylvania) have both developed test programs that ultimately will provide utilities with information to operate transformers more reliably.

General Electric has completed that portion of the study involving potential short-time failure modes. The objective was to observe the effects of gassing at elevated temperatures on the characteristics of typical oil-paper insulation systems. Sample coils employed for this testing provided a structural arrangement similar to that in a transformer and permitted heating of the sample by current flow to simulate true thermal gradients. Conductor coils of thermally upgraded kraft paper were wound over rectangular copper conductors, and cable coils of thermally upgraded crepe kraft were wound over 1/0 stranded copper. Experimental observations of these systems indicated that there were gas bubble discharges when the hot spot exceeded 140°C; streams of bubbles emerged from the surface of the winding conductors and from the ends of the cable coils. Dielectric breakdown strengths dropped gradually with conductor hot spot temperatures, with a sharper drop in strength appearing to develop in the 150°C range. The details of this work by General Electric will be presented at the 1979 IEEE Summer Power Meeting.

Westinghouse has completed a parallel study on the effects of gas evolution initiated by hot metallic surfaces. The effects of various hot metals in contact with oil in the transformer tank were investigated; metals employed included carbon steel, copper, and aluminum. Tests were performed in the 100–300°C range for periods of 72 hours. The tanks were then cooled and the gases formed were analyzed. From these experiments, it was concluded that the gassing of the metal-oil system (no insulation) does not appear to begin until 200°C is reached. The gases evolved from the hydrocarbon oil include low-molecular-weight hydrocarbons, such as acetylene, ethylene, ethane, methane, carbon monoxide, and carbon dioxide. The amounts of gases increase with temperature and appear to vary with the nature of the metal. Westinghouse will report on its overall progress at the 1980 IEEE Winter Power Meeting.

Both studies will evaluate the thorough investigation of degradation modes and will attempt to clarify the effects of bubbling (a possible short-term failure mode) and of insulation degradation (the classic long-term failure mode). *Project Manager: Bruce Bernstein*

POWER SYSTEM PLANNING AND OPERATIONS

Hierarchical control and data management

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

In a three-year, $534,000 study, Computer Sciences Corp. is to develop multilevel processor concepts for optimal distribution of control and analysis functions (RP1047-1). These concepts must be tested at various processing levels within the hierarchy and analyzed to define requirements for data flow, data base management, and overall distributed computer capacity. Computer Sciences is investigating all levels of electric utility control, beginning with pool control centers, extending through company and regional control centers, down to the bulk-power remote substations.

The hardware implementation for the defined basic hierarchical structures is being established and refined. The areas of hardware investigation include the instrumentation, the remote terminal unit, the computer subsystem, the communications, the man-machine interface, and the overall system availability requirements. Software and firmware requirements for optimal operation of the conceived hierarchical systems are being established. Definitions of control and computational analysis functions and associated executive dynamics will be developed.

In a 30-month, $589,000 project, Case Western Reserve University (CWR) will study the large amount of data available from bulk-power remote stations (RP1047-2). Whereas the Computer Sciences project addresses the data management problem from the top down, this research will concentrate on the wealth of data available from remote substations.

CWR plans to use a pattern-recognition technique called associative memories to discern the characteristics of a new set of real-time power system data from the remote terminals. Stored in the computer memory are other sets of these data that correspond to widely different power system conditions. Because of the potential speed of computation of the associative memory techniques, a system operator would have a timely indication of the state of the system. This contrasts with the present method of scanning a large data base to find indications of changing system conditions.

In this study, real-time operating data from the Cleveland Electric Illuminating Co. will be used by CWR. The operating problem under study concerns power system security in the face of various operating contingencies. *Project Manager: Charles Frank*

Low-frequency oscillations

When major electric power systems are interconnected through tie lines of relatively small capacity, low-frequency intersystem oscillations are likely to be troublesome for some operating conditions. Spontaneous intersystem oscillations, which have occurred in the western and some midwestern states, attest to this aspect of system behavior. The long distances that separate concentrations of generating capacity in those systems also separate many individual generating plants from other machines, so localized, poorly damped, higher-frequency modes of oscillation also exist. The potential for unstable oscillations must be considered in planning the bulk generation and transmission system, in designing control systems for turbine generators and dc line terminals, and in system operations.

Present practice depends almost entirely on time-domain simulation for large-system analysis, with relatively high computing costs. Information is received in a form that is often not suitable for study purposes.

Westinghouse has nearly completed a project that has resulted in an alternative method to time-domain simulation for analyzing low-frequency intersystem oscillations (RP744). This alternative involves the use of a linearized system model and employs frequency-domain techniques to determine those complex conjugate eigenvalues that are most intimately related to generator rotor motions.

The models and computer program development are complete. An intersystem oscillation study that involves 965 buses has also been completed for the Mid-American Power Pool. A similar study for the Western System Coordinating Council system is under way. The resultant computer program will be distributed by the Electric Power Software Center on completion of the project in fall 1979. *Project Manager: John Lamont*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

ENERGY ANALYSIS

The Energy Analysis Department groups its research for the electric utility industry into three programs: Supply, Demand and Conservation, and Systems. A staff of about 25 professionals, including economists and engineers, manages more than 150 research projects. Research expenditures amounted to $5,700,000 in 1978. More than 50 technical reports have been published as part of EPRI's effort to communicate R&D results to the industry. In addition, many workshops, seminars, and conferences have been held to facilitate the use of EPRI research results by specific utilities.

Supply

A clearer picture of short- and intermediate-term energy supply is emerging from the integration of EPRI contractor studies, reports by others, and the ongoing stream of events. The longer-term future remains fraught with uncertainty. It is simply not clear which new technologies and which energy sources will play major roles past the year 2000. Nor is it clear when the uncertainties will be resolved. Of most importance is the major uncertainty about environmental and social acceptability of emerging technologies. Next in importance are the economics of emerging technologies and the size of the resources on which they are based.

The Intermediate Term The Supply Program's work has been focused on the period 1985–2000 and was designed primarily to support EPRI's R&D planning. In response to directions from the Energy Demand and Supply Task Force, a number of projects dealing with the next 10–15 years have been undertaken: *Outlook for World Oil Into the 21st Century With Emphasis on the Period to 1990* (EA-745), *Foreign Uranium Supply* (EA-725), intermediate-term domestic uranium supply (RP1294), and intermediate-term coal supply (RP1431).

Supply 77 provided projections to the year 2000 (EA-634-SR). EPRI's Planning Staff recently requested that the forecast horizon be extended to the year 2030. Supply research covers the period from 1970 to 2030. The focus of utility interest is on the 1979–2010 period; of primary interest to EPRI are supply projections extending from 1985 to 2030.

