The Power Corridor

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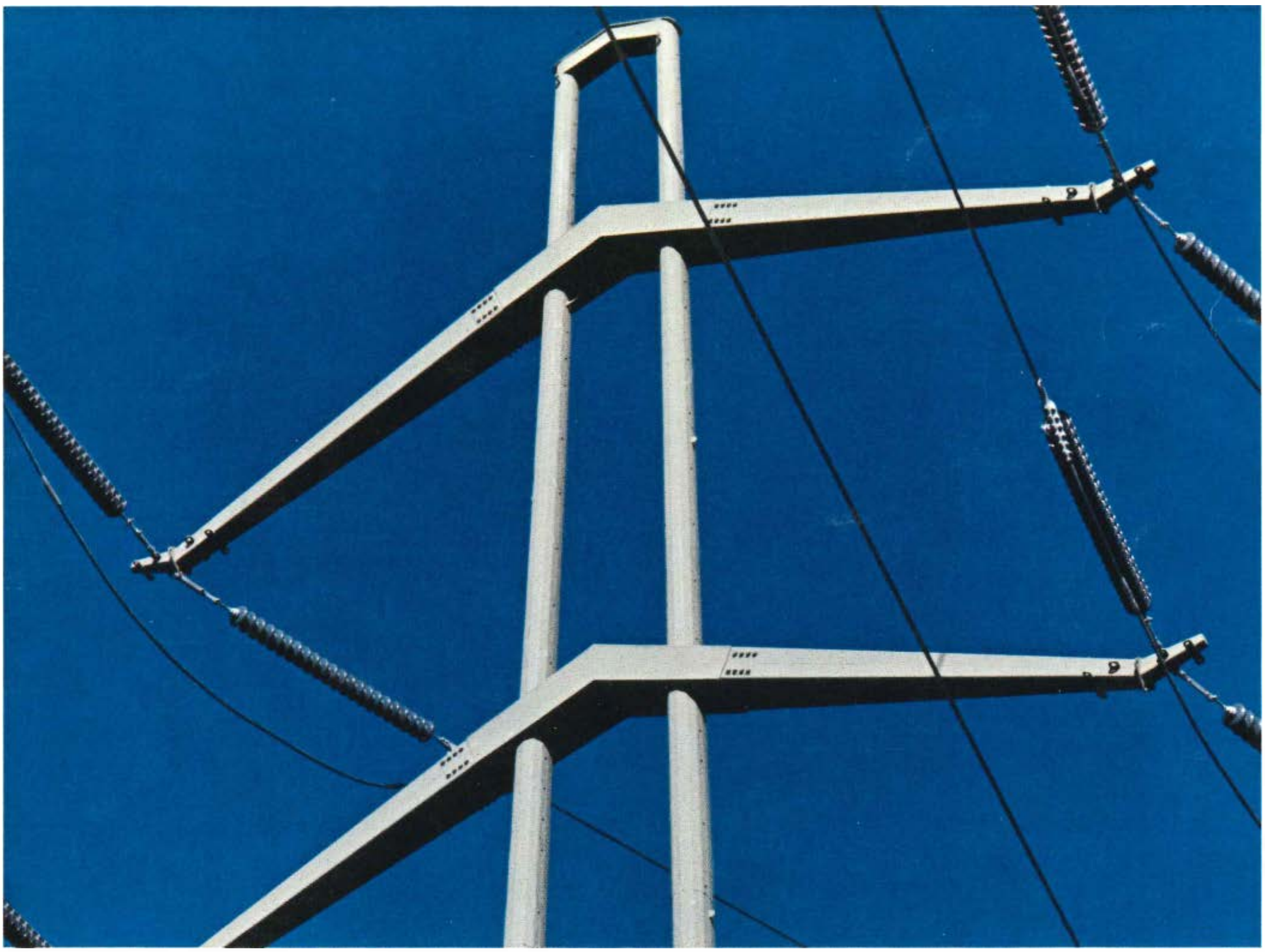

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Cover. A slender steel sculpture by Pacific Gas and Electric Co. brings grace to the transmission of 230-kv power across the California sky.

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The Indispensable Power Pipeline

The nation's attention is repeatedly drawn to the energy crisis; the debate over nuclear versus fossil fuel has intensified recently; and increased capital costs of various power generation options are making headlines in both financial and technical journals. In the background, almost unnoticed by much of the population, lie questions on how ever-larger quantities of electric power will be transported from generator to load.

Roughly 60% of this ''power pipeline'' consists of distribution systems, which have been quietly undergoing a metamorphosis of their own over the last decade. But that is another story, for another time. The remaining 40% of the pipeline is made up of transmission lines—mostly overhead—that crisscross the country. Once a symbol of progress, these overhead lines are now attacked by some critics as visual pollution, by others because of the land they require, and by still others as unwelcome neighbors. But make no mistake about it, there will be more and more overhead transmission lines in our future.

Research now underway will provide technically acceptable underground transmission methods, but their cost is likely to remain prohibitive for general use. The many possible problems associated with overhead lines must therefore be examined and solved if the increased electric loads of the future are to be economically served. EPRI's Overhead Lines Program is aimed directly at such solutions.

The feature article in this issue discusses the technical and economic aspects of overhead transmission. It thus puts into perspective the hard choices that must be made in designing and building more efficient pipelines for bulk electricity transmission.

John J. Dougherty, Director
Transmission and Distribution Division

Authors and Articles

Make it work. Make it work economically. Make it work economically and environmentally. Make it work economically, environmentally, and soon.

How the research setting has changed! The two feature articles in this EPRI JOURNAL are evidence. They deal with recognized areas of utility operations: high-voltage transmission of electricity and the boiler fuel, coal, that generates most of it. But in the face of growing power demands, changing patterns of fuel supply, and new dimensions of environmental need, the articles review evolutionary—if not revolutionary—shifts in practice that must be made if utility operations are to fulfill their function much beyond the next 10 years.

□ "Packing the Power Corridor" (page 6) is what Frank Young has been doing ever since he earned his BSEE from Stanford University in 1955. He went straight to Westinghouse Electric Corp., where—even while studying for his 1962 MS at the University of Pittsburgh—he did distribution studies, sampled transformer and transmission design, and in 1959 became a sponsor engineer among Westinghouse customers in New England.

Pooled utility operations were then new, and Young's work with CONVEX (Connecticut Valley Electric Exchange) was part of a pioneering effort in computer simulation of transmission requirements for system expansion. Scale economies of pooling also led Young into 500-kv design work for the Vepco and Southern California Edison systems.

Another HV frontier for Westinghouse was the Waltz Mill Underground Transmission Test Facility, which Young managed from 1966 to 1972. Here his responsibilities included design and operation of the 1100-kv substation and cable test program. Westinghouse later established a UHV technology center and Young became manager of the team focusing on design of a fog chamber for 1500-kv tower and insulator testing.

On loan to EPRI during 1974, Young was the first member of the Transmission and Distribution Division staff. Sensing that the next steps in HV transmission research were likely to be sponsored by EPRI, he joined the Institute in September 1975 as manager of the AC and DC Overhead Lines Program.

Young is a member of IEEE and CIGRE and is a representative to ANSI. His business and professional work has taken him abroad many times, most recently to Moscow in April of this year as a member of the U.S. delegation in the U.S./USSR technical exchange program on UHV transmission.

Young

□ There are probably no more than 200 men and women in the U.S. professional community devoted to conversion of high-sulfur coal and oil to clean boiler fuels. Three of them are Ronald Wolk, Norman Stewart, and Seymour Alpert, who share research roles at EPRI and the authorship of "Solvent Refining for Clean Coal Combustion" (page 12).

Ron Wolk and Sy Alpert met many years ago when both were with Hydrocarbon Research, Inc., in Trenton, New Jersey. Wolk was a 1958 chemical engineering graduate from Brooklyn Polytechnic Institute, and HRI was his first job. Working in various hydrogenation processes, he soon was responsible for pilot plant operations, and when Alpert left the firm, Wolk replaced him as manager of H-Oil development.

During 16 years with HRI, Wolk continued his education, earning an MS in chemical engineering from Brooklyn Polytechnic in 1962 and doing further course work both there and at Rutgers. His specialization in several areas, notably hydrodesulfurization catalysis, residual oil conversion and desulfurization, and coal liquefaction, led to 40 U.S. patents and, in 1973, a position as associate laboratory director for HRI.

Since March 1974 Wolk has headed EPRI's coal liquefaction research activity, and he is now manager of the Clean Solid and Liquid Fuels Program in


Wolk


Stewart


Alpert

the Advanced Fossil Power Systems Department.

□ Norman Stewart, EPRI's technical manager for the Wilsonville (Alabama) SRC project since March 1974, has specialized in pilot plants during most of his 24-year professional career. In his view, "The art of process research is doing things on the right scale—sometimes bench, sometimes pilot."

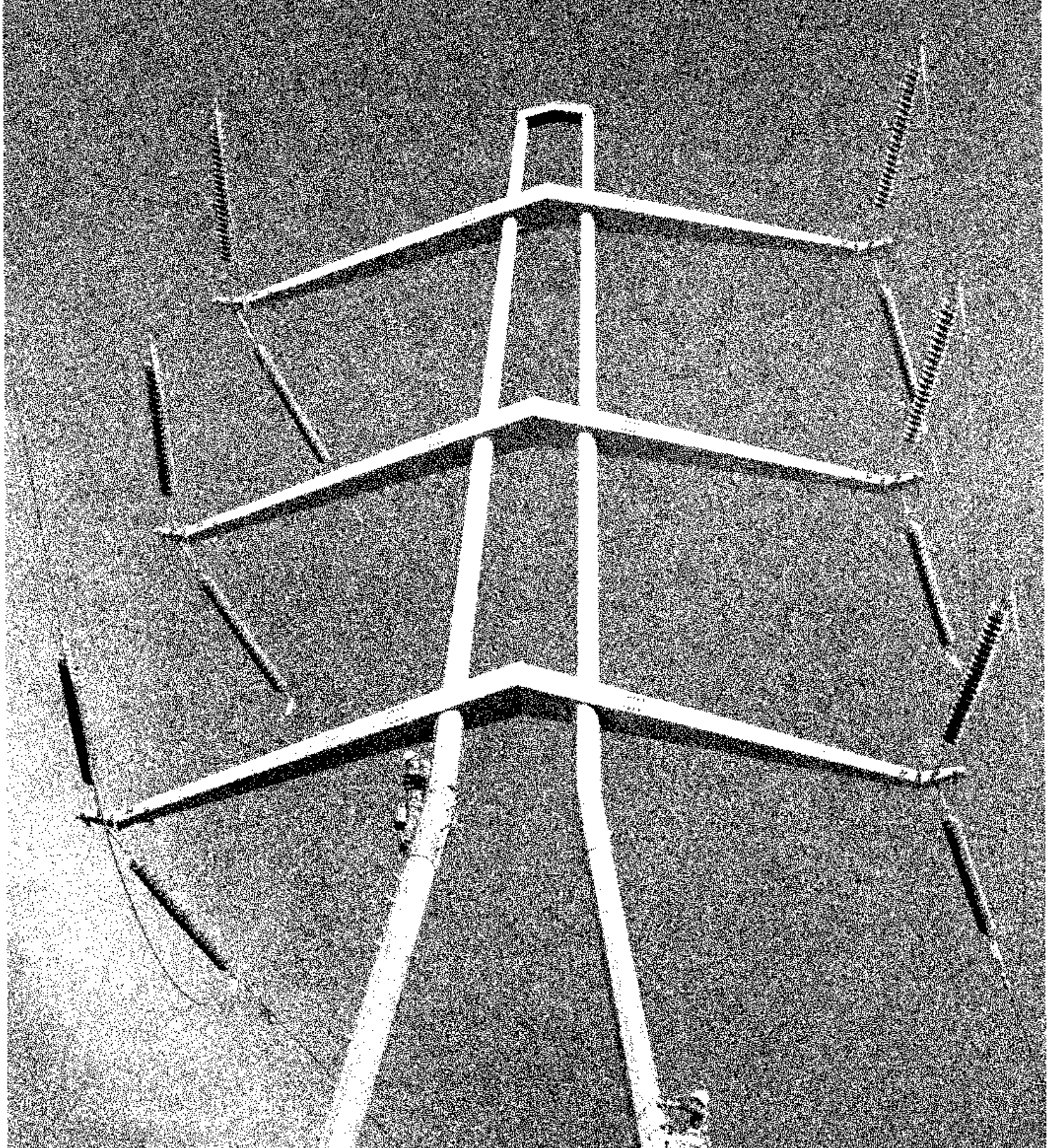
A 1952 graduate in chemical engineering from the University of Houston, Stewart worked for 10 years in several chemical production and rocket fuel development operations before joining Cities Service Oil Co. in 1962. His design studies and bench-scale research for petrochemical processes led to implementation of the HRI H-Oil process (where he met Wolk and Alpert). Stewart coordinated scale-up of an H-Oil residual hydrocracker from bench to semi-commercial scale, and he was a consultant on startup of a production unit in Kuwait.

Before coming to EPRI, he also supervised pilot plant research on several Cities Service chemical product developments and coordinated process engineering for feasibility and modification studies and plant startup activities.

□ Seymour Alpert, like Ron Wolk, began his chemical engineering career at HRI after graduating from Brooklyn Polytechnic Institute. He also continued his education, earning an MS in economics and business at Rutgers University in 1955. From 1952 to 1970, except for a brief time with Curtiss Wright Corp., he was an engineer in the HRI research laboratory, becoming manager of H-Oil development in 1965.

In 1970, Alpert moved into the consulting field, first with Chem Systems in New York, then (1971) with Stanford Research Institute in Menlo Park, California. Drawing on his experience in coal and oil process development, he engaged in numerous technical and economic evaluation studies of clean fuels, pollution controls, and solid waste conversion while continuing to exercise an inventive mind that has produced more than 40 patents (several of them with Ron Wolk, as well as with others).

Alpert shares with Wolk a sense of the urgent need for engineering demonstration of clean fuel processes. Feeling that the utility industry's technological focus in EPRI affords this opportunity, Alpert came to the Institute in September 1973 to provide staff guidance in fuel process technologies. He was recently named technical director for fuels in the Advanced Fossil Power Systems Department.



Packing the Power Corridor

by Frank S. Young

Once a symbol of progress, the high-voltage transmission line is heavily criticized today. But it is still a vital performer as we build new capacity at one end, add new loads at the other, and impose new environmental values along every mile of right-of-way. ◻ An EPRI state-of-the-art feature

Frank Young is manager of the AC and DC Overhead Lines Program for EPRI's Transmission and Distribution Division.