The Long Term The need for information on the post-2000 period is increasing for several reasons: A general lowering of demand estimates made in recent years means that a larger proportion of the long-term benefits from EPRI's R&D will be in the post-2000 period; interest has been increasing in a number of technologies that are expected to contribute in the post-2000 period (e.g., central station solar power and fusion); and the year 2000 is more than five years closer than it was when EPRI first defined information needs. Although a number of earlier studies dealing with domestic resources included long-term implications, several new studies that are under way or being planned deal specifically with the long-term future (2000 and beyond). The basis for improved forecasts of supply from domestic energy sources and from technologies that are not a major subject of EPRI research will be provided by the results of a project that has just begun (supply projections for non-EPRI technologies, RP1482.) Forecasts of supply from new technologies on which EPRI does have major research programs draw heavily on analyses made for those specific programs, as well as on studies made by other organizations.

Acceptability of New Technologies The environmental and social acceptability of new technologies and of new resources are among the most difficult aspects of long-term supply forecasting. The question will be addressed in two research contracts jointly sponsored with the Environmental Assessment Department (development of socioeconomic impacts assessment guideline for utility use, RP1226, and environmental and social consequences of a shortage in generating capacity, RP1374). The economic analysis of new technologies is also difficult but can be based on engineering-economic types of analysis.

Supply Availability The availability of foreign energy resources to the United States is a matter of increasing relevance in EPRI's planning, as well as in national planning. Although major EPRI studies on world resources and world supply will build on existing studies and analyses, much of the existing work has serious deficiencies. Because it will be several years before these studies are completed, EPRI is planning a workshop on foreign oil and gas supply to provide an early assessment of such developments as the recent higher estimates of Mexico's oil and gas resources. A subsequent seminar for utilities will apply the understanding of foreign supply gained at the workshop to EPRI's research program and to utilities' own planning.

In the fall of 1977, when *Supply 77* was being prepared, there was concern about the ability of coal output to meet demand, about how high uranium prices might go, about whether the decline of domestic crude oil and natural gas output could be stopped, and about how high world oil prices would rise. The prospect for the short-to-intermediate term is that supply and demand will come into equilibrium (as indicated by the fact coal prices did not skyrocket after the coal strike and currently planned expansion of coal output is being curtailed). Uranium prices, which appear to have reached a plateau at about $43 per lb ($95/kg), are likely to decline in constant dollars for a number of years before resuming an upward trend. Domestic crude oil production appears to have stabilized, and natural gas is in sufficient supply so that the government is encouraging the use of natural gas in markets where such use was discouraged a year ago.

The prospects for equilibrium result from marketplace adjustments on both the supply side and the demand side, as well as on such nonmarket adjustments as voluntary conservation and government regulation. However, the market does work within the constraints placed on supply and demand by environmental forces and government policy—this basic assumption of *Supply 77* still appears valid. Equilibrium in world oil markets was disrupted by the Iranian revolution, and it may take several years to reach a new equilibrium at higher prices.

Ultimately, forecasts of primary energy supply enter into the Energy Analysis Department's forecast for electricity supply and demand. Primary energy sources provide fuel either for power generation or for activities in the economy, most of which could potentially be supplied by electricity. A few uses, such as raw materials for petrochemicals and asphalt for paving, could not be met by electricity.

One of the most difficult aspects of supply analysis is the realistic matching of the short- and intermediate-term analysis (which is based on known and planned facilities and resources) with the long-term analysis (which is based, by necessity, on much broader considerations, less specific constraints, and more tenuous estimates). *Program Manager: Milton Searl*

Demand and conservation

The principal objective of the Demand and Conservation Program is to improve the understanding of how households and firms use energy in general and electric energy in particular. This knowledge is applied primarily to the forecasting of energy consumption under a wide range of potential conditions of economic growth, energy prices, and government conservation measures. The program staff produces its own set of forecasts on the basis of projects conducted under contract and in-house research. These are used as background information by EPRI's Planning Staff and by the public for decisions on the future of national energy consumption and on public policy.

In addition, this program's research is intended to provide insights and improved methods that electric utilities may use for their own forecasting. A significant amount of its research is also devoted to increasing the depth of knowledge on the purely physical aspects of energy consumption.

In this review of program highlights, several major aspects of the work will be omitted because they were covered in the R&D status reports in recent issues of the *EPRI Journal.*

Prospects of Industrial Cogeneration Although industrial cogeneration offers a clear thermodynamic potential for reducing purchases of electric power from utilities, the reality is that the electricity generated by industrial firms, much of which has been through cogeneration, has declined both absolutely and relatively. The pieces of this puzzle are many and their interlocking is subtle. A major effort to sort them out has been undertaken by Mathtech, Inc., which is constructing a model to take explicit account of the alternative ways in which firms may use and produce energy (RP942). The model uses mathematical programming techniques to find the least-cost combination of production processes, given the wide variety of possibilities for producing process heating and either producing or purchasing electricity. A final report is expected to be available later this year.

In addition, a workshop was organized by the University of Arizona (RP1050) in April 1979 to review the state of the art of the economics and technology of cogeneration and was attended by those in the forefront of cogeneration research. The proceedings of this workshop should prove to be a valuable reference for members of the electric utility industry, industrial firms, and government.

Energy Consumption in the Commercial Sector The customer class designated as small light and power consists mainly of firms involved in business other than manufacturing. This covers an enormous range of activities, which are grouped in the commercial category. It is the least investigated and least understood of the major customer classes. One attempt to increase knowledge of this important sector was an analysis of demand for energy in the commercial sector (RP662) undertaken by Data Resources, Inc. Although a number of innovative approaches to modeling this sector were investigated by the contractor, one of the more useful has been to separate the forecasts of energy consumption in the commercial sector into two groups, one for the quantity of future construction of commercial buildings and another for the rate of energy use per square foot. Relative energy prices and prospective levels of economic growth are particularly important in this model. The model promises to increase the capacity for analyzing the degree to which electricity and fossil fuels can substitute for one another.

Hourly and Seasonal Load Shapes Forecasting variation in electric loads by hour and season is of the same order of importance as forecasting annual kilowatthour sales. Two recent projects are expected to contribute significantly to the state of knowledge in this area. One was a workshop conducted to investigate the best means of accounting for time-differentiated prices in forecasting hourly and standard load shapes and to discuss findings on the extent of time-of-day price elasticities (RP1050). The workshop was set up to coincide with the timing of EPRI's Electric Utility Rate Design Study, and the body of information coming out of that workshop will provide a needed contribution to the EURD study. The methods discussed should prove to be valuable to the industry as more time-differentiated rates come into effect. The findings, though tentative, should contribute to decision making and public discussion. Publication of the proceedings of the workshop is expected this summer.

Forecasting hourly and seasonal load shapes is also the subject of research on a regional load curve model (RP1008), which is under contract to Data Resources, Inc. The objective of this project is to develop a technique for forecasting regional hourly load shapes, taking into account the relative numbers of customers in each class, the weather, energy prices, and other variables. The principal output of this project will be a model whose forecasts can be used by EPRI's Planning Staff. However, the general findings and methods developed by this project should also be valuable to individual utilities and power pools in their own analytic work.

Utility-Level Forecasting Problems Two companion projects will increase the number of alternative methods available to utilities for forecasting and will assess both the quality of current data and the future data needs of electric utilities. A study on the feasibility of adapting state and national electricity consumption forecasting methods to the service area level (RP1477) is under contract to Booz, Allen & Hamilton, and an investigation of the determinants of electric energy use (RP1478) is under contract to Mathematical Sciences Northwest, Inc., with Puget Sound Power & Light Co. as cosponsor.

The many difficulties in determining which models may be adapted and how well they would perform for utilities are the topic of

RP1477. In this study, three utilities of different sizes and customer characteristics will test the models.

A critical but seldom investigated aspect of all model building—the quality of the data that are modeled—is the focus of RP1478. The study seeks to answer the questions of how good the data are that are being used, whether better data are available for the same purpose, what new data should be developed by electric utilities and government agencies, and other questions relating to the general topic.

An additional effort will be made to air the problems of data quality and the availability and success of alternative forecasting methods at the Second EPRI Symposium on Electric Utility Load Forecasting to be held in Denver, June 25–27. This symposium, open to all members of the electric utility industry, will focus on practical issues of forecasting from the perspective of the practitioners. Most of the papers, which will be presented by representatives of electric utility companies or their designees, will address practical approaches to such problems as forecasting hourly and seasonal load shapes and incorporating the impact of government conservation measures into energy consumption forecasts. In addition, discussion topics will cover forecasting from the regulators' viewpoint, recent developments in forecasting methods, and efforts to compare forecasting models.

Managing Load Research Data Many utility companies need improved methods for handling the vast amounts of data that result from load research activity and the data accompanying socioeconomic, weather, and other variables that are necessary for the analysis of loads by end use and by customer class. A recent impetus to this type of activity was provided by the Public Utility Regulatory Policies Act of 1978, which calls for increased activities by utilities in making available data relating to electric utility rate making and other activities. A recently approved project on a load data management and analysis system (RP1588) seeks to make available a computer software system that can store load research and related data and permit easy retrieval for data analysis. Prospective contractors are bidding on this project.

Forecasts of National Energy Consumption The staff of the Demand and Conservation Program uses models developed in its contracted research to provide forecasts of energy consumption by each form of energy and for each user class to the year 2000 and beyond. In preparation is a document on this year's forecasting effort (demand 79). This is the third such study that the program has prepared. The forecasts provide important input to EPRI's Planning Staff, and such models may be run at their request for different sets of assumptions at several times during the year. In addition, a technical report will be published on conditional forecasts for energy prices and government conservation measures, assuming high consumption, base consumption, and conservation. *Program Manager: Robert Crow*

Systems

Four major projects of the Systems Program are costs and benefits of over- versus undercapacity, model verification and assessment, peaking and cycling, and the Brookhaven model.

Costs and Benefits of Over- Versus Undercapacity A framework was developed for assessing the relative costs and benefits of alternative rates of increase in generating capacity under conditions of uncertain future demand (RP1107). Decision Focus, Inc., developed a model in conjunction with four participating utility systems: Long Island Lighting Co., Pacific Gas and Electric Co., Tennessee Valley Authority, and Wisconsin Electric Power Co. The results indicate that inclusion of the costs associated with unserved energy is important in determining the least-cost planning reserve margin (EA-927). Both very high and very low planning reserve margins are costly to consumers, but the cost of low planning reserve margins is greater. In general, uncertainty in the demand forecast justifies a higher planning reserve margin.

For some companies, moving toward a more economic generation mix justifies a higher planning reserve margin than is indicated by reliability considerations and demand uncertainty alone. Consequently, the second phase of the project will examine the impact of uncertainties in the technology-mix decision on the least-cost planning reserve margin. Participating in the technology-mix project (in addition to the four original utilities) will be Bonneville Power Administration, Houston Lighting & Power Co., Illinois Power Co., Northern States Power Co., New York Power Pool, Pacific Power & Light Co., Southern California Edison Co., and San Diego Gas & Electric Co.

Model Verification and Assessment The objective of the EPRI–MIT model verification and assessment laboratory is to assess energy policy analysis models that are of direct interest to EPRI and the electric utility industry (RP1015). In its first year of operation, the laboratory assessed the Baughman-Joskow regionalized electricity model, which had been used to study the industry's future by both utility and nonutility groups. In its second year, the laboratory is studying the ICF, Inc., coal and electric utilities model. This model has been used extensively by DOE and EPA in the recent debates about appropriate alternative new-source performance standards for coal-burning power plants. Methods and procedures are also to be developed for the efficient organization and conduct of policy model assessments. In addition to providing for independent validation of important energy policy models, such assessments are intended to serve and support the interests of EPRI and the electric utility industry in planning future model development activities and in conducting policy research and debate on important national and international energy issues.

Peaking and Cycling In the peaking and cycling project, a preliminary analysis was made of the expected economic viability in the 1990s of such daily energy storage technologies as advanced batteries and heat and cold storage devices (RP1108-1). An integrated model was built to investigate the impact of storage in the face of changing customer mix, use patterns, and load growth. The model employs end-use detail to build up projections of system load shapes, which are then modified to assess the effect of storage on generation costs. The peaking and cycling model has been used in other EPRI projects that investigate load-shape-related issues, and its computer code is being documented to make it accessible to users outside EPRI.

Brookhaven Model Brookhaven National Laboratory conducted a study on the adaptation of the reference energy system for developing an integrated dynamic model of energy supply, demand, and environmental analysis (RP442). Its first objective was to develop regional reference energy systems, which are essentially accounting frameworks and indicate flow of energy from source to end use for specified years. The second objective was to modify the existing preliminary version of the Dynamic Energy Systems Optimization Model (DESOM) to make it more useful to the electric utility industry. The regional reference energy systems data base and the modified version of DESOM were transferred to EPRI during this project. *Program Manager: Stephen Peck*

SUPPLY 79

All major energy forms will be desired in increasing amounts into the foreseeable future. The Supply Program's updated analysis indicates the likely supply expansion and the associated prices for various energy sources. As such, the analysis is a set of projections based on series of assumptions. Different assumptions would lead to different projections. Growth in electricity output, as well as in the fuels supporting it, is likely to continue to exceed that of other energy forms through 2030. In this analysis, it is foreseen that constant dollar prices of all energy forms will increase, with electricity prices rising less than oil and gas prices.