Energy resources draw the spotlight today. Because they are no longer seen as abundant for all time, research efforts are focused on extending usefulness. Exploration to establish new reserves is one direction. Technology development for more efficient resource conversion is another. In this context, the unique attributes of electricity ensure that its use will increase more rapidly than that of any other energy form.

But more electricity is not just a matter of better fuel-cycle efficiency or more generation capacity. It also means more transmission capability. Thus, as we provide more electricity, we must also answer the question, "How will it be delivered to the customer?" Without answers that work, that we can afford, and that we accept, our best efforts to develop and deploy new power plants are futile.

High volume, zero inventory

The convenience of electricity, as well as its efficiency, is responsible for the increasing electrification of our economy. Electricity powers diverse processes—for heat, for light, for motion, for chemical change. What's more, electrical equipment is small relative to its capability, free of operating complexity, reliable to a unique degree, and ready to be activated simply by closing a switch.

Electricity has only two serious drawbacks. It cannot—so far—be generated economically in small quantities or stored in large volume. Flashlights, portable shavers, hand-held calculators, and digital wristwatches only emphasize this limit. Bulk electricity can be neither stored in a reservoir or warehouse nor transported in a tank truck or hopper car. It must be used at the instant it is produced, and a metallic connection must exist all the way from generator to load.

In the abstract, this seems obvious or oversimplified. In the daily practice of utilities, it is fundamental. Wires must link every power plant to its loads, whether they are rolling mills in Pittsburgh or patio lamps in San Diego. This reality portrays overhead transmission, what it has made possible already, and what it will be called on to do in the future.

Defining transmission functions

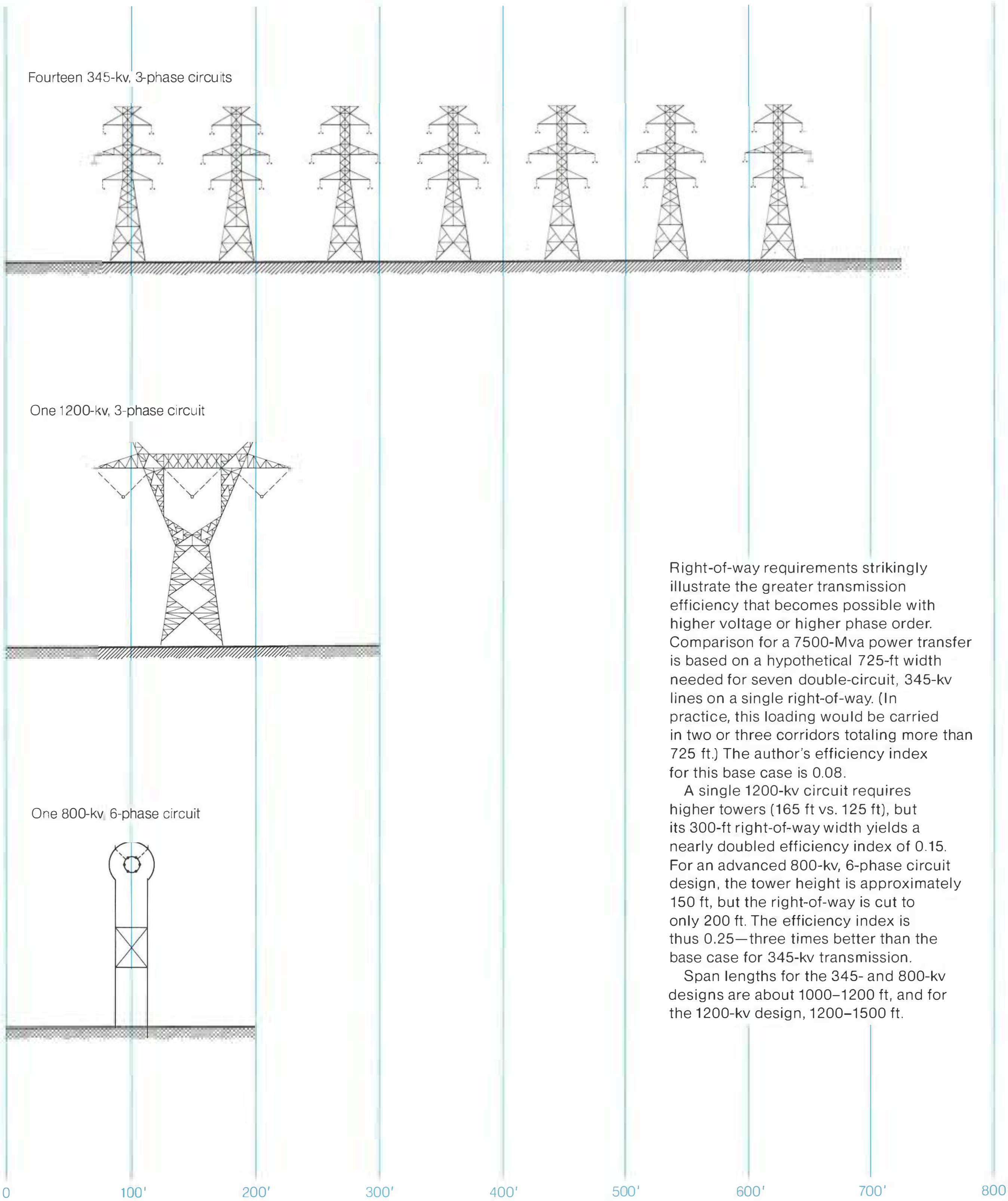
The first "long" high-voltage transmission line in the U.S. operated near Telluride, Colorado, carrying power at 40 kv a little more than two and a half miles up to the Gold King Mine, where a lack of timber precluded wood-firing a dc generator. The year was 1891. Today, a 276,000-circuit-mile network of transmission lines covers the country, ranging from 115 to 765 kv.

Transmission lines now serve three main functions. The most common is as a point-to-point connection between generator and distribution load center. The origin may be a mine-mouth coal-fired plant, a remote hydroelectric dam, or a geothermal complex.

Another important use of transmission lines is for generation reserve-sharing between large systems. Individual electric utilities realize generation savings by interconnecting their systems for pooled operation. This is why transmission line construction boomed and 345-kv and 500-kv lines were introduced throughout the U.S. in the mid-1960s.

The third main use for transmission lines is to gain cost economies through interchange of energy between systems. When one utility can generate a surplus of energy at a lower cost than its neighbor, the energy is sold and delivered across interconnecting transmission lines.

These three functions are characterized by one fact: all lines are long. Although the average U.S. transmission distance is frequently cited to be less than 50 miles, the optimal length of interconnecting high-voltage lines is 100 to 300 miles. Since underground transmission cables (the only alternative) are not yet able to match overhead



Right-of-way requirements strikingly illustrate the greater transmission efficiency that becomes possible with higher voltage or higher phase order. Comparison for a 7500-Mva power transfer is based on a hypothetical 725-ft width needed for seven double-circuit, 345-kv lines on a single right-of-way. (In practice, this loading would be carried in two or three corridors totaling more than 725 ft.) The author's efficiency index for this base case is 0.08.

A single 1200-kv circuit requires higher towers (165 ft vs. 125 ft), but its 300-ft right-of-way width yields a nearly doubled efficiency index of 0.15. For an advanced 800-kv, 6-phase circuit design, the tower height is approximately 150 ft, but the right-of-way is cut to only 200 ft. The efficiency index is thus 0.25—three times better than the base case for 345-kv transmission.

Span lengths for the 345- and 800-kv designs are about 1000–1200 ft, and for the 1200-kv design, 1200–1500 ft.

circuits at these distances, right-of-way availability and use become foremost considerations.

As population density increases, the availability of overhead transmission corridors decreases. Utilities must therefore strive to increase the power transfer capability of their present holdings. Future corridors must be able to carry higher power while satisfying both economic and environmental criteria.

Power transfer efficiency index

Because several factors enter into the optimal use of a right-of-way, a single solution is difficult to obtain. However, even a "back of the envelope" calculation takes into account the two most important considerations. First, the amount of power that can be carried by a transmission circuit is roughly proportional to the square of its voltage; the typical line loadings listed in Table 1 may therefore be expected. Second, right-of-way width is roughly proportional to voltage; approximate requirements for various voltage levels are also shown in the table.

But which of the transmission voltages or line loadings makes best use of its right-of-way, and what is the measure of relative efficiency? No precise calculation exists (although several have been attempted), but a simple index can be derived to serve as a useful guide:

$$\text{efficiency index} = \frac{\text{line loading}}{(\text{R/W } w)(\text{tower } h)}$$

With tower height included, the two-dimensional right-of-way becomes a three-dimensional power corridor. The designer's objective is to maximize line loading and minimize corridor cross-section. Table 2 presents index values for several single-circuit, horizontal configurations of transmission lines at representative voltages and typical tower heights.

Toward a higher index

Bold steps are needed to improve the use of overhead transmission rights-of-way. Yet, unless we develop materials not previously available or change the rules of transmission design, we do not foresee any sharp breakthrough. Within today's technology, there are four main ways to gain a higher right-of-way efficiency index:

- Employ double-circuit structures where reliability considerations permit
- Use the highest voltage consistent with line loading and system economics
- Develop compact designs
- Increase power transfer capability of lines

The line designer faces a certain dilemma, however, in implementing these choices: technical and economic constraints must be resolved; esthetic and environmental issues must be addressed.

The first and most obvious way to increase right-of-way utilization is to use double-circuit lines. Power is thus doubled, while the right-of-way requirements are altered only slightly. For example, a double-circuit, 500-kv line with a tower height approaching 190 ft would require only a 170-ft right-of-way. The index would thus increase from 0.05 to 0.074, a 48% improvement in efficiency.

The second way to better right-of-way efficiency is to use higher transmission voltage. Table 3 compares the number of circuits required for a 7500-Mva loading at various voltages. For example, one 1200-kv line uses about one-fifth the land area that would be needed for the equivalent fifteen 345-kv lines on a single right-of-way. Furthermore, index values show the 1200-kv line to be 2.6 times more efficient in right-of-way use.

Table 1
TRANSMISSION CORRIDOR PARAMETERS

Line Voltage (kv)	*Line Loading (Mva)*	*Right-of-Way Width (ft)*
345	500	150
500	1200	200
765	2500	250
1200	7500	300

Table 2
POWER TRANSFER EFFICIENCY

Line Voltage (kv)	*Tower Height (ft)*	*Efficiency Index*
345	90	0.037
500	120	0.050
765	135	0.074
1200	165	0.152

Table 3
7500-Mva POWER TRANSFER EFFICIENCY*

Line Voltage (kv)	*Number of Circuits*	*Right-of-Way Width† (ft)*	*Efficiency Index*
345	15	1425	0.058
500	7	935	0.067
765	3	650	0.085
1200	1	300	0.152

*Based on a 1200-kv single-circuit line.
†All circuits on one right-of-way.

The third way to increase corridor capacity is to reduce phase spacing. A major problem, however, is conductor motion. Two types must be considered. The first is wind-induced motion, called galloping in its most violent form. Although this has been much discussed and studied, it has so far defied practical solutions. Ice shedding by conductors, with its associate dancing motions, also limits compact line designs. Reductions in the clearances between lower voltage lines, where the span length is characteristically shorter, may offer improvements in right-of-way use.

The final technical approach to transmission corridor efficiency involves power transfer capability. This is a complex subject because it also involves system stability and reliability. Basically, for a line to carry more load, its impedance must be reduced. Bundled conductors, used primarily to reduce corona, have the secondary effect of increasing line loading. They are now commonly employed to increase power transfer at 138 kv and 230 kv, even though not required to control corona phenomena in these voltage ranges.

Series capacitors also permit increased transmission line loading. But despite their success on some long lines, they have not yet been widely applied for this purpose.

Dc transmission should also be mentioned. Judged purely on the basis of right-of-way use, dc is advantageous. In the case of 1400-Mw power transfer on a bipolar line, the apparent efficiency index is 0.08. Dc, however, cannot be evaluated solely on this basis. Despite its advantageous operating characteristics, costly terminal equipment makes it useful in only a few applications today (for example, long point-to-point lines, asynchronous ties between systems, and dc cable circuits).

Environmental issues

Three additional technical problems face the transmission line designer and limit his ability to pack the overhead power corridor: electric field effects, audible noise, and esthetic design.

The problem most loudly proclaimed today relates to the electric field established in the vicinity of a line. Two effects are commonly discussed—the shock a person may experience when he touches an object under the line and the biological effects that may be field induced.

The shock is comparable to what occurs when you walk across a rug on a dry winter day and touch a doorknob. In working near a high-voltage line, the discharge is also small, but your involuntary reaction is startling and can be hazardous, depending on your activity—for example, if you are on a ladder or carrying an awkward load. Accompanying the discharge is a flow of current through the body, which can be compared with the shock hazard defined in electric safety standards. Although this shock can be annoying, a large and comprehensive program of research is showing that its true danger is minimal.

The second concern about electric fields near overhead transmission lines is that they may induce biological effects in plants, animals, and people. Alleged illness of high-voltage substation workers in the USSR has particularly stirred worldwide concern. Although no similar problems have been reported in the U.S., comprehensive research is in progress, and the results will be useful in determining if there are design limits for overhead transmission lines.

Why have electric fields only recently been identified as an object of concern? One may surmise that progress in one area of technology has created problems in another. In particular, advances in the control of transient voltages have permitted proportionally smaller insulation clearances as line voltage has increased. For example, at 345 kv a 270% surge must be considered. But with surge suppression, insulation for a 500-kv system can be based on a 200% surge, and a 1200-kv system would use surge suppression to limit transients to the 150–170% range. The resultant reduced insulation clearances are also reflected in lower towers and line-to-ground clearances.

In building lines with shorter, more closely spaced towers to improve right-of-way use, we have encountered the perception threshold of these field effects at 765 kv. Utilities, researchers, regulatory commissions, and the public are concerned. Since we know that higher voltage enables a dramatic increase in right-of-way utilization, agreement on field effect standards is very important.

The second environmental problem is audible noise. Corona phenomena associated with high voltage have been the subject of research ever since the 40-kv circuit was built to the Gold King Mine. By selection of conductor size and phase spacing on the line, corona generation can be controlled. The critical parameter is voltage gradient at the conductor surface. As line voltage increases, a larger diameter is required to hold down the voltage gradient. At 500 kv, 2 or 3 conductors per phase have been used. For 765-kv circuits, a 4-conductor bundle is needed. Bundles of 8, 12, or 16 subconductors are being proposed for 1200-kv lines.