Supply 79, the synthesis of the research performed through early 1979 for the EPRI Supply Program, projects the availability and price of fuel to the electric utility industry and of all forms of energy to the economy for the next 50 years. The research is based on assumptions about the energy and environmental policies of governments at all levels—national, state, and local. This continues to be the most crucial element in forecasting supply. The costs and constraints imposed by government energy and environmental policy and the technologies that will be available for the rest of the century are secondary to policy and environmental assumptions.

Electric power

The ultimate role of electricity in the economy remains unclear. The question cannot be successfully analyzed until the role of energy in economic growth is settled, and progress on that score is slow. Nevertheless, it is useful to analyze the characteristics of electricity supply in relation to a base case and then to investigate the variation in these characteristics under different assumptions. This is done in the forthcoming report on supply 79. The base case assumes that the depressing effect of higher prices and conservation on electricity consumption is offset by higher prices of other fuels and the trend toward electrification so that the postwar relationship between electricity and economic activity continues.

Electricity supply in the year 2000 is projected at 5.25 trillion (10^{12}) kilowatthours in this base case. This is nearly two and a half times the 1978 output. The expansion of fuel supply and construction of new capacity to meet this level of output will not be easy, but it is judged to be well within the capability of U.S. industry. Capacity will be required for normal retirement of existing plants, conversion or retirement of other capacity because of government-mandated fuel switching, increased environmental control regulations for new plants, and for meeting additional loads. The construction task facing the industry between now and the end of the century is nearly equal to a tripling of present generation facilities. Additional transmission and distribution facilities will also be required.

Between 2000 and 2030, the growth of electric power will become asymptotic to the growth of economic activity. A requirement is projected for about 11 trillion (10^{12}) kilowatthours annually by 2030.

In the base case, average revenue requirements per kilowatthour (stated in constant 1978 dollars) will rise from 3.5¢ in 1977 to 4.7¢ by 2000. A further increase to 5¢ by 2030 is predicted. Wide variations will continue to exist between utilities, regions, and classes of suppliers.

Natural gas

After some years during which natural gas producers could not meet demand at the prices allowed under federal regulation, natural gas is now, at least temporarily, in oversupply. The Natural Gas Policy Act of 1978 provides the structure for establishing gas prices in the future. Unfortunately, the structure is very complex, makes little sense when viewed in terms of the economic theory of supply, and will involve endless litigation. It is assumed that by 1990 the average wellhead price of natural gas will approximate, if not exceed, the price of distillate fuel oil delivered to residential and commercial customers, less transportation and distribution costs. Fuel oil prices will, in turn, be based on world crude oil prices. Under decontrol the average wellhead price of natural gas (in 1978 dollars) is expected to rise from \$0.85/1000 ft^3 (2.41¢/m^3) in 1977 to \$3.38/1000 ft^3 (9.57¢/m^3) in 2000 and to \$4.57/1000 ft^3 (12.94¢/m^3) by 2030.

Production of natural gas, in this projection, will increase from 19.2 trillion (10^{12}) ft^3 in 1977 to 21.5 trillion ft^3 in the year 2000 and decline to 15.8 trillion ft^3 by 2030. Unconventional sources and high-Btu gas from coal will provide less than 10% of domestic production in the year 2000 but will account for two-thirds of production by 2030.

Imports of ~6 trillion ft^3 from Canada, Mexico, and overseas will supplement domestic production in the year 2000.

Oil imports

World oil supply and demand have been in balance for several years, although recently disturbed by the Iranian situation. The U.S. refiner acquisition cost (in 1978 dollars) of imported crude oil is expected to rise from \$14.50/bbl in 1978 to \$19.50/bbl by the year 2000 and to \$33.50/bbl by 2030. (Prices this year may be above trend because of the Iranian crisis.) At the anticipated prices, imports are likely to be available to meet U.S. needs. Balance-of-payment problems and concern about dependence on foreign oil are likely to be more of a constraint on imports than availability of foreign crude.

Domestic production of crude oil and natural gas liquids

The decline in domestic production of crude oil and natural gas liquids appears to have been arrested. If domestic crude oil prices are allowed to reach parity with world oil prices after 1985, petroleum liquids production should increase from an estimated 10.25 million bbl/d in 1978 to 10.9 million bbl/d in 1985 and swing upward to over 13.0 million bbl/d by the year 2000. The upswing will result from a slowing in the rate at which onshore production is decreasing, an increase in offshore output for the lower 48 states, an increase in the capacity of the Alaska pipeline to 2 million bbl/d, and swelling offshore production in Alaska.

The above figures for 2000 do not include an estimated 500,000 bbl/d of shale oil production and an estimated 200,000 bbl/d of synthetic liquids from coal. Also, these figures do not include coal converted to liquids solely for utility use. The average wellhead price for lower-48 crude oil is expected to increase from \$9.00/bbl in 1978 to \$18.50/bbl (under decontrol) in 2000 (in 1978 dollars).

Beyond the year 2000, production from all conventional sources, except enhanced oil recovery and offshore Alaska, is predicted to decline. Production from enhanced oil recovery and offshore Alaska will grow throughout the period 2000 to 2030. The wellhead price for lower-48 production will increase to \$33.50/bbl by 2030.

Although the amounts are quite uncertain, production of shale oil and syncrude from coal will continue to increase beyond 2000. It is assumed that shale oil production will reach 3 million bbl/d by 2030. No basic constraints on shale oil, other than economic constraints, are assumed. It is assumed that syncrude production from coal will amount to 2.5 million bbl/d by 2030, not including coal converted to liquids for utility use.

Nuclear power—uranium

If the normal economic forces are only

slightly retarded by political and social forces, installed capacity of nuclear power plants is projected to increase from 52 GW (e) at the end of 1978 to 100 GW (e) in 1985 and 256 GW (e) in the year 2000. Over twice as much nuclear capacity would be installed in the 2000–2030 period as projected for the 1970–2000 period. Installed capacity in 2030 is estimated at 800 GW (e). A substantial number of these plants may be breeder reactors. Uranium availability is not expected to be a constraint on this scale of nuclear power growth.

Prices for new purchases of uranium were below $45/lb ($100/kg) in 1978. These prices (in 1978 dollars) are expected to decrease to around $35/lb ($80/kg) in 1985. Then they are expected to increase gradually to the $45–$50/lb ($100–$120/kg) range by 2000.

Coal production

Coal production reached nearly 700 million t/yr in 1977. By 1985, production is projected to be around 1 billion (10^9) t/yr and to reach 1.9 billion t/yr in the year 2000, including coal for synfuel production. By 2030, coal production is expected to reach 2.5 billion t/yr.