The engineering aspects of audible noise are understood, including its direct correlation with rain and fog. What is not clearly understood are its psychological effects: At what level do people become annoyed with the noise from a transmission line? Whatever the answer that may be established, it has direct implications for effective right-of-way use. Design tradeoffs can be made—number of conductors, phase spacing, and right-of-way width. Audible noise at the edge of the right-of-way will govern the final design.

The third environmental consideration of overhead transmission is the esthetic design of the lines. While this may not have a direct bearing on the right-of-way efficiency index, it will surely influence the cost of transmission.

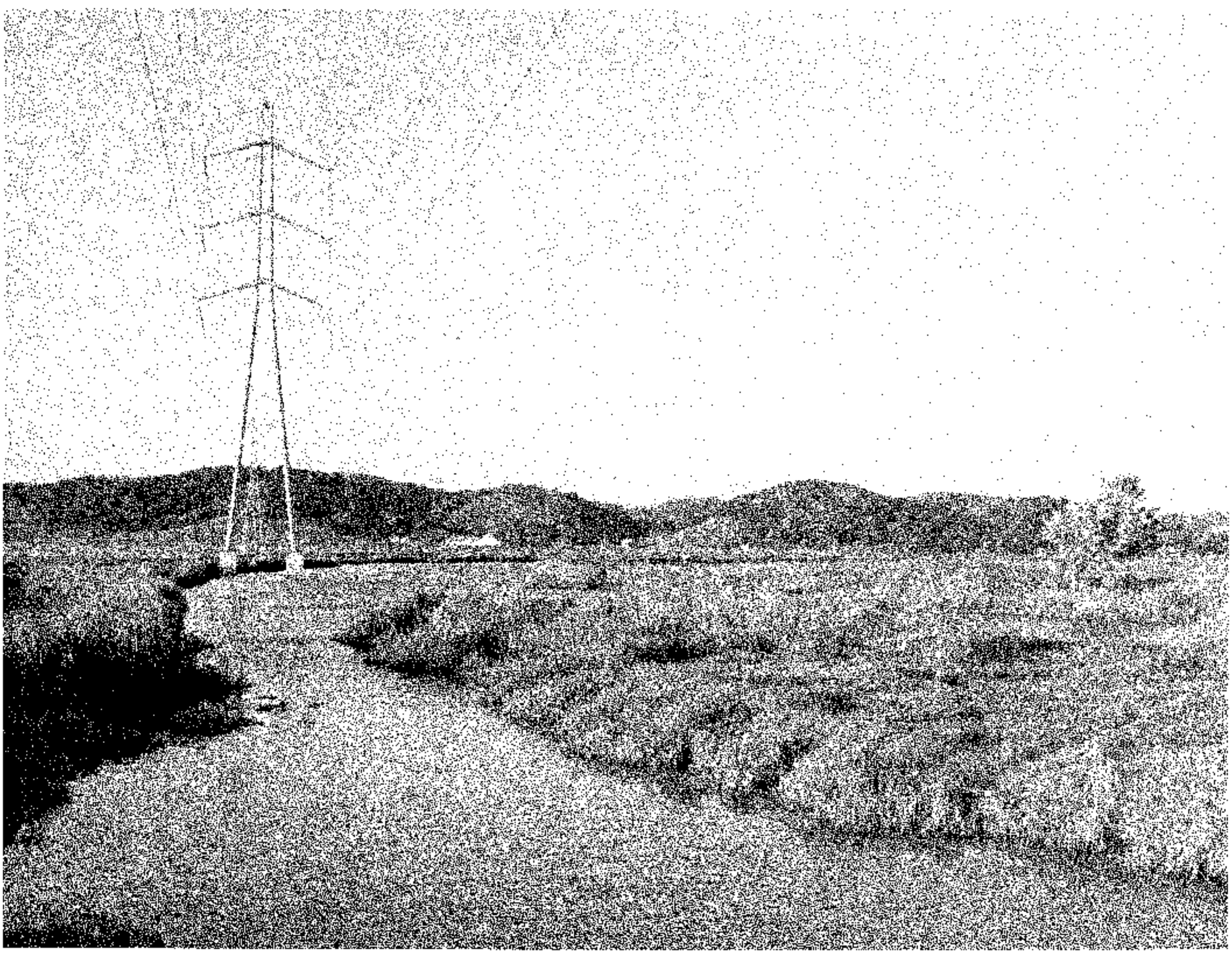
High phase order

The final concept for improving right-of-way use that should be mentioned is higher phase-order transmission. Briefly, by using transformer connections, a 3-phase input can be changed to a 6-, 12-, 24-, or 36-phase output. Insulation between phases is reduced. The critical gradient on conductors is reduced, and the net result is a very compact transmission line design. The concept unfortunately suffers from high terminal cost and complex substation design. Final judgment, however, should be reserved until more data are available. ERDA is conducting a feasibility study to determine the merits of such a system.

More load and longer lines

Overhead transmission has a place in the utility system. So long as we must use conductors and move large blocks of power over long distances, it will probably have no economic equal. Also, the use of still higher voltage as a means of improving right-of-way use should not be discounted. Recent studies show the cost per Mva-mile of transmission still decreasing as a function of voltage, at least up to the 1200-kv level.

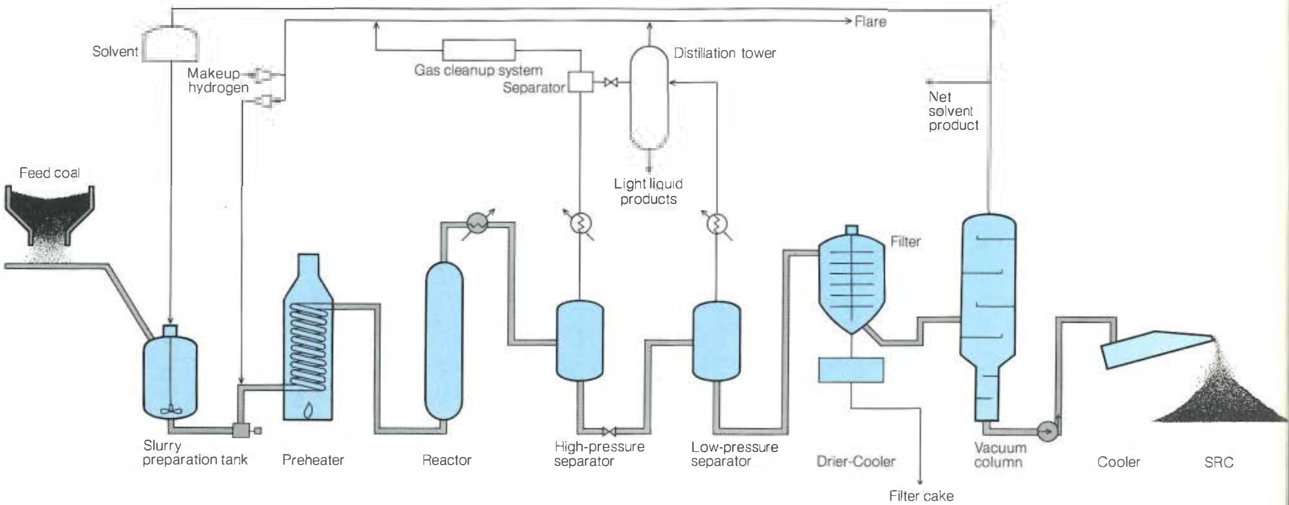
Nevertheless, among the energy issues today, environmental factors in overhead transmission is one focus. Field effects and esthetics are especially loudly debated. These cannot be dismissed lightly, but if economy is to be influential in how energy is transported from generator to user, overhead lines must continue to be built.



800-ft spans of 230-kv double-circuit transmission line trace their way across tidewater marshes and meadows north of San Francisco Bay. A 1969 design by Pacific Gas and Electric Co., the 125-ft tapered tower legs are hollow rolled and welded hexagonal steel sections. Crossarms reach 26 ft, tip to tip, with 15-ft vertical phase spacing. *Article photos courtesy PG&E.*

Solvent Refining for Clean Coal Combustion

by Ronald Wolk, Norman Stewart, and Seymour Alpert



As development continues on process equipment and controls, two pilot plants are successfully refining several U.S. coals to meet EPA sulfur specifications. Equally important is finding the best way for utilities to pulverize and burn SRC. ▫ An EPRI technical feature

Ronald Wolk is manager of the Clean Solid and Liquid Fuels Program in the Advanced Fossil Power Systems Department of EPRI's Fossil Fuel and Advanced Systems Division. Norman Stewart, a member of the program staff, is EPRI's manager for the Wilsonville project. Seymour Alpert is technical director for fuels in the Advanced Fossil Power Systems Department.

The authors acknowledge the contributions of Robert Carr to the SRC combustion test program.

The term *solvent-refined coal* (SRC) creates the appealing image of a major fuel resource that is free of pollutants, concentrated in form, and relatively constant in heat content.

In fact, SRC is not all that simple. The range of natural coals, their constituents, and their combustion properties differ markedly. In turn, the interrelationships among SRC process factors are complicated. As a result, the required plant must be defined by empirical results from bench-scale tests and pilot operations. This promises to be complex and costly.

Nevertheless, there is the promise of removing a troublesome fraction of sulfur and particulates from coal before they escape up the stack from a utility boiler—or are trapped in expensive scrubbers and precipitators (with consequent awkward disposal problems). The promise is intriguing; it justifies the research that first began in a small way 40 years ago.

Process history

Solvent refining removes sulfur and particulates from coal by the use of hydrogen in a reaction system at elevated temperature and pressure. In this process, a substantial portion of the coal is dissolved by an internally generated solvent. Particulates are removed by filtration or other methods. About 70% of the sulfur is converted to hydrogen sulfide and filterable iron sulfides. The end product, a liquid under reaction process conditions, is cooled to an essentially ash-free solid of reduced sulfur content that is useful as a fuel for power generation. A critical matter is the rate of solvent generation. It must be "balanced" to provide the solvent needed to slurry new coal entering the

Figure 1 In the SRC production process, feed coal is first slurried with recycled solvent, normally in the range of 2 parts (by weight) solvent to 1 part coal. The solvent is obtained by distillation and normally boils in the 350–800°F range.

Process slurry is normally maintained at about 100°F in feed mixing tanks. Reciprocating pumps raise it to reactor pressure, which can vary from about 1200 to 2500 psi. The selected value depends on feed coal properties (for example, sulfur content) and the need to achieve a 0.96% sulfur content in the SRC. Recycled hydrogen-rich gas, normally about 85% hydrogen, is then injected into the slurry.

The mixture passes through a preheater to raise its temperature to the 750–800°F range. This is where the liquefaction reaction begins, and its extent depends on the type of coal, the solvent properties, and the preheater exit temperature and pressure. The slurry then enters a vertical, unhindered cylindrical reactor (dissolver) for a residence time of 15–60 min. Reaction heat adds 20 to 80 degrees; normal reactor temperatures are thus in the 825–875°F range.

The flow from the reactor is cooled by heat exchange and passes into a separator maintained slightly below reactor pressure and at about 600°F. Gaseous products from this unit are further cooled to about 150°F to remove condensable material, then purified to remove sulfur as hydrogen sulfide. Most of the gas is recycled to the preheater inlet, where makeup hydrogen is added to replace the amounts chemically reacted and purged from the system.

Beyond the separator, the liquid stream is flashed to about 150 psi, creating two phases. The vapor stream is cooled and the resultant liquids are sent to the distillation train for recovery of lower boiling species. The liquid stream is filtered, producing a cake of ash and unconverted coal.

Two steps remain for the filtrate. First, it is vacuum-distilled to recover solvent. (Most of the solvent is recycled to the slurry tank, but any net surplus is removed as a product.) The residual heavy liquid is then cooled to form a solid SRC product. Several methods of solidification have been used to date: spraying onto a water-cooled belt, spraying onto a water-cooled vibrating tray, and spraying into a pool of water

process, despite the cracking of the solvent to lower boiling liquids and gaseous products.

The process technology for this reaction was first developed by Pott and Broche in Germany during the 1930s. They used coal-tar liquids or hydrogen-rich liquids (derived from other liquefaction plants) as once-through solvents and ceramic filters for solids separation. No gaseous hydrogen was used in the reactor; hydrogen to liquefy the coal was transferred from the solvent. Operating conditions for the liquefaction reactor were about 800°F and 1500–2200 psig. Conversion of coal to liquid form was about 80%. (Higher conversion in this early process was frustrated by the extensive formation of coke at greater temperatures and pressures.)

Development of solvent refining was continued in Germany by Uhde. Gaseous hydrogen was used, as well as solvent recovered from the process itself. Reaction temperatures were raised to about 840°F and hydrogen partial pressures to about 3500 psig at the reactor inlet. By these means, conversions of about 90% were obtained.

In the early 1960s Spencer Chemical Co., under the auspices of the federal Office of Coal Research, investigated this general approach for the liquefaction of U.S. coals. Reactor inlet hydrogen pressures as low as 1000 psig were used in tests on Kentucky, Pittsburgh, and Wilkeson bituminous, Wyoming subbituminous, and North Dakota lignite coals. Conversions exceeded 90% in many cases, but solvent sufficiency was not demonstrated for all coals at all combinations of operating conditions. The sulfur content of the heavy liquid fraction—which by then was called solvent-refined coal—generally correlated with the sulfur level of the feed coal. Its heating value normally exceeded 15,500 Btu/lb (versus 11,000–12,000 Btu/lb for natural coal). Work on Kentucky coal was carried out at a scale of 1 t/day. Solids were separated by rotary pressure precoat filtration, and the final product was formed on a water-cooled stainless steel belt.

Two large pilot plant operations mark current U.S. progress with SRC. One, at 6 t/day, began in 1973 at Wilsonville, Alabama, under the sponsorship of EPRI and Southern Services, Inc., and operated by Catalytic, Inc. The other, at 50 t/day, began in 1974 at Fort Lewis, near Tacoma, Washington, under ERDA sponsorship and operated by Pittsburg and Midway Coal Mining Co., a subsidiary of Gulf Oil Co. Both facilities employ filtration for solids removal: a batch precoat filter at Wilsonville and a rotary precoat filter at Tacoma.

The major processing steps and equipment used to produce SRC today are shown schematically in Figure 1. Tracing the process sequence provides a basis for noting variations in concept and practice.

Evaluation of U.S. coals

SRC evaluation at Tacoma has been limited to a Kentucky coal from Pittsburg and Midway's Colonial Mine. This coal is a mixture obtained from the No. 9 and No. 14 seams. Initial operations were devoted to a process-variable scan to generate information needed in establishing optimal coal-processing conditions. Now the plant is stockpiling 3000 tons of material that meets EPA sulfur and particulate specifications for solid fuel (about 0.96 w/o sulfur and 0.16 w/o mineral matter). This SRC will be tested during 1976 in a 22-Mw boiler at Plant Mitchell, a station of the Georgia Power Co.

Five major U.S. coals have been tested at Wilsonville: the Kentucky coal used at Tacoma, Pittsburgh No. 8 coal, two Illinois No. 6 coals, and Wyoming subbituminous coal. Bench-scale data have also been obtained for each of these coals (as well as for Kaiparowits and Black Mesa coals).

The conditions for satisfactory plant operation vary with the type of coal that is processed. The set of operating conditions used for each of the five major coals is presented in Table 1, along with the operating conditions required to meet EPA product specifications for sulfur and ash content.

SRC yields are a function of operating severity; that is, they decrease with increased time and temperature. At high severity levels, higher yields of light liquids, solvent, and light gases are obtained at the expense of SRC yield. In addition, the high oxygen content of subbituminous coal leads to lower SRC yields. SRC yields as high as 65% may be obtained on Kentucky coal. On the other hand, yields of about 55% are typical for Illinois No. 6 (Monterey Mine) and about 45% for Wyoming coal.

Table 1
WILSONVILLE SRC OPERATIONS

Coal Source					
State	*Kentucky*	*Pennsylvania*	*Illinois*	*Illinois*	*Wyoming*
Mine	*Colonial*	*Loveridge*	*Burning Star*	*Monterey*	*Belle Ayr*
Seam	*9 and 14*	*Pittsburgh 8*	*6*	*6*	*Roland Smith*
Feed Coal					
Sulfur content (%)	3.1	2.6	3.1	4.4	0.7
Process Parameters					
Temperature (°F)	800–850	855	820	855	855
Pressure (psig)	1500–2400	1700	1800	2400	2400
Feed rate (lb/hr/ft^3 reactor)	25–50	25	23	25	20
Coal Conversion (%)	91–95	91	90	95	85
SRC Output					
Yield (%)	55–65	69	63	54	47
Sulfur content (%)	0.8	0.9	0.9	0.95	0.1

Preliminary observations

Process difficulties have been encountered in some of the Wilsonville operations. The following examples illustrate special problems where solutions must be empirical.

First, fluidizable solids have accumulated in the reactor (dissolver) section for every coal processed. The rate of solids formation appears to be a function of the type of coal, but the equilibrium amount retained in the reactor is more likely a function of reactor hydrodynamics. Inventories of solids after long on-stream times range from about 20 to 50 lb/ft^3 reactor volume. When smooth process operations are upset for mechanical reasons, there is a preferential purging of these materials from the reactor. Difficulties are then encountered in the letdown valves and downstream process vessels. Several methods of coping with this problem are being investigated.

Second, Wyoming coal has been singularly difficult; it requires high hydrogen partial pressures and a high solvent-to-coal ratio to maintain satisfactory plant operation. A unique problem in the Wilsonville slurry feed system has arisen during experiments with this coal. Mixtures of coal and solvent seem to polymerize during the slurrying process, thus interfering with feed pump performance. This has not been experienced with bituminous coals.

Third, conversion levels correlate inversely with filter performance. For example, when reaction severity must be increased to achieve product sulfur specifications, conversion levels also rise, but filtration rates typically fall. Recovery of solvent from filter cake has proved very difficult at both Wilsonville and Tacoma; some recovery methods have encouraged coke formation. Also, heat exchangers used to cool reactor effluent have fouled under certain operating conditions with certain coals.

Ranking the coals processed to date places them in the following order, from least difficult to most difficult in operability: Kentucky No. 9 and No. 14, Pittsburgh No. 8, Illinois No. 6 (Burning Star Mine), Illinois No. 6 (Monterey Mine), and Wyoming coal. Bench-scale tests of these coals to determine yield structure and response to variables had earlier revealed similar difficulties of operability. Furthermore, the solids buildup noted in the Wilsonville reactor has also been found in the bench-scale work.

Process refinements

There are several ways by which overall process economics can be improved. Foremost among these are an understanding of reaction kinetics and how they relate to product yield distribution and desulfurization level. With some eastern bituminous coals, for example, the initial coal dissolution reaction seems to occur very rapidly, while with western subbituminous coal the reaction is slower. SRC yields as a function of reactor residence time are shown in Figure 2 for the Kentucky and Wyoming coals. Maximum SRC yield with Kentucky coal occurs very rapidly. But with increasing residence time, this SRC yield is lost to the production of gas and lighter liquids. It is therefore apparent that the relative proportions of preheater and reactor residence times must be optimized to achieve the most desirable economic combination for each coal.

Of even greater importance in scaling up the SRC process is the solids separation equipment required. Filtration enables the highest SRC recovery, but it requires the most complex equipment, as well as expensive quantities of filter precoat materials. Recent experiments and an economic analysis show that solvent precipitation (a simplified solids separation step) has the potential for reducing relatively high filtration costs. Specific liquids can cause the heaviest, least valuable part of the product to precipitate and entrap unconverted coal and ash. Clean overflow materials from a solvent precipitation settler have shown that the SRC product derived from that stream can have an ash content as low as 0.08 w/o.

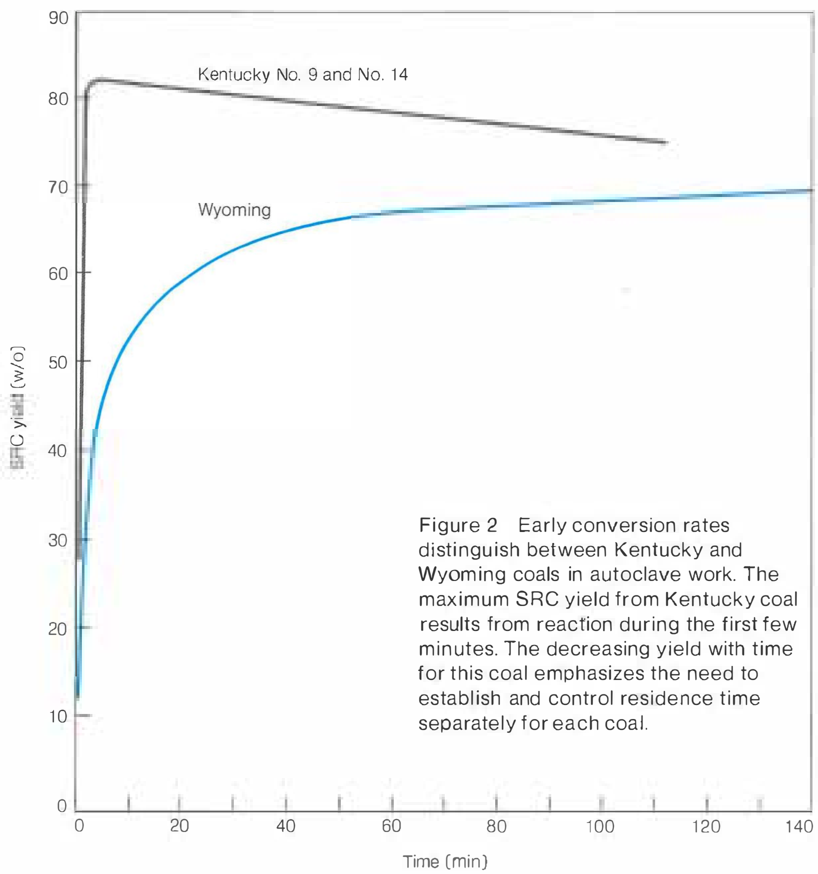


Figure 2 Early conversion rates distinguish between Kentucky and Wyoming coals in autoclave work. The maximum SRC yield from Kentucky coal results from reaction during the first few minutes. The decreasing yield with time for this coal emphasizes the need to establish and control residence time separately for each coal.

Several other approaches to solids separation use combinations of centrifuges and hydrocyclones to effect only partial separation of solids. With certain coals, this would be sufficient for the resulting SRC to be used as a feed to boilers that already have electrostatic precipitators. Since the cost of separation is substantial, these moderately low-ash products should be less costly.

Magnetic removal of iron sulfide compounds is another method that may be useful as a partial solids separation technique. The use of hydrocyclones, centrifuges, and magnetic separators is still at a more or less exploratory level, with little actual pilot-plant-scale experience. During 1976 and 1977 a new centrifuge installation will be operated at Wilsonville. Solvent precipitation may also be tested. Magnetic separation appears at this time to be somewhat further off.

SRC is normally a solid product at ambient temperatures, with a melting point in the 300–400°F range. By increasing the process severity and the amount of hydrogen consumed, it is possible to produce a liquid product analogous to heavy fuel oil. The major economic penalty is the cost of the additional hydrogen that must be introduced. However, the heavy liquid yield is not directly comparable; there is also an increased yield of light liquids.

Part of the "extra" hydrogen can be regained by using the light products as a source of hydrogen. Careful process economic studies are necessary to optimize yield structure, product quality, and hydrogen generation costs.

Product utilization

Extensive SRC pulverization and combustion tests have been performed. In general, SRC is easily pulverized and, under proper conditions, little energy is required to attain the particle size needed for pulverized-fuel boilers. However, pulverized SRC has the unusual property of tending to agglomerate.

Problems associated with this phenomenon can be avoided by proper design of transportation and combustion equipment. For example, both laboratory and larger-scale testing have demonstrated that only minor revision of existing ball-and-race and bowl-mill machines (lower spring pressure and mill speed) makes such equipment satisfactory for pulverizing SRC. Continuous tests with a Babcock & Wilcox E-21 ball-and-race pulverizer, direct-fired into a 50×10^6 Btu/hr Stirling boiler, indicate that SRC can be pulverized and burned satisfactorily.

In general, SRC seems to ignite like an oil, but it requires a longer burnout time—more like an anthracite. However, combustion of SRC in the Stirling boiler required injecting a greater amount of excess air to maintain a clear stack than when burning the parent pulverized coal. This problem may have been peculiar to the boiler in which the test was run, or it may have been caused by the burner used (Figure 3). There is speculation that the burner design did not provide for proper air-fuel mixing and that increased amounts of excess air were therefore required to achieve complete combustion. (Part of this air came from infiltration through the furnace brick setting.) Also, the mixing and residence time behavior of the Stirling boiler are not typical of utility applications. Additional tests are planned with improved combustion equipment.

Boiler heat transfer rate is another important consideration in the current SRC assessment. A long-term, small-scale SRC combustion test carried out for EPRI by Combustion Engineering, Inc., attained an average heat transfer rate much higher than that attained when firing coal. SRC combustion does not produce a slag layer on furnace surfaces because of its low ash content. In natural coal combustion the heat transfer rate varies due to the formation and breaking off of slag layers. In a properly designed boiler SRC may therefore prove to be a superior fuel because ash removal requirements are eliminated and heat transfer rates can be maintained at a high level.

Related savings, such as elimination of electrostatic precipitators, soot blowers, and ash slurry ponds, may also help make SRC an economically as well as technically attractive fuel for electricity generation.

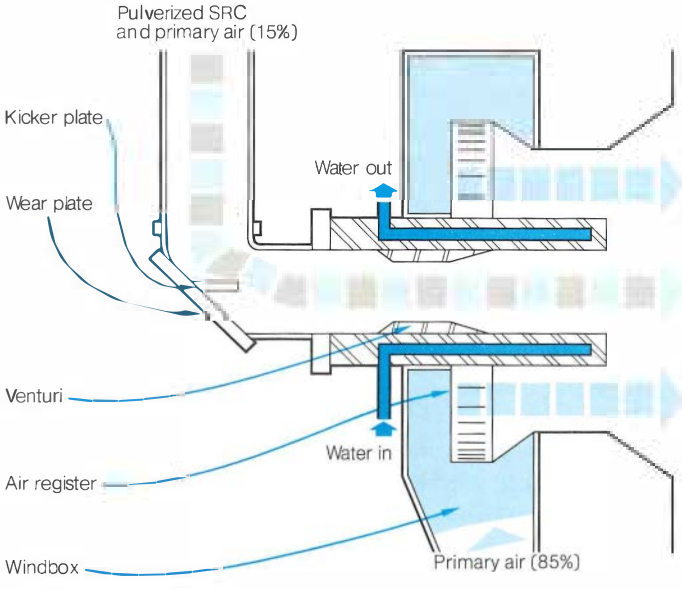


Figure 3 Initial SRC burner design is water-jacketed to keep pulverized SRC at about 150°F despite a windbox temperature range of 500–600°F. This avoids the possibility that SRC particles could soften and stick together, resulting in deposits on the burner wall and poor combustion. Also, since a conventional nozzle impeller might be fouled by SRC, a venturi is used to control fuel flow and stabilize the burner flame. The kicker plate was added to improve distribution of SRC and primary air at the burner.

The normal nitrogen content of SRC is about 1.5–1.8 w/o, compared with 1.0–1.2 w/o in natural coal, because the SRC process does not remove this constituent. Pilot plant data are not yet of sufficient quality to permit prediction of NO_x emission levels that would result from firing utility boilers with SRC. More thorough combustion testing, in particular at higher, more representative furnace temperatures, is required.

New objectives

SRC is of particular interest to electric utilities as a way to extend coal-fired plant life, even while meeting newly lowered limits for sulfur emissions. As an example, the Southern Company—instrumental in the pilot plant work at Wilsonville—burned over 26 million tons of coal in 1974 and forecasts consumption of more than 43 million tons annually by 1980. On a national basis, coal is the fuel for about 50% of electricity generation.

The SRC process promises to yield a cheaper fuel than other, more complex schemes for coal liquefaction. Also, the use of SRC preserves—with only minor changes—utility practices for the transportation, storage, and pulverization of solid fuel.

The prospect, therefore, is that coal-fired plants facing environmental restrictions can be maintained as baseload units by a modest burner conversion to SRC. It is also quite plausible that successful completion and scaling up of the SRC process will lead to new coal-fired generating plants specifically designed to burn SRC.

Based on experience at both the Wilsonville and the Tacoma pilot plants, the SRC process is ready for firm design and cost evaluation. A conceptual study by Ralph M. Parsons, Inc., is underway now, with EPRI sponsorship. But beyond this preliminary effort, if the business climate permits, solvent refining should be undertaken at full commercial scale, say 2000 t/day, to produce and burn clean solid fuel on an electric utility system.

Alternatives to Oil and Gas

In light of the rapid depletion of domestic oil and gas and the uncertainty of imported oil supplies, it is crucial that the United States evaluate alternative energy sources. A recent EPRI study (SR-34), *Nuclear Power, Coal, and Energy Conservation*, analyzes the likely alternatives. A summary of the study is presented here.

Copies of the special report, *Nuclear Power, Coal, and Energy Conservation* (SR-34), are available on written request from EPRI Records and Reports Center, P.O. Box 10412, Palo Alto, CA 94303.