Electric utility consumption of coal, around 475 million t/yr in 1978, is projected to exceed 800 million t/yr in 1985 and 1.5 billion t/yr in 2000. Between 2000 and 2010, utility coal consumption is expected to peak and then decrease to 1.3 billion t/yr by 2030.

Average prices for first-year deliveries to utilities under new contracts is anticipated to rise from an estimated $1.30 per million Btu in 1978, to $1.60 in 1985, to $1.80 in 2000, and to $2.10 in 2030. Average prices for all coal delivered to utilities will be less than first-year delivery costs, and there will be wide regional variations. *Program Manager: Milton Searl*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP109-7	Corrosion of Chromium-Coated Steel in Sodium Polysulfide Environments	2 years	281.2	Laboratoires de Marcoussis (France) *K. Kinsman*
RP725-12	Evaluation of the Apitron and Ducon Particulate Control Devices	16 months	147.3	Southern Research Institute *R. Carr*
RP779-25	Investigation of the Liquefaction of Partially Dried and Oxidized Coal	7 months	96.5	Gulf Research & Development Co. *L. Atherton*
RP842-5	Improved FCG-1 Cell Technology	9 months	998.0	United Technologies Corp. *E. Gillis*
RP922-5	Definition and Conceptual Design of a Small Fusion Reactor	13 months	96.4	Physics International *D. Paul*
RP982-16	Maintenance of Stack Gas Emission Control Coordination Center and Inquiry Service	1 year	30.0	Battelle, Columbus Laboratories *C. Dene*
RP986-5	Coal Devolatilization Data for Reactor Modeling	4 months	33.2	Massachusetts Institute of Technology *G. Quentin*
RP990-4	Combustion Turbine–Combined-Cycle R&D Project Priority Analysis	1 year	125.8	Encotech, Inc. *R. Schainker*
RP991-6	Penetration Analysis of Fossil Fuel and Advanced Power Generation Systems	5 months	41.6	Niagara Mohawk Power Corp. *O. Gildersleeve*
RP1041-6	Catalytic Hydrogenation of Coal-Derived Distillates	2 months	29.0	Conoco Coal Development Co. *W. Rovesti*
RP1085-3	Development of Composite Component, Molten Carbonate Fuel Cell Assembly	12 months	181.7	Energy Research Corp. *J. Appleby*
RP1179-7	Preliminary Assessment of Alternative Atmospheric Fluidized-Bed Combustion Power Plant Systems	7 months	92.5	Burns and Roe, Inc. *C. McGowin*
RP1195-5	Magma Electric, East Mesa 10-MW (e) Binary-Cycle Power Plant Performance Analysis	9 months	25.0	Colley Engineers & Constructors, Inc. *V. Roberts*
RP1198-9	Zinc-Chlorine Battery Electric Costs	13 months	163.9	Airco Speer, Inc. *J. Birk*
RP1260-9	Evaluation of Flood Levels for Solid-Waste Disposal Areas	7 months	51.8	Hydrocomp, Inc. *D. Golden*
RP1260-10	Engineering Evaluation of Magma Cooling-Tower Demonstration	11 months	49.6	CH2M-Hill *R. Jorden*
RP1266-13	Study of Universal Pressure Boiler System for Cycling Operation	9 months	55.9	Babcock & Wilcox Co. *J. Dimmer*
RP1275-3	Advanced Heat Recovery/Thermal Storage Systems for Industrial Applications	17 months	67.7	Charles A. Berg Associates *R. Mauro*
RP1319-1	Advanced Cooling Techniques: Full-Scale Engine Demonstration	4 months	178.9	General Electric Co. *A. Cohn*
RP1344-1	Protective Coatings for Utility Gas Turbines	2 years	492.5	United Technologies Corp. *J. Stringer*
RP1348-2	Biomass for Energy and Chemical Feedstocks: Agronomic Studies With Euphorbia Lathyrus	4 years	160.0	University of California at Davis *J. Cummings*
RP1402-3	Oil-Fired Combined-Cycle NO_x Emissions	1 month	8.1	KVB, Inc. *M. McElroy*
RP1403-1	Engineering Assessment of a Low-Heat-Rate, Pulverized-Coal Power Plant	15 months	638.1	Westinghouse Electric Corp. *D. Giovanni*
RP1405-1	Sludge Disposal Demonstration From 20-MW (e) Limestone Dual-Alkali Scrubber	32 months	572.3	Custion Equipment Associates, Inc. *D. Golden*
RP1410-4	Low-Pressure Impactors and Sampling Train	2 months	57.8	Meteorology Research, Inc. *R. Rhudy*
RP1413-1	Utility Requirements and Criteria for Fusion Options	2 years	353.2	Burns and Roe, Inc. *F. Ford*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1647-1	Field Evaluation of Scrubber-Generated Particulates	20 months	258.0	Meteorology Research, Inc. *R. Hooper*
RP1653-1	Entrainment in Wet Stack	14 months	138.5	Dynatech R/D Co. *R. Rhudy*
RP1676-1	Investigation of New Fuel Cell Electrolyte Concepts	11 months	40.0	ECO Incorporated *J. Appleby*