Coal and nuclear power are the most realistic and economic alternatives to rapidly diminishing oil and gas and uncertain supplies of imported oil as energy sources for the United States.

These conclusions are based on an economic model designed to explore options that would enable the U.S. to switch from its heavy dependence on oil and gas to a more diversified energy economy over the next 20 to 40 years.

Peter L. Auer of Cornell University, Alan S. Manne of Harvard University, and Oliver S. Yu of EPRI, who conducted the study, considered four options:

- Adopting stricter, more effective energy conservation practices
- Stimulating increased production of domestic oil and gas
- Shifting a larger portion of energy demand to the more abundant coal and nuclear supplies
- Exploiting underused resources such as geothermal power and waste heat and such inexhaustible energy sources as solar radiation and nuclear fusion

None of these options, however, is free from objections. Energy conservation and cutting of waste in energy use, for instance, are attractive in principle, but many of the applications abound in social, technical, economic, and legal obstacles. Also, the hope that solar- or fusion-produced electricity will be free of many of the objections to coal-fired plants or nuclear reactors must await the outcome of developments that can ensure the economy and acceptability of those advanced concepts.

A diversified program in energy research and development in the U.S. is called for. But it is necessary that the country concentrate its investment in nuclear fission and coal to produce electric energy and synthetic fuel in substitution for oil and gas, while also curtailing growth of demand for energy, and particularly the demand for oil and gas, through energy conservation.

Time and the options

Time is crucial in evaluating the options. The fast breeder reactor (FBR) is needed as insurance against high-cost uranium and coal during a period of transition away from an energy economy based on oil and gas toward one with a potentially infinite resource base, such as solar, fusion, or advanced FBR.

The U.S. also needs to develop a synthetic fuels industry beginning in the 1990s. Initially, coal-based fuels such as methane and methanol would be developed, then hydrogen derived from nuclear fission, and eventually perhaps hydrogen from fusion and/or solar energy.

A 75-year time span was adopted to cover the depletion of our supplies of oil, gas, and rich grades of uranium ore. The principal assumptions of the model involve costs, resource bases, discount rates, demand, and technological options.

Costs are expressed in terms of "real" 1975 dollars. Capital charges are based on a service life of 30 years.

The ultimately producible resource base of petroleum and natural gas from conventional sources in the U.S. is assumed to be equal to a 40-year supply at *current* consumption rates. A more optimistic case of a 65-year supply is also considered. Petroleum and natural gas costs are assumed to remain at 1975 imported oil costs of $2 per million Btu. The size of domestic coal reserves does not appear to merit serious concern. However, the rate at which coal is used will be a significant factor. Both likely and pessimistic uranium supply projections, based on ERDA estimates, have been used.

The discount rate used to estimate benefits accrued over long periods of time must be given careful consideration. The value of today's dollar when received 25 years hence would be only 9¢ if a 10% discount rate is used. For this reason, a range of alternative discount rates—5%, 7½%, and 10%—are used to study the sensitivity of this significant factor.

Demand projections are derived from a model that incorporates the price effects of energy supply. A higher price of one energy source would induce conservation of that source and prompt its substitution by another.

The technological options considered include petroleum and natural gas supplies from conventional sources, as well as from oil shale, synthetic fuels, coal, and electrolytically produced hydrogen. Hydroelectric and geothermal power generation, accounting for about 16% of the country's current generating capacity, is assumed to grow at an annual rate of 2%. Advanced technology (solar or fusion) is assumed to lag behind FBRs by 20 years.

It should be emphasized that the model used in this analysis is *not* a forecasting model, but rather a planning model by which the consequences of alternative future energy-economic scenarios can be examined. For example, despite the fact that recent domestic political developments have not brought the U.S. close to the goals of energy independence, it is a fundamental assumption of the model that the nation will strive toward these goals by limiting its future energy imports to a certain level.

It also should be pointed out that the study is particularly interested in assessing the economic viability of two major near-term energy technologies: coal-based synthetic fuels and the fast breeder reactor. For this reason, the developments of many other technological options, such as oil shale and the high-temperature gas-cooled reactor, are deliberately assumed to occur at their potential upper limits rather than at more achievable lower levels.

It is estimated that the combined benefits to the national economy from both the FBR and coal-based synthetic fuels would be about $450 billion (in 1975 dollars at a 5% annual discount rate) over the period between 1975 and 2045.

Projected effects of a nuclear moratorium on coal consumption and the cost of electricity by the year 2000. Six times as much coal would be needed to produce the required electricity and synthetic fuels, and electricity would cost $14 more per 1000 kilowatt hours.

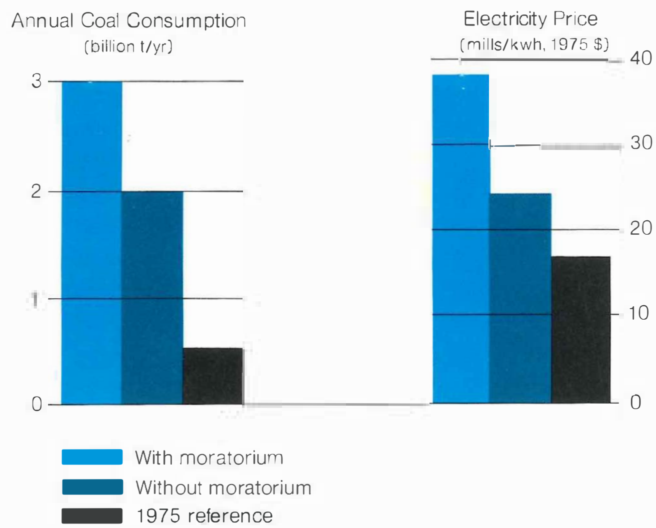


Table 1

BENEFITS OF NEW TECHNOLOGIES

($ billion)[a]

	Constant Coal Costs ($1/million Btu)		*Rising Coal Costs*[b]			
Total amount of domestic oil and gas available	2Q[c]		2Q[c]		3Q[d]	
Annual discount rate	10%	5%	10%	5%	10%	5%
FBR benefits	4	123	26	435	15	270
SYNF benefits	103	176	8	0	3	0
FBR + SYNF (combined) benefits[e]	127	587	47	449	22	277

[a]Present values of the differences in economywide energy costs, with and without the specified technology, excluding R&D costs, discounted to 1975.

[b]Base-case assumption: Coal costs remain constant at $1/million Btu up to an annual consumption rate of 25 quads (twice the 1970 level); thereafter, they rise linearly to $2 at 50 quads, $3 at 75 quads, and so on.

[c]Q = 10^{18} Btu. 2Q is equivalent to 45 years of supply at 1970 rate of production.

[d]3Q is equivalent to 68 years of supply at 1970 rate of production.

[e]There is a synergistic effect between technologies—the combined benefits are greater than the sum of individual benefits.

The study does not argue that a firm commitment is justified at this time to an all-electric or an all-hydrogen economy. Rather, it underscores the fact that in the foreseeable future a much greater reliance on both coal and nuclear energy will be needed to sustain the general economy.

Cost of a nuclear moratorium

The model used in this cost-benefit analysis is also applied in assessing the economic consequences of a nationwide nuclear moratorium.

To offset a nuclear moratorium, it would be unrealistic to rely on advanced technologies such as solar energy or nuclear fusion until the twenty-first century. Nor would it be politically prudent to depend on increases in imported oil and gas. This leaves us with just two alternatives to nuclear energy for the next 20 to 40 years: (1) heavy reliance on coal for the production of both electricity and synthetic fuels; and (2) conservation, induced by sharp rises in energy prices. Both routes are expensive.

In the event of a nuclear moratorium, coal consumption would have to rise sixfold between now and the year 2000. It is highly doubtful that this could be accomplished in an environmentally and economically sound manner.

Conservation could reduce energy demands, but at a cost. With nuclear energy available, electricity in the year 2000 would cost $24 per 1000 kilowatt hours and demand would be at 6.6 trillion kilowatt hours. With a moratorium, the cost of electricity would rise to $38 per 1000 kilowatt hours. This price would induce conservation, reducing demand by 19%.

The extra costs of a coal-based, conservation-oriented economy resulting from a nuclear moratorium are estimated at more than $80 billion annually (in 1975 dollars) by the year 2000. Nearly half of these costs would be reflected in each month's residential electricity bills. The rest would be paid in the form of higher prices for all goods and services that consume electricity.

Authors of report

Peter L. Auer is director of the Laboratory of Plasma Studies and codirector of the Energy Project at Cornell University (a project funded by the National Science Foundation). He is a consultant to EPRI and a former consultant to the chairman of the U.S. Atomic Energy Commission on energy research and development planning and to the Federal Energy Office.

Auer headed the Plasma Physics Department at Sperry Rand Research Center in Sudbury, Massachusetts, in the early 1960s after eight years as a physicist with the General Electric Research Laboratory in Schenectady, New York, conducting research in plasma physics and gaseous electronics.

Following receipt of his PhD in chemistry and physics from the California Institute of Technology in 1950, Auer engaged in chemical research in nuclear fuel processing and reactor design in connection with a materials testing accelerator project for the California Research and Development Co. in Livermore, California.

Auer has written numerous technical articles and is regional editor of *Plasma Physics.* He is a Fellow of the American Physical Society and a senior member of the IEEE.

Alan S. Manne is professor of political economy at the John F. Kennedy School of Government, Harvard University. He was a professor of economics and operations research for more than a decade before moving to Harvard in 1974.

Manne is a consultant to the National Science Foundation and the World Bank, as well as to EPRI. He has served as an economist with the International Institute for Applied Systems Analysis in Laxenburg, Austria, as an economic adviser with the U.S. Agency for International Development in New Delhi, India, and as a research associate with the MIT Center for International Studies in New Delhi. Manne was an economic analyst with the Rand Corp. in the early 1950s and later a member of the economics faculty at Yale University. He earned his BA, MA, and PhD (1950) in economics from Harvard.

Manne is the author of *Economic Analysis for Business Decisions* and *Studies in Process Analysis,* among other works. He is a Fellow and Council Member of the Econometric Society, has received the Lanchester Prize of the Operations Research Society of America, and is editor of the *Journal of Development Economics.*

Oliver S. Yu is a project manager in the technical assessment group of the Planning Staff at EPRI, having joined EPRI in 1974 as a project manager in the Energy Systems Modeling Program. Yu is a council member of the Energy Systems Group of the Operations Research Society of America, has served as a panelist and panel chairman in discussions of energy conservation and energy systems planning models at national meetings of ORSA/TIMS. He is a consultant on systems analysis for Stanford Research Institute, where he was a senior research engineer in the Engineering Systems Division and an operations analyst in the Management Sciences Division before joining EPRI.

Yu was an analyst in the Ministry of Economics in Taiwan, Republic of China, where he received his BS in electrical engineering from Taiwan University. He has an MS in electrical engineering from Georgia Institute of Technology, an MS in statistics, and a PhD in operations research from Stanford University.

Division Report
Transmission and Distribution

John J. Dougherty, Director

DC TRANSMISSION PROGRAM

This issue includes a detailed description of dc transmission and substations. The next issue of the JOURNAL will review the Underground Transmission Program.

The modern converter technology needed for practical high-voltage direct current (HVDC) transmission systems is relatively new. In less than two decades it has grown from the 100-kv, 20-Mw link between the Swedish mainland and the island of Gotland in 1954 to the ±400-kv, 1400-Mw northwest/southwest Pacific HVDC intertie commissioned in 1970.

The primary HVDC application to date has been point-to-point transmission over long distances or through cables or as frequency converters. EPRI's program in HVDC transmission is an attempt to make available the transmission technology that will meet load growth requirements in an environmentally acceptable manner.

In the U.S. the need for HVDC technology will probably increase. The technology will have to provide for delivery of power from minemouth or nuclear generating installations to urban load centers, especially if part of the transmission at the receiving end is by cable. If dc is to fill this role, then apart from the development work on transmission lines, much needs to be done on reducing the cost and space requirements for HVDC terminals.

The R&D effort in dc transmission is divided into three program areas: dc substations, dc overhead lines, and dc cables. Subprograms in the first two of these areas are described in the following paragraphs.

Compact Terminals

The cost of converter terminals and the relatively large sites they require have deterred the use of dc transmission in spite of its technical advantages. The large areas used for converter terminals would be a problem even in sparsely populated areas if dc systems with 600–1200-kv pole-to-ground voltages were built. Thus, an effort in applying the gas-insulated substation technology to dc should be given high priority. Although it is possible to develop components and test them in a laboratory environment, actual proven operation in a realistic configuration is necessary before the compacting techniques can be trusted for commercial applications. EPRI, Consolidated Edison Co. of New York, Inc., and General Electric Co. are jointly sponsoring a compact HVDC terminal project to be built at the Astoria Substation in New York (RP213).

The project has been described in T&D Division research progress reports and in the February issue of the JOURNAL. The two main features are the 100-Mw terminals, which are connected to two separate ac buses in the ac substation a short distance apart (Figure 1). The current rating is 1000 amp. The dc insulation is built for 400 kv, and a 300-kv dc bias is used to elevate the dc potential of the system over ground potential for realistic insulation design.

When actually building the terminals (one of which is shown in Figure 2), the designers will have to provide a system that is maintainable as well as reliable. Materials must be tested to handle not only the stresses of short-term laboratory tests but also the long-term operating stresses of the system. The equipment will be encapsulated, thus reducing the radio noise associated with operation of converters, which could be a problem in systems located near population centers.

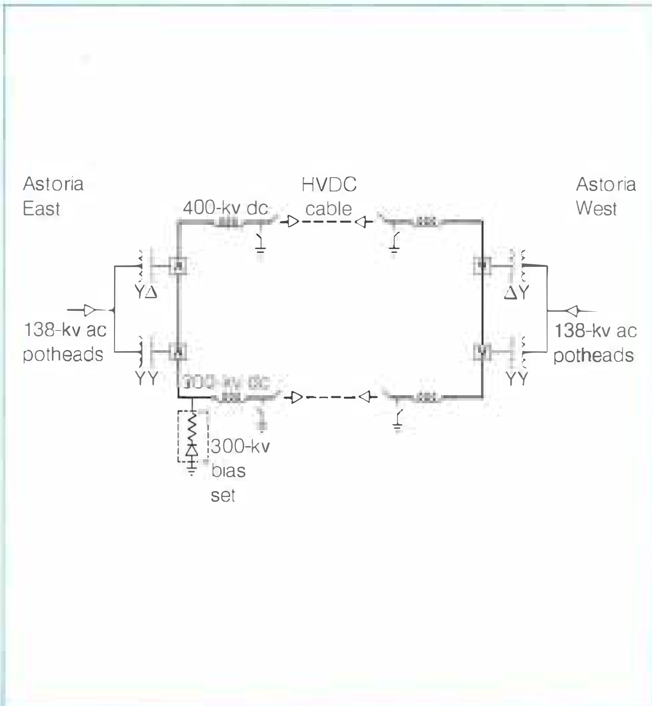
All sections of the dc system except the filters have been compacted. These sections include bus connections between transformers and valves, the valves themselves, and all bus connections on the dc side to the two dc cables that connect the terminals. Several technological problems have been investigated during the course of the equipment development.

It is known from gas-insulated ac systems that particles can cause breakdown of the insulation inside the bus sections. The behavior of particles under dc stresses was one problem that had to be investigated for proper bus design.

Materials compatibility is another area that required significant attention. Dc bus insulators and switchgear, such as disconnecting and grounding switches for bus sections, have been built. Interfaces to transformers, valves, and cable potheads have been developed. A compact potential transducer is also a tangible result of the project.

Dead tank valves with SF_6 insulation and Freon cooling

Figure 1 Simplified one-line diagram of the 100-Mw dc terminal being installed at the Astoria Substation of Consolidated Edison Co. in New York. The dc insulation is designed for 400 kv. A 300-kv bias overground potential will provide a realistic test of the insulation integrity.



are being developed in this project, providing an additional reduction of the volume needed for converter terminals compared with that needed for air-insulated terminals.

The project calls for at least five years of operation, during which work to optimize components and test operation of new or improved components will be undertaken. *Project Manager: Narain Hingorani*

Valves

The use of thyristors in converter valves provided valve designers with a component that made it possible to build valves with almost any voltage rating. The thyristor elements have predictable performance but need to be carefully protected against voltage and current surges. Existing plasma valve technology is still considered useful. One example is the ERDA-sponsored work with Hughes Research Laboratory to develop a liquid metal plasma valve.

EPRI has sponsored two light-fired thyristor development projects: one with Westinghouse Electric Corp. and one with General Electric Co. (RP567, RP669). The new light sources and fiber optic systems that have appeared on the market along with the new thyristors will make it possible to control the thyristors by means of light pulses brought directly into the semiconductor wafers (Figure 3). Merging this with an internal thyristor design that is self-protecting against forward over-

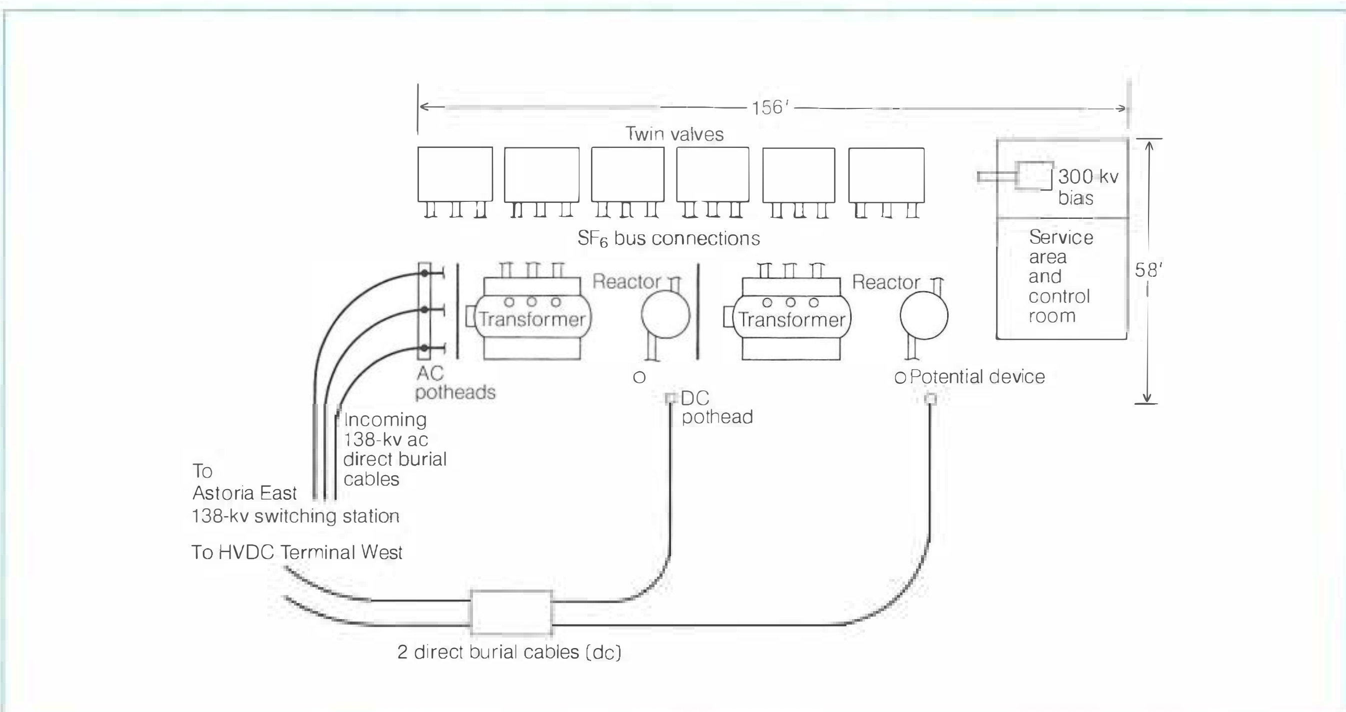


Figure 2 Astoria East Terminal of the EPRI prototype dc link. Encapsulation and gas insulation of the equipment lead to a compact station suitable for urban centers.

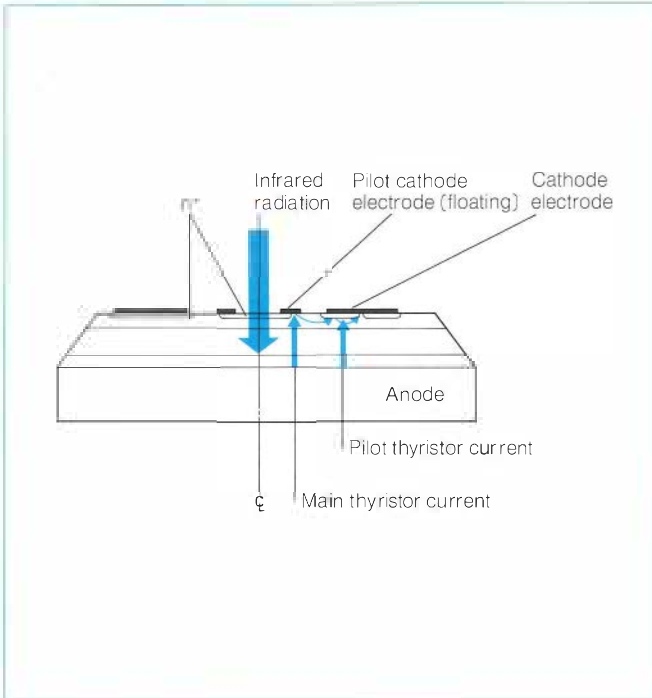


Figure 3 Cross section of a light-fired thyristor. Pulses are brought directly into the semiconductor wafers. This design could significantly reduce the cost and complexity of HVDC valves.

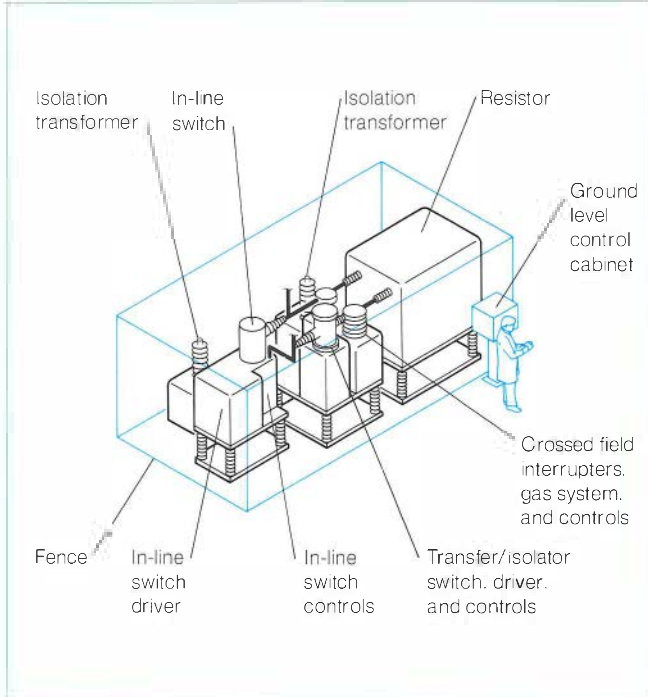


Figure 4 Conceptual design of a metallic return transfer breaker. During forced monopolar operation, application of this device allows use of the second conductor of a bipolar line as a return path for neutral current.

voltages will significantly reduce the complexity and cost of HVDC thyristor valves.

The ability to grow large-diameter crystals for semiconductor devices is rapidly improving. It appears that diameters of 100 mm or more are within reach. This would significantly increase the current and voltage rating of thyristors. Improved cooling methods for the thyristors or techniques that reduce the thermal resistance from the wafers to the cooling media would also improve the current rating of the thyristors.

Once they have been developed, the components will be integrated into valve modules and possibly into full-scale valves for testing. *Project Manager: Narain Hingorani*

Switchgear

The utilities will not have the full benefits of the dc transmission technology until dc breakers are available, making it possible to interconnect several dc converter stations on the dc side. This requires dc power circuit breakers. Because not enough is known about various requirements of a dc circuit breaker, it has been necessary to pursue system studies. A description of the dc circuit breaker specification project with Hydro Quebec Institute of Research (IREQ) was included in the February issue of the JOURNAL (RP326).

The design of a dc breaker for high voltages is difficult. A current zero has to be forcibly created in the system by the breaker without damaging the breaker itself. A less demanding application is the transfer of current from one circuit to another. Such a device is needed in bipolar transmission systems in which a loss of one of the poles results in operation of the other pole with ground return. The long-term use of this so-called ground return is limited to sites where the side effects of ground current can be tolerated. Reconnecting the system to use the conductor of the failed pole as the return path for the neutral current is a way of minimizing this problem. The transfer between the ground return and the metallic return operating modes should be possible without a shutdown of the system. A metallic return transfer breaker, a concept proposed by Dr. Hingorani, is being developed for this purpose at Hughes Research Laboratories (Figure 4). It is anticipated that the work on this transfer breaker will further the development of dc breakers with more severe duty (RP667).

One key element of a dc breaker is an energy absorber. The new, highly nonlinear arrester elements that are being developed could possibly benefit the dc breaker technology by bringing the residual current to very small values for final interruption of the circuit. Work in this area can be expected in the future. *Project Managers: Narain Hingorani, Stig Nilsson*

Ground Current

The ground current from directly grounded dc transmission systems could possibly have side effects. The effect of most concern is the possibility of corrosion near the anode. Induced currents in the earth and electrolytic processes in metal objects buried in the ground produce the same effect. An established practice, therefore, is to install cathodic protection where metallic structures are buried in the ground.

The use of ground current has been a technically viable alternative for long-term use in many parts of the world, especially where the anode is located in ocean water. Work needs to be done to correctly predict corrosion effects and establish mitigating measures. A project to investigate this area is planned. Effort is also planned for electrode design and installation deep in the ground.

Control and Protection

Energy metering in an HVDC transmission line is not yet feasible. The existing transducers are not sufficiently linear and do not have the output power to drive existing energy-metering devices. However, in interconnected dc systems it will be necessary to have energy meters on the dc side. New current transducers and potential transducers will be needed for this.

EPRI has undertaken to develop an electronic current transducer with a target performance specification sufficient for metering accuracy (RP668). A new, compact potential transducer with similar performance characteristics is already a direct result of the compact dc substation project.

The introduction of dc breakers into the system will impose new requirements on dc line fault protection. It will be necessary to disconnect any faulted portion of the dc side by means of the breakers. Consequently, improved protection methods for dc breaker applications will be needed.

The controllability of a dc power transmission link is one of the advantages of a dc system. But it also needs attention to ensure that the system is properly controlled in a way that benefits the ac systems. The introduction of an element, such as a breaker, will affect the requirements of the control systems and vice versa. System studies and development of control systems are needed in this area. *Project Manager: Stig Nilsson*

Substation Insulators and Bushings

The development of new insulator materials and new bushings as a part of the ac substation program is being followed with interest. It will be necessary to test and certify the new materials and bushings for dc applications. Pollution deposits and leakage currents in a dc system may adversely affect the new materials. As new materials appear on the market, it is anticipated that they will undergo long-term tests in dc test circuits.

Transformers and Reactors

Converter transformers are the interface between the dc and the ac systems. Hence, one side of the transformer has to be capable of withstanding the dc voltage stresses. Superimposed on the dc voltage are transients generated by the converters themselves, as well as conducted transients from both the ac and the dc circuits. This is a challenge to the transformer designers who have the task of controlling the voltage stresses across insulating materials.

An additional factor that the transformer designer has to consider is the significant harmonic current generated by the converters that can cause hot spots through eddy currents in various portions of the transformers. The technology appears to be relatively well understood, but as new ac transformer designs evolve, work may be needed to determine how the designs fit into a converter transformer application.

The operation of dc converters requires frequent operation of the transformer load tap changers to compensate for the voltage regulation in the dc circuits. The duty on the load tap changers is much higher on a dc converter transformer than on a normal ac transformer. Available power thyristors may have ratings that make them feasible for load tap changer applications, which would virtually eliminate any wear-out problems with tap changer operations, and may provide very fast voltage control through high-speed tap changes.

Surge Arresters

An exciting possibility is the use of the new arrester element being developed for ac substations as a gapless arrester in dc substations. These arresters, made up of highly nonlinear metal oxide resistor blocks, clamp the overvoltage in the same manner as zener diodes in electronic circuits. Use of present gapped arresters results in large insulation margins for adequate protection. Gapless arresters would be of tremendous help in the protection of converters against overvoltages and would certainly contribute to reduction of protective levels for thyristor valves.

Harmonics

Harmonic currents generated by converters require filters to prevent telephone interference, and capacitor banks are needed to make up for reactive power requirements of converters. The harmonic filters and capacitors occupy significant areas in a typical converter terminal. The reliability of thyristor valves and consequent adaption of 12-pulse operation have made it possible to eliminate the fifth and seventh harmonic filters on the ac sides, thereby greatly simplifying the ac filter arrangements. However, the present-day filters and capacitors are too voluminous for compact terminal application.

It is therefore necessary to reduce the size of the filters and capacitors to be compatible with other components of a compact dc substation for minimum site requirements.