Nuclear Power Division

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP393-2	Analysis of Reinforced Concrete Under Highly Stressed Localized Impact Conditions	3 months	5.5	Science Applications, Inc. *G. Sliter*
RP620-30	Turbine Generator Steam Cycle Evaluation	2 months	25.0	Baltimore Gas and Electric Co. *G. Baston*
RP707-4	Determination of Neutron Multiplicities of Fissile Nuclei	6 months	35.0	DOE *O. Ozer*
RP825-3	Program Support on EPRI Radiation Assessment and Control Projects	10 months	20.0	Nuclear Water & Waste Technology, Inc. *R. Shaw*
RP963-3	Multidimensional Two-Phase Flow Simulation for Steam Generator Modeling	1 year	40.0	University of Pittsburgh *P. Bailey*
RP1021-3	Investigation of Steady-State Radiation Embrittlement of Reactor Vessels	25 months	948.9	Westinghouse Electric Corp. *T. Marston*
RP1021-4	Fracture Toughness Correlations and Reference Curves	12 months	39.1	Materials Research and Computer Simulation *T. Marston*
RP1227-4	Demonstration to Prove the Feasibility of Employing a Magnetic Field Velocity Measurement Technique to Measure Thin-Film Water Flow	3 months	20.4	Auburn International, Inc. *M. Merilo*
RP1253-3	Assessment of Proliferation-Resistant Technology	4 months	24.9	Advanced Technology Associates, Inc. *R. Williams*
RP1324-2	Study of the State of the Design for Pipe Whip	8 months	36.3	Tennessee Valley Authority *H. Tang*
RP1325-3	BWR Pipe Joint Reliability Modeling, Phase 0	4 months	34.7	Engineering Decision Analysis Co., Inc. *T. Oldberg*
RP1325-4	Corrosion Fatigue Characterization of Irradiated Reactor Pressure Vessel Steels	2 years	239.6	Westinghouse Electric Corp. *R. Jones*
RP1331-1	Stellite Replacement	29 months	497.0	General Electric Co. *R. Shaw*
RP1390-1	Containment Integrated Leak Rate Testing Improvements	14 months	185.2	Stone & Webster Engineering Corp. *T. Libs*
RP1390-2	Refueling Equipment Component Reliability Improvements	19 months	266.8	United States Crane Certification Bureau, Inc. *T Libs*
RP1394-1	Techniques to Mitigate BWR Pipe Cracking in Existing Plants	21 months	1474.7	General Electric Co. *M. Povich*
RP1394-4	Computational Analysis and Experimental Evaluation for Residual Stresses From Induction Heating	17 months	395.0	Battelle, Columbus Laboratories *M. Povich*
RP1398-2	Proposal of the Metal Properties Council on Stress Corrosion Characterization of Turbine Rotor Materials	25 months	241.3	Metal Properties Council, Inc. *M. Kolar*
RP1398-3	Stress and Corrosion Tests on Steel Alloys	3 months	6.9	Lockheed Missiles & Space Co., Inc. *M. Kolar*
RP1438-1	Review and Analysis of Critical-Flow Data	17 months	215.6	S. Levy, Inc. *K. Nilsson*
RP1439-1	RETRAN Analysis of a Large X-Trip Blowdown Experiment in a Steam Generator Heavy Water Reactor	1 year	89.0	United Kingdom Atomic Energy Authority *L. Agee*
RP1447-1	In-Plant System for Continuous Low-Level Ion Measurement in Steam-Producing Water	42 months	682.2	General Electric Co. *T. Passell*
RP1563-1	BWR Resin-Intrusion Survey	8 months	74.1	Radiological and Chemical Technology, Inc. *A. Miller*
RP1573-1	Nuclear Plant Response to Grid Electrical Disturbances	11 months	200.0	EDS Nuclear, Inc. *J. Kendall*
RP1583-1	Development of Multigroup Coarse-Mesh Methods for Reactor Analysis	1 year	94.2	University of Illinois at Urbana-Champaign *E. Fuller*

Electrical Systems Division

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP380-3	Bark Banding With Maintain Cf-125 to Inhibit Tree Growth—Field Trials	2 years	32.0	University of California at Riverside *R. Tackaberry*
RP1419-1	The Effect of Reduced Voltage on Operation and Efficiency of Electrical Loads and Systems	3 years	550.5	University of Texas *H. Songster*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1423-1	Explosion-Resistant Bushing for Gas-Insulated Equipment	20 months	134.9	Interpace Corp. Lapp Division *V. Tahiliani*
RP1425-1	HVDC System Control for Damping Subsynchronous Oscillations	25 months	323.4	General Electric Co. *S. Nilsson*
RP1467-1	HVDC Ground Electrodes	20 months	305.8	International Engineering Co., Inc. *J. Dunlap*
RP1526-1	Plan for Distribution System Simulator	16 months	135.3	McGraw-Edison Co. *H. Songster*
RP1535-1	Broadcast Radio System for Distribution Communications	1 year	250.0	Altran Co. *W. Blair*
RP7832-2	Determination of AC Conductor and Pipe Losses of Pipe-Type Cable Systems	22 months	171.1	Pirelli Cable Corp. *F. Garcia*
RP7832-3	Analytic Determination of AC–DC Resistance Ratio	1 year	54.6	Cable Technology Laboratories, Inc. *F. Garcia*
RP7840-2	Three-Conductor Gas Cable Field Demonstration	43 months	454.8	The Detroit Edison Co. *J. Shimshock*
RP7873-2	Thermomechanical Bending Effects on EHV Pipe Type Cables	47 months	1199.4	Empire State Electric Energy Research Corp. *S. Kozak*

Energy Analysis and Environment Division

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP434-33	Analysis of Block Rate Structures Based on Marginal Costs	5 months	11.9	National Economic Research Associates, Inc. *R. Malko*
RP804-2	Coal and Electric Utility Model Code Resources Data Base Modification	3 months	8.0	ICF Incorporated *T. Browne*
RP940-2	Relation of Air Pollution to Human Health in New York City	21 months	62.0	University of Pittsburgh *R. Wyzga*
RP940-3	Relation of Air Pollution to Human Health in New York City	22 months	23.8	Princeton University *R. Wyzga*
RP1015-4	MIT Assessment of the ICF Coal and Electric Utility Model	6 months	35.0	ICF Incorporated *R. Richels*
RP1060-2	Modifications for the EPRI Differential Absorption Lidar System	1 year	461.1	SRI International *G. Hilst*
RP1109-4	Lake Acidification Investigation	2 years	174.4	Brookhaven National Laboratory *R. Goldstein*
RP1217-2	Behavior of Natural Resource Prices	6 months	30.0	Resources for the Future, Inc. *A. Halter*
RP1219-1	Transportation Network Changes and Their Effect on Energy Supply	15 months	29.2	North Dakota State University *E. Altouney*
RP1224-6	Evaluation of Feasibility of Using Large-Scale Aquatic Microcosms to Address Major Ecological Problems of the Electric Power Industry	1 year	94.7	Lawler, Matusky & Skelly Engineers *R. Brocksen*
RP1302-1	Unconventional Solid Fuels for Electric Utilities	10 months	148.7	Gordian Associates Inc. *R. Urbanek*
RP1308-2	Development of an Airborne Lidar for Characterizing Particle Distribution in the Atmosphere	10 months	348.1	SRI International *R. Perhac*
RP1315-2	Bioassay of Air Emissions From Fossil-Fueled Power Plants	5 months	86.8	Global Geochemistry Corp. *A. Colucci*
RP1430-1	Integration and Application of EPRI Coal and Electric Utility Models	1 year	40.0	Synergic Resources Corp. *T. Browne*
RP1430-3	Integration and Application of the EPRI Coal and Electric Utility Supply Model	19 months	104.9	Gordian Associates Inc. *T. Browne*
RP1477-1	Feasibility of Adopting State and National Electricity Consumption Forecasting Methods to Service Area Level	3 months	299.9	Booz, Allen & Hamilton, Inc. *R. Crow*
RP1479-1	Geostatistical Estimation of Coal Seam Characteristics and Coal Reserves	18 months	95.0	Southern Illinois University *J. Platt*
RP1483	Incorporation of RAM, URSM, and UARG Model in Electric Supply System	18 months	62.9	Optimal Decisions *M. Searl*
RP1487-3	Toxicant Extraction Procedure and Utility Industry Solid Waste	7 months	49.0	Radian Corp. *R. Perhac*
RP1488-1	New Cooling Lakes, Assessment Methodology	27 months	449.1	Tetra Tech, Inc. *R. Reynolds*
RP1613-1	Transfer of Electricity Supply Model to Industry	15 months	200.0	Gordian Associates Inc. *R. Malko*
RP1616-1	Plume Model Validation, Management Contract	46 months	1426.2	The Research Corporation of New England *G. Hilst*
RP1635-1	Effects of Sulfur Dioxide on Grassland Ecosystems	2 years	176.3	Colorado State University *R. Goldstein*
RP1638-1	Potential Carcinogenicity of Fossil Fuels	37 months	547.8	University of Texas, Medical Branch *A. Colucci*