DC Overhead Lines

EPRI is sponsoring two research projects related to transmission line design. These projects have considered lines in two separate voltage categories: Studies were conducted on voltages up to ±600 kv dc, followed by research on line designs up to ±1200 kv dc.

The Bonneville Power Administration, using the dc test facility at The Dalles, Oregon, has been investigating the details of design and maintenance for ±600-kv lines (RP104). Included have been studies of radio and TV influence and audible noise from the line. Insulator research was conducted both outdoors and in a specially constructed fog chamber. Hot line maintenance demonstrations also emphasized the feasibility of these procedures. A dc design reference book is now being reviewed by an industry steering committee and will be available soon.

With the engineering design of dc lines up to ±600 kv established, the next logical step will be to prove the feasibility of lines of higher voltage. IREQ was awarded a project for this task (RP430). Its work is proceeding on three parallel fronts. Long-term bipolar line and bus corona studies cover the ranges of ±600 kv–±900 kv, ±750 kv–±1050 kv, and ±900 kv–±1200 kv. These will establish preliminary design concepts for conductor bundles for systems nominally rated 750 kv, 900 kv, and 1050 kv, respectively. Measurements of corona loss, RI and TVI, audible noise, ozone generation, and electric field strengths are being made on a short test span.

Insulation studies are directed to both line and station insulation. Bus configurations using post insulators and full-scale towers corresponding to a bipolar line structure are being tested with a variety of voltage wave shapes and varying dc bias.

The final element of this preliminary research effort on higher dc voltages is a study of the required capacity, or "stiffness," of the power supply used for flashover tests of contaminated insulators. From these tasks will come direction for more detailed research and testing on HVDC transmission lines up to the ±1200-kv level. *Project Managers: Narain Hingorani, Frank Young*

Research Related to Electric Fields

Although no projects presently underway are specifically directed to the effects of electric and magnetic fields found in the vicinity of dc transmission facilities, a number of projects are in the planning stages. These projects are being designed to provide appropriate instrumentation and measuring techniques, characterization of fields and space charges by dc facilities, and biological and nonbiological effects. Implementation of specific research will be highlighted in future issues of the JOURNAL. *Project Managers: Narain Hingorani, Frank Young*

Division Report
Nuclear Power

Milton Levenson, Director

THERMOGRAPHIC IMAGING OF NUCLEAR FUEL RODS

Study of the causes for fuel-related loss of capacity factor in nuclear power reactors has focused attention on the gap region separating the ceramic UO_2 pellets from the surrounding Zircaloy cladding tube.

The structure of the gap region has long been the subject of calculation but only rarely of direct measurements. This region of the fuel rod is of particular importance because:

- It contributes a major part of the uncertainty in the calculations of fuel-stored energy (needed for licensing).
- Closing of the gap by pellet cracking, clad creepdown, and fuel swelling eventually leads to pellet clad interaction (PCI), which in turn occasionally leads to cladding strain and loss of leak-tightness.

Both factors have had substantial impact on plant capacity factors. For instance, uncertainty in fuel-stored heat associated with the so-called densification problem has been partly responsible for several reactor deratings in past years and has been a factor in the change in fuel designs (8×8 and 17×17 rod arrays for BWR and PWR) to reduce linear heat ratings.

Most of the progress in understanding the mechanical aspects of the fuel cladding gap region has been the result of inference or calculation rather than direct measurement. The most direct data-supporting inferences of the gap width—centerline thermocouple readings and microstructure feature measurements—cannot resolve local gap variations. In the absence of direct evidence to the contrary, a simple model that assumed a monolithic fuel body centered within the cladding was used for a time by AEC and NRC. It has since become clear that the assumption of an uncracked fuel body and circumferentially constant gap width entails considerable error in many calculations. The thermal technique reported here for imaging the structure of the gap region may be a significant contribution to the present ability to diagnose actual fuel rod behavior. It also has potential future value as an inspection tool.

The concept of thermal imaging has been widely used to find and quantify gaps in bonded structures. For example, Green (*1*) has investigated the use of a nonscanning radiometer for inspection of bonding defects in aluminum clad metallic fuel rods. The availability of sensitive and convenient thermal-imaging devices suggests the possibility of obtaining accurate local and statistical distributions of gap size. Preliminary calculations showed that good sensitivity to gap size should be possible and that there should be an ability to observe pellet chips, cracks, or debris-in-gap of the order of the cladding thickness in minimum dimension. The following is a report of the results of reduction-to-practice with actual fuel rods, representing a cooperative effort of EPRI, Stanford Research Institute (SRI), Spectrotherm Corp., and General Electric Co.

Measurement Technique and Experimental Verification

An experimental project carried out at SRI developed the measurement technique in preliminary form. Full details of the experiment will be given in the final report for the SRI project. The method capitalizes on the fact that after the cladding experiences a uniform step increase in temperature due to a sudden energy addition, each element of cladding area cools off at a rate determined by the local degree of thermal contact—or gap size—between the pellets and the cladding (Figure 1). Following pulse heating of the cladding, the time-varying thermal signature at the cladding surface thus contains information concerning the variations in gap width that may be imaged by using an infrared camera.

In the experiments at SRI, a capacitor bank was discharged through leads attached to the cladding tube. In this manner, the cladding tube temperature over a length of 1 foot was raised about 20°C in 1 millisecond. To minimize the effect of specular reflections, the cladding tube was painted with flat black paint. (In practice, this requirement might be avoided or met with a water-soluble coating.) The fuel rod surface was imaged, using a Spectrotherm Model 800 industrial infrared imaging system.

In cooperation with the Nuclear Energy Division of General Electric, a helium-filled fuel rod was specially prepared to contain normal, undersize, and chipped fuel pellets. Chip sizes present ranged from "acceptable" on the basis of typical manufacturing specifications to "grossly rejectable." The method developed for imaging the fuel cladding interface is illustrated in Figure 2.

The rod was held in a fixture and rotated at a rate of 2 rps. (Rods were scanned with both horizontal and vertical orientation of the rod axis. No difference was observed in the thermograms, presumably due to the ability of the plenum spring to prevent lateral pellet motion.) The camera was set to scan parallel to the axis of the cladding tube.

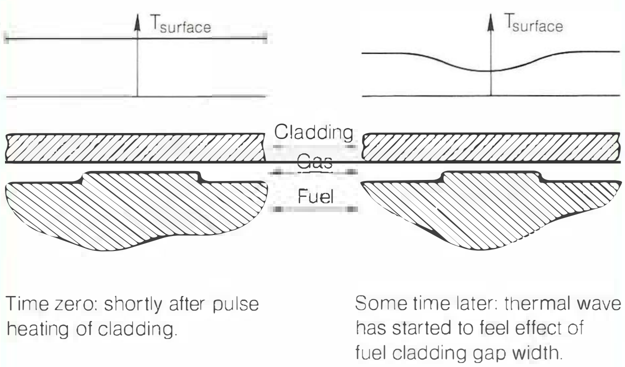


Figure 1 The effect of variable fuel cladding gap on the cladding surface temperature is shown by graph (top) of temperature versus location on cladding surface.

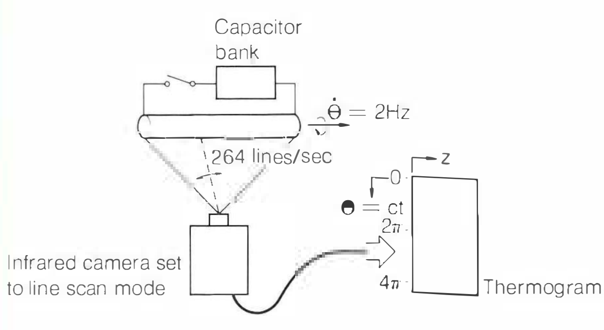


Figure 2 Diagram of measurement system developed for producing a thermographic image of the fuel cladding gap region.

The thermal camera produces a quantitative gray-scale display of the measured temperatures on a video screen. In this manner a planar image is formed that represents a temperature map of the entire cladding surface. Figure 3 shows a typical result. The unclad pellet stack, as photographed prior to loading, is shown above the thermogram.

Moving downward along the thermogram, the temperature remains uniform for about ½ revolution, or ¼ second. As the thermal wave passes through the cladding to the vicinity of the gap, a region of the maximum definition is produced, showing in some detail features of the fuel cladding gap. Maximum lateral line resolution in the image is of the order of the cladding thickness, a proposition that is observed in this experimental work and was previously derived by thermal calculation (2). Proceeding further down the thermogram, the fuel rod becomes isothermal and the definition of the thermal image is lost.

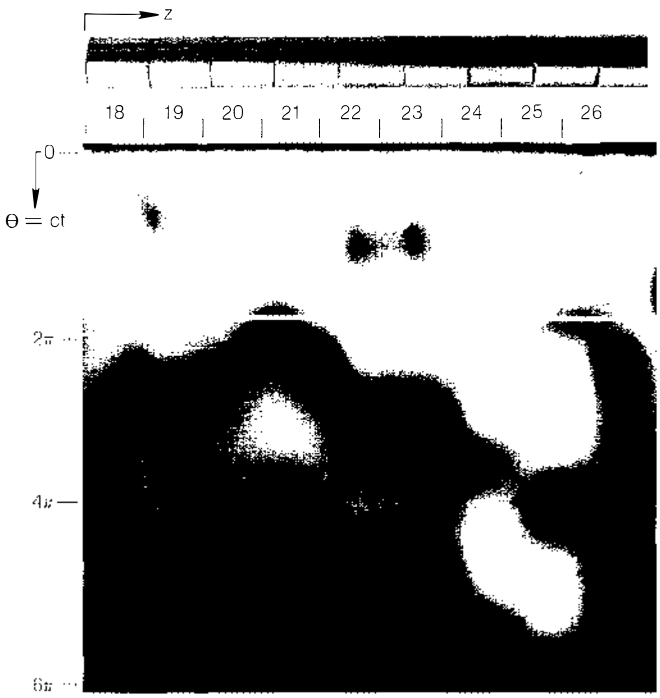
In Figure 3, pellets 18 through 23 are nominally unflawed pellets. However, pellet 21 is evidently cocked, as evidenced by the slanting line separating the light from the dark regions. Pellets 24 and 25 are 380 mm undersize and are slightly chipped. The large light-colored region opposite those pellets indicates that they are undersize. Pellets 24 and 25 are evidently also cocked. Finally, pellet 26 is more seriously chipped, as shown by the black-white transition that slants downward from left to right. Chips with lateral dimensions (dimensions in the image plane) greater than the cladding thickness produce usable signatures, although discrimination is difficult in the lower size ranges.

Prospects for Use in Fuel Research

Using the existing equipment, application of the thermal measurement technique to unirradiated, as built, fuel is now practical. Some added effort may be useful to quantify the correspondence of gray scale to gap size. For irradiated fuel, a shielded version of the sensing part of the camera instrument will be required. According to the camera manufacturer, it is practical to separate the relatively compact package consisting of lens, detector, and preamplifier from the rest of the electronics. An immediate prospect for application lies in checking the predictions of gap closure models, of particular importance in heat transfer calculations. The quantity of most importance is the gap conductance at full power. Measurement at zero power but with variable power history would help to benchmark the characteristics of the models under time variation.

Of equal interest is the contribution thermography can make

Figure 3 Thermogram for region including pellets 18–26 represents a gray-scale display of the temperature distribution measured at the cladding surface. Unclad pellet column is shown above the thermogram.



to understanding fuel failures due to pellet cladding mechanical interaction. The rapidity of gap closure and the degree of heterogeneity of the gap at "closure" are vital to the understanding of the mechanisms associated with pellet cladding mechanical interaction. Gap closure rate determines the time of onset of PCI, while heterogeneity determines the degree of stress concentration associated with a given stress-producing event. The thermographic technique measures gap conductance, a function of both the gap dimension and the thermal conductivity of the gas. Hence, in the absence of an independent measurement of gap thermal conductivity, only the relative gap dimensions of irradiated fuel are known. Theoretical studies indicate that the stress concentration is proportional to the spacing of the heterogeneities (pellet cracks) with fine spacing being favorable to low stress concentration. In principle, the thermogram can provide a measure of the potential for cladding damage under a power increase.

It should be noted that all experimental and analytic work to date has considered rods with helium fill gas. The reduction of gas thermal conductivity when diluted by large volume fractions of fission gas significantly lowers the gap conductance in irradiated fuel rods. For rods in which large gaps persist at high burnup, the thermograms will have a somewhat lower signal-to-noise ratio.

Prospects for Use as a Receiving Inspection Method

Another prospective application for the method lies in receiving-fuel inspection by utilities. Thermography represents a potential nondestructive method of measuring the internal structure of the fuel. This could form a part of the basis for determining compliance with possible specifications aimed at minimizing the occurrence of stress concentrations due to fuel geometry. Features such as nonsquareness of ends, barreling, hourglassing, undersizing, and chipping of pellets are resolvable. Fine debris in the gap (potentially produced in assembly or shipping of the fuel rods) would be difficult to detect directly, due to the established resolution limit. However, such debris should be detectable as a constraint on the amplitude of the gap width variation when the rod is vibrated or rotated laterally. Adoption of a specification on mechanical integrity of the as-received fuel column is not yet recommended because quantitative data that can correlate features of the preirradiation fuel column to the propensity for cladding strain or cracking are only beginning to be available. With the further development of the thermographic techniques, it should be possible to establish such correlations. *Project Managers: E. L. Zebroski, Terry Oldberg*

References

1. D. R. Green. "Principles of Emittance—Independent Infrared Nondestructive Testing." *Applied Optics*, Vol. 7 (1968), p. 1779.

2. *Thermographic Imaging of Nuclear Fuel Rods: Final Report.* Prepared by R. C. Honey and D. G. Falconer. Palo Alto, Calif.: Electric Power Research Institute, forthcoming (NP-134).

PLUTONIA FUEL STUDY

The Plutonia Fuel Study (RP396) was initiated in May 1975 to investigate the irradiation-induced densification and plutonia (PuO_2) homogenization of mixed-oxide fuels for light water reactor applications. The project is being conducted by Battelle, Pacific Northwest Laboratories and is being funded by EPRI and seven industrial organizations: Babcock & Wilcox Co., British Nuclear Fuels Limited, Central Research Institute of the Electric Power Industry (Japan), Combustion Engineering, Inc., Exxon Nuclear Co., General Electric Co., and Westinghouse Electric Corp. This project, in conjunction with the Halden Reactor Project and vendor programs, complements the EEI/EPRI Fuel Densification Project (RP131) that was completed in 1975. The earlier project determined the specific variables that control the irradiation-induced densification of UO_2 fuel pellets. Methods for producing nondensifying fuels and for confirming their behavior by out-of-reactor testing were also developed.