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 10090, Palo Alto, California 94303; (415) 961-9043. There is no charge for reports requested by EPRI member utilities, government agencies (federal, state, local), or foreign organizations with which EPRI has an agreement for exchange of information. Others pay a small charge. Research Reports Center will send a catalog and price list on request.

Standing orders for free copies of reports in EPRI program areas or Technical Summaries of reports for each EPRI technical division may be placed by EPRI member utilities, libraries of U.S. national, state, and local government agencies, and the official representative of any foreign organization with which EPRI has an information exchange agreement. For details, write to EPRI Communications, P.O. Box 10412, Palo Alto, California 94303.

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

ELECTRICAL SYSTEMS

Investigation of High-Voltage Particle-Initiated Breakdown in Gas-Insulated Systems

EL-1007 Final Report (RP7835)

This is a report of work conducted by Westinghouse Electric Corp. on particle-initiated breakdown in gas-insulated systems. The theoretical and experimental project was designed to gain a more thorough understanding of breakdown and the effects of particle parameters, field nonuniformity, gas composition, number and position of particles, time and level of voltage application, voltage wave form, and insulators. The most significant finding was that a minimum breakdown level does not occur when a particle is touching the electrode, but rather when it is a short distance from the electrode. *EPRI Project Manager: Ralph Samm*

ENERGY ANALYSIS AND ENVIRONMENT

Feasibility of an Epidemiological Study of Workers Occupationally Exposed to High-Voltage Electric Fields in the Electric Power Industry

EA-1020 Final Report (TPS76-639)

This feasibility study by Equitable Environmental Health, Inc., investigated the practicality of an epidemiological study on workers occupationally exposed to high-voltage electric fields. Identification of a target population to be studied, examination of the various epidemiologic methods that could be undertaken, and cost estimates were the objectives. As an initial step, a sample questionnaire was sent to several utility companies. Tentative recommendations on possible approaches, specific cost estimates, and time projections are stated. *EPRI Project Manager: Harry Kornberg*

How Electric Utilities Forecast: EPRI Symposium Proceedings

EA-1035-SR Special Report (WS-77-46)

The papers included in this volume were presented at the EPRI Symposium on Electric Utility Load Forecasting held in New Orleans in December 1977. The 20 presentations cover a wide range of forecasting approaches and philosophies currently being used by electric utilities. Topics for the sessions were Forecasting Residential Kilowatthour Consumption; Forecasting Peak Demand and Load Shape; Forecasting Commercial Kilowatthour Consumption; The Forecasting Problems of Small Utilities; Forecasting Industrial Kilowatthour Consumption; and Integrated Approaches to Forecasting. *Editor: Robert Crow*

FOSSIL FUEL AND ADVANCED SYSTEMS

A Feasibility Study for Enhancing the Development of Fusion Energy

ER-778-SR Special Report

This report investigates the feasibility of a comprehensive study of the issues involved in the development, demonstration, and commercialization of fusion power. Such a project's objective would be to enhance the prospects for useful applications of fusion energy by stimulating the search for ways to shorten the time, reduce the costs, and limit the risks associated with achieving significant use. The report includes an examination of the commercial development of selected large-scale technologies, the specification of methods for examining the compatibility of the fusion program with utilities' needs, and a plan for a detailed study of the safety and environmental issues of fusion power. *EPRI Project Manager: Noel Amherd*

Commercial Solar-Augmented Heat Pump System

ER-1004 Interim Report (RP925-1)

Southern California Edison Co. reports on the background and experience at midway point of an ongoing project to demonstrate the operation of a solar-augmented heat pump system. The purpose of this two-year effort is to monitor the performance and to evaluate the economic feasibility of combining a solar heat pump system with reject heat. A second objective is to operate the combined solar collector–water storage tank in a test-bed mode and to determine the amount of solar energy obtained and used under non-business-hour operations. *EPRI Project Manager: Gary Purcell*

Electrostatic Precipitator Plate Rapping and Reliability: Full-Scale Collector Plate-Rapping Tests

FP-1006 Final Report, Vol. 2 (RP532-2)

Cottrell Environmental Sciences, Inc., sought to obtain data in support of an analytic model development of precipitator collecting-surface responses to rapping. Full-scale and pilot-scale precipitator plates were rapped with blows of various types and magnitudes, and the resultant strains and accelerations were measured. Findings show that the dynamic response of the collecting surface is extremely complex. In the long term, this research could lead to an optimal design for collector plates used in electrostatic precipitators. *EPRI Project Manager: Owen Tassicker*

Compilation and Assessment of SRC Experience: Data Book

AF-1019 Final Report (RP987)

Prepared by Bechtel National, Inc., this report reviews and analyzes pertinent information on the production of solvent refined coal (SRC) and its use as a utility boiler fuel. Transportation, fuel handling, pulverization, and combustion and emission control requirements are evaluated on the basis of a full-scale SRC burn test at Georgia Power Co.'s Mitchell Station. Conceptual designs of potential plant revisions and their cost estimates provide a starting point from which site-specific revisions can be designed and estimated. *EPRI Project Manager: H. H. Gilman*

Tokamak Reactor Codes: MAK0 and MAK1

ER-1032 Final Report (RP546-1)

Science Applications, Inc., developed a series of computer codes that describe a one-dimension model of an experimental plasma within an operating fusion reactor. The codes listed solve time evolution of the density and energy conservation equations with alphas, neutrals, and two impurity species. These codes are applicable to a wide variety of physics and engineering studies of tokamak reactors. They can be used as a tool to predict, estimate, and develop fusion device responses during the R&D phase. *EPRI Project Manager: F. R. Scott*

Executive Summary: Workshop on Biomass Energy and Technology

AF-1036-SY Final Report (WS-78-89)

This summary, prepared by Science Applications, Inc., presents an overview of a biomass workshop jointly sponsored by EPRI and the Gas Research Institute. Held November 8–9, 1978, in Santa Clara, California, the workshop focused on acquainting electric and gas utilities with recent results of biomass production and use and assessed the utilities' level of interest in producing fuels and energy from biomass. *EPRI Project Manager: D. F. Spencer*

Conceptual Design of Thermal Energy Storage Systems for Near-Term Electric Utility Applications

EM-1037 Interim Report, Vols. 1 and 2 (RP1082-1)

The use of thermal energy storage (TES) with steam power plants has been widely proposed as a means of supplying the power to meet daily peak load demands on electric utility grids. General Electric Co.'s ongoing project is the first comprehensive engineering evaluation of TES for utility central station application. This interim report documents the methodology and results of the selection system used to identify the most promising TES concepts. After screening more than 40 concepts for possible use with representative coal-fired and nuclear power plant designs, the field was reduced to 12 selections. Cost and performance estimates, judgments of technical risk, near-term availability, and conservation potential resulted in the selection of 4 systems for further study. *EPRI Project Manager: William Stevens*

NUCLEAR POWER

Evaluation of Operation Techniques to Reduce Radiation Fields in LWRs During Maintenance

NP-332 Final Report (RP820-1)

Nuclear Services Corp. conducted a survey of operating nuclear stations to determine design features and operation techniques being used to reduce shutdown and primary system radiation fields. Seven boiling water reactors and seven pressurized water reactors were visited, and several more plants were contacted by questionnaire and by telephone. The report includes a preliminary comparative evaluation on the radiation effects of these design features and operation techniques. *EPRI Project Managers: R. A. Shaw and D. L. Uhl*

Survey of Corrosion Product Generation, Transport, and Deposition in LWRs

NP-522 Final Report (TPS76-663)

Corrosion products from reactor coolant pipes, tanks, and other surfaces in LWRs are the dominant source of radiation fields. Control over these radiation fields is intimately tied to the ability to control the generation, transport, and deposition of the corrosion products. This study by Battelle, Columbus Laboratories surveys the present knowledge and identifies necessary research efforts that would be particularly applicable to radiation control. *EPRI Project Manager: Robert Shaw*

Further Examination of the Pool-Type 1000-MW (e) LMFBR

NP-881-SY Interim Report, Vol. 1 (RP620-21 and RP620-22)

Atomic International Division of Rockwell International Corp., and Bechtel National, Inc., examined a 1000-MW (e) pool-type saturated-steam-cycle LMFBR to further verify the feasibility of the major technical features of the pool concept. Special emphasis was given to seismic requirements, safety criteria and methodology, site fabrication and construction requirements, and design refinements. This work continues to support the previous indication that the pool concept is feasible in the context of U.S. design, construction, and licensing practice. *EPRI Project Manager: Joseph Matte III*

Evaluation of a Unique Void Fraction Monitoring System

NP-1012 Final Report (RP1019-1)

Two-phase instrumentation is a key problem area in interpreting thermal-hydraulic experiments relating to nuclear safety. Auburn International, Inc., evaluated an instrument it has developed and patented that permits volume fraction measurement of the conductive component in a two-phase flow. It rigorously calibrated and evaluated the Auburn void fraction meter over a range of two-phase conditions and flow stream cross-section diameters. Results suggest that the Auburn meter is an effective instrument for void fraction measurement and should be considered for experimental applications. *EPRI Project Manager: David Cain*

Airborne Particulate Releases From LWRs

NP-1013 Final Report (RP274-16)

This report by Nuclear Environmental Services provides a summary of airborne particulates from LWRs. Average release rates for the particulates were computed for each area of the plant for different modes of plant operation. The study was conducted at six plants. Conclusions indicate that particulates, like radioiodine, are released from a few principal areas. These releases are correlated to reactor coolant concentrations and to power plant operations. *EPRI Project Manager: Henry Till*

Determination of Fit-Up Stresses in the Recirculation Bypass Line in the Brunswick-1 Reactor

NP-1021 Topical Report (RP700)

This project deals with one aspect of an overall effort to understand the role of stress in BWR pipe cracking. A principal element of the total stress state is that which results from piping fit-up during fabrication. The report describes the experimental strain gage activity and analytic stress modeling with which Failure Analysis Associates measured actual values of these stresses in a commercial plant. Results demonstrate that construction fit-up stresses are relatively small in recirculation bypass lines and have been adequately accounted for in current code piping analyses and piping design. *EPRI Project Manager: Floyd Gelhaus*

Requirements for Analysis of Transient Fuel Rod Behavior During Design Basis Events

NP-1022 Final Report (RP1117-1)

Combustion Engineering, Inc., identified and characterized potential licensing applications for a transient fuel rod behavior computer code. It established computer code requirements for four categories (regulatory, interface, code system/model, and operation) and assessed the applicability of these requirements by using them to evaluate a current state-of-the-art fuel rod behavior code (FRAP-T3). This study provides useful input to the development of an advanced transient fuel rod behavior computer code for nuclear steam supply system licensing analyses. It also defines the spectrum of design basis events and delineates the interface codes used in licensing applications. *EPRI Project Manager: Richard Oehlberg*

Fracture Properties of 1Cr-Mo-V Rotor Steels

NP-1023 Technical Report (RP700-1)

Failure Analysis Associates reports on thesis research done at the University of California at Los Angeles that is to some degree related to the reliability of steam turbines. The deformation, fracture, and fatigue properties of 1Cr-Mo-V turbine rotor steel were evaluated for a wide range of loading conditions and metallurgical structures controlled by melting and heat treatment practices. The mechanical property differences and corresponding metallurgical differences between older, air-melted steels and newer heats that are vacuum degassed were also determined. *EPRI Project Manager: Floyd Gelhaus*

RAP—A Simple Core Reflood Analysis Program

NP-1027-SR Special Report

The Reflood Analysis Program (RAP), a computer code developed by EPRI, describes the nuclear steam supply system response to the reflood portion of a hypothetical LOCA. The primary output from RAP (as a function of time) includes quench front velocity, reflood rate, quench front height, and core pressure. System performance parameters are required as input. The RAP governing equations are described, and the variables are defined. A computer code listing, a sample problem, and the results from the sample problem run are provided. A user's section explains the use of the RAP computer code and describes the required input. *EPRI Project Manager: Richard Oehlberg*

ELECTRIC POWER RESEARCH INSTITUTE
Post Office Box 10412, Palo Alto, California 94303

NONPROFIT ORGANIZATION
U.S. POSTAGE
PAID
PERMIT NUMBER 7577
SAN FRANCISCO, CALIFORNIA

EPRI

ADDRESS CORRECTION REQUESTED