Although the properties and irradiation behavior of mixed-oxide fuels appear to be little different from those of UO_2, the current licensing climate surrounding plutonium recycle will require confirmation of this viewpoint. The Plutonia Fuel Study will therefore address safety-related issues that will be required by the NRC to support licensing of fuels that contain plutonium.

The study will include:

- An investigation of the in-reactor densification characteristics of mixed-oxide fuels
- An evaluation of the effects of irradiation on fuel microstructures
- A determination of the extent and rate of thermal- and irradiation-induced homogenization of PuO_2 in the UO_2 matrix
- A broadening of the data base for modeling the detailed structural behavior of mixed-oxide fuels

The scope of the project includes the fabrication, preirradiation characterization, irradiation, and postirradiation characterization of several fuel types. The test matrix has been selected so that effects arising from differences in the pore-size distribution, PuO_2 particle size, PuO_2 loading, and PuO_2 distribution (resulting from a mechanically mixed versus a coprecipitated fabrication process) will be evaluated. These parameters have been chosen so that for some of the fuel types the microstructure and irradiation behavior would be representative of mixed-oxide fuels currently being fabricated by fuel vendors. A composite fuel design will permit separation of the effects of temperature and fission rate on densification. The resolution of this issue assumes importance in the irradiation of mixed-oxide fuels because the fission density is higher in the PuO_2 particles than in the surrounding UO_2 matrix.

Fabrication of ten different mixed-oxide fuel types has been completed. Irradiation of archive samples of two UO_2 pellet types from the earlier project (RP131) will serve as a control. Four pellet types furnished by the cosponsoring fuel vendors will also be a part of the program. The characteristics of the fuel types fabricated by Battelle are presented in Table 1.

Initial density measurements have been completed. Alpha-autoradiography data confirm the uniformity of the plutonium particle distribution in pellets produced from mechanically mixed powders. A comparison of photomacrographs and alpha-autoradiographs suggests that for those fuel types that contain PuO_2 particles $\lesssim 100$ μm diameter and that were sintered at a high temperature (~1675°C), the PuO_2 particles act in some measure as a pore former. It appears that the PuO_2 particles diffuse in the surrounding UO_2 matrix, leaving a pore surrounded by a plutonium-rich diffusion zone that is ~50 to 75 μm thick. The homogeneity of pellets produced from coprecipitated UO_2-PuO_2 was also confirmed.

Two Zircaloy clad fuel pins have been fabricated. Each pin is contained in an individual Na-K–filled stainless steel capsule. The capsules will be irradiated in the General Electric Test Reactor to two exposure levels. Peak linear power ratings of ~9 kw/ft will result in maximum fuel temperatures such that irradiation-induced densification and homogenization effects will predominate. Final assembly of the pins and

Table 1
PLUTONIA FUEL STUDY TEST MATRIX

Type	*Nominal Density (% TD)*	*Grain Size (μm)*	*Median Volume Pore Diameter (μm)*	*Nominal w/o PuO_2*	*PuO_2 Particle Diameter*
11	93	>10	1–2	0	—
12	93	>10	1–2	3	Coprecipitated
13	93	>10	1–2	3	<44 μm
14	93	>10	1–2	3	60–100 μm
15	93	>10	1–2	3	300–500 μm
16	93	>10	1–2	6	<44 μm
17	95	>10	1–2	6	<44 μm
18	93	>10	~12	3	<44 μm
19	93	<10	<1	0	—
20	93	>10	<1	3	Coprecipitated
21	93	>10	<1	3	<44 μm
22	93	>10	<1	3	60–100 μm

capsules was completed satisfactorily and irradiation started February 15, 1976. The low-burnup capsule was discharged March 26, 1976; the high-burnup capsule is scheduled for discharge in mid-June. *Project Manager: Howard Ocken*

EXTERNAL FUEL CYCLE

The external fuel cycle program area refers to those functions needed to produce and ensure a reliable supply of nuclear fuel and to assure the safe and economical disposition of this fuel after its use in electric generation units. The specific functions of interest include the cost and availability of uranium resources, enrichment technology, fabrication of initial recycle for materials, and reprocessing and disposal of wastes from both fuel-cycle and generation-unit operations.

The identification of potentially desirable research and development activities relating to the external fuel cycle is not a difficult problem. However, the comparative complexity of these areas in government agencies and industrial vendor interest make it difficult to sort out areas in which utility-sponsored R&D or analysis can be effective. Accordingly, this program area consists mainly of staff efforts, modestly funded studies aimed at clarifying needs and practical options, and relatively small efforts aimed at specific hardware or technology developments.

The present EPRI external fuel cycle program involves a coordinated effort in the Nuclear Power Division and the Energy Systems, Environment, and Conservation (ESEC) Division. Most of the projects tend to complement major ERDA projects. The current ESEC activities are focused on assessment of the uranium resource base (RP489, RP490) and on the associated technologies of mining and refining of uranium ores (RP803, RP807). Staff efforts are primarily concerned with the monitoring of ERDA and industry programs that determine the cost and availability of nuclear fuel for electric generation applications. These staff studies help determine areas in which relatively modest programs can be effective. For example, RP306-3, Radioactivity of Recycle Fuel: Effect on Fabrication of Mixed-Oxide Fuels, has recently been initiated because it was recognized that comparatively few data are available on this subject. The actual radiation levels have great impact on the applicable techniques and investment required for fabrication and on the costs of mixed-oxide fuel for either recycle or breeder reactor fuel.

Other current staff efforts include:

- Assessments of status of nuclear waste disposal
- The accommodation of spent fuel in long-term storage sites as mandated by reprocessing delay
- Examination of reprocessing status and technology and obstacles to implementation
- Fuel-cycle critical-cost analysis and projections

Progress on these efforts is normally discussed with department and division task forces and published on completion.

Enrichment technology is represented by several feasibility level projects. At the national level, enrichment efforts are focused on:

- Capacity and process improvement of existing diffusion production facilities
- Centrifuge enrichment development
- Laser isotope separation research

The important criteria for these various efforts include: (a) anticipated overall cost per separative work unit, (b) relative power consumption, (c) minimum-scale investment for economic production (which affects the ability to meet enrichment demand anticipated beyond 1985), and (d) adaptability in low tails-assay production or tails rework in the interests of resource conservation. Assurance of market levels and growth rates, as well as siting problems for the necessary electric power source, enter into evaluations.

Foreign enrichment interests are somewhat similarly oriented except that there is less entrenched commitment to diffusion processes and there is more extension and intensive effort in aerodynamic separation techniques. Classically, the aerodynamic methods have been characterized by comparatively simple construction and equipment as well as by high or moderate power consumption relative to diffusion processes.

EPRI selected aerodynamic methods for exploratory investigation with the specific objective of determining if the simplicity of the equipment could be retained while reducing power consumption. The prospects for economically viable enrichment at comparatively low production rates and at least partial use of less rather than more electric power sources are of interest. Programs in process derive from earlier analytic studies of the Becker nozzle being developed in Germany. The jet membrane approach (RP506-4) aims at reducing power consumption by substituting a condensable fluid for the helium gas used as the uranium carrier. The velocity slip approach (RP506-1, 2) offers the prospect of centrifuge-type performance and implementation without the necessity of ultraspeed rotating equipment.

The isotope separation programs are currently in the stage of practical laboratory test operation and evaluation. Concurrent design and economic analyses of potential scale-up are underway. Investment in any process tends to be paralyzed by the prospect of many promising options, one of which might obsolete any currently proven process. It is expected that the critical data necessary for industrial evaluation of aerodynamic systems relative to the other approaches will be available by early 1977. *Project Managers: M. Lapides, R. Williams*

Division Report
Energy Systems, Environment, and Conservation

René H. Malès, Director

ENVIRONMENTAL ASSESSMENT DEPARTMENT

Polychlorinated biphenyls (PCBs) are now under severe indictment as an environmental contaminant. As used commercially, PCBs are mixtures of chlorinated biphenyl compounds and some contaminants, including chlorinated benzofurans, and have been sold under a variety of generic and trade names. Key physical and chemical properties of PCBs include low volatility, high dielectric strength and constants, low solubility in water, high solubility in organic solvents and fats, and resistance to most forms of chemical attack.

In the electric power industry, PCBs are widely used as transformer fluids where regulations or situations require nonflammable fluids; and in capacitors, the dielectric properties make PCBs the fluid of choice. Other past and present applications include use as a plasticizer and/or fire retardant in a wide variety of waxes, resins, inks, paints, and rubber products. PCBs have also been widely used in hydraulic and heat transfer fluid formulations and as an additive in some lubricating oils.

Until the late 1960s little attention was paid to the possible role of PCBs as an environmental contaminant and public health problem. The EPA has estimated that approximately 700,000 tons of PCBs have been produced in the U.S. since 1929. Of this total, 375,000 tons are still in service in the U.S. and 250,000 tons have entered the U.S. environment (75,000 tons were exported). Peak production of PCBs by Monsanto Industrial Chemicals Co., the sole U.S. producer, was somewhat less than 40,000 tons per year during the late 1960s. For the year 1970, Monsanto's production was approximately 38,000 tons. Total worldwide production is estimated to have been 75,000 to 100,000 tons per year. (This is probably half the maximum production of DDT during the late 1960s.)

The total North American PCB flux into the environment was estimated as about 25,000 tons in 1970. This was broken down into 1500 to 2000 tons per year into the atmosphere from vaporization of plasticizers and vaporization from open burning, 4000 to 5000 tons per year into fresh and coastal water from spills, etc., and 18,000 tons per year into dumps and landfills. The total North American PCB flux into the environment for 1974 has been estimated as 7600 tons. A current estimate by the EPA Office of Toxic Substances places a lower limit on PCB flux of 4500 tons per year. Most of the reduction in estimated PCB flux is due to elimination of sales by Monsanto to dispersive users of PCBs.

Despite reduction of estimated PCB flux in North America, PCB levels in many areas, such as the Great Lakes, remained unchanged between 1969 and 1974, according to a recent review. The most critical problem involves levels in fish from the Great Lakes and the Hudson River. The current U.S. standards for PCBs in fish for human consumption is 5 ppm, while the Canadian standard is 2 ppm. PCB levels of up to 165 ppm in fish from the Great Lakes and 350 ppm from the Hudson have been detected, although average levels have been much lower. The commercial fishery for striped bass in the Hudson River has been curtailed, and since a significant portion of the fish in the Great Lakes exceed the current 5 ppm standard, a similar action might be expected. EPA analyses of fat samples from people in the U.S. indicate that at least three-fourths of the individuals screened have had at least detectable levels of PCBs.

Exposure to PCBs has been shown to cause a variety of physiological effects. The most famous incident occurred in the late 1960s in Japan, when over a thousand individuals were affected by contaminated rice oil. Symptoms observed of what became known as Yusho disease included acne-form eruption, pigmentation of skin and nails, fatigue, anemia, increased eye discharge and swelling of upper eyelids, and stillbirths. PCB exposure has been shown to cause a variety of physiological effects in addition to those symptoms related to Yusho disease. The various PCB formulations appear to have different effects and supposedly similar PCB formulations from different sources also have different effects. This is probably because in each formulation there are several PCB compounds and contaminants, such as chlorinated benzofurans. Some observed effects include interference with reproduction in minks and chickens, induction of birth defects and chromosomal damage in chickens, liver abnormalities (including both benign and malignant tumors), and photosynthesis inhibition in some diatom and algal species.

In 1971 Monsanto voluntarily limited sales of PCBs to those applications considered "closed cycle," such as electrical transformers and capacitors, and sales were reduced to approximately 18,000 tons in 1971. At the same time improved disposal procedures were set up under ANSI Standard C107. PCB manufacture was banned in Japan in 1972, and use restriction and recovery laws have been adopted in several countries, France for one.

The environmental levels of PCBs observed in major U.S. freshwater ecosystems and the existing information on toxic effects of PCBs leave little doubt that the use of PCBs in this country must be phased out as rapidly as substitutes become available. Environmentally acceptable PCB substitutes must be developed, and routes of PCB flux into the environment must be controlled. Measures that are being considered or adopted include regulation of emissions from manufacturers utilizing PCBs and inspection of on-line PCB-containing equipment to ensure that emissions from normal operations, accidents, and equipment failure are minimized. Proper disposal or recycling of PCBs from retired equipment is essential. Disposal of capacitors and transformers after drainage of fluids must be carried out in a fashion that eliminates escape of residual PCBs into the environment.

At present the following substitute fluids or technologies have been proposed or are available to replace PCB use in transformers and capacitors. Dow Corning Corp. has suggested the use of polydimethyl siloxane (currently being used in Japan). Dow Chemical Co. and McGraw-Edison Co. have developed butylated monochlorodiphenyl oxide and claim that it is more biodegradable, less bioconcentratable, and less toxic than PCBs. RTE Corp. has developed a long-chain hydrocarbon called RTEMP for use in transformers. Exxon Chemical Co. produces diisononyl phthalate, which is now being used in some capacitors. Other possibilities include the use of gas- or vapor-insulated transformers.

Whatever chemical or technical approach is selected, it is obvious that a repetition of the environmental problems related to PCBs is undesirable. Some basic considerations that should be given to any potential PCB substitute are:

□ Low toxicity. Any selected substitute should be as benign as possible. It should not be highly mutagenic, carcinogenic, or teratogenic. It should not adversely affect wildlife populations when normal operational losses into the environment occur. Also, manufacturing processes should not result in the production of contaminants such as chlorinated benzofurans, which may be responsible for many of the toxic effects attributed to PCBs.

□ Rapid degradation in the environment into nontoxic compounds and low tendency to bioconcentration. These properties are essential to prevent buildup of chemicals in the ecosystem.

□ Easy disposability. If the substitute meets the preceding criteria, then elaborate disposal procedures would not be required.

In addition to the above, substitutes must also have suitable operational criteria. Apart from electrical properties, desirable operational characteristics would include:

□ Low flammability. This is an oversimplification of a complex problem area. Considerations such as explosiveness and generation of toxic fumes during combustion have to be balanced against each other to assess desirability of a particular material in this area.

□ Resistance to chemical attack and compatibility with other materials in capacitors and transformers to ensure long service life.

Low flammability and high resistance to chemical attack, unfortunately, may not be compatible with rapid environmental degradation, and it is obvious that compromises will have to be made. Precipitous decisions on substitutes should not be made—substitutes may have environmental, operational, or economic problems that are even worse than those of the PCBs themselves. *Robert K. Kawaratani*

ENERGY SUPPLY

Transportation, transmission, distribution, and storage constitute essential links in supplying energy to the ultimate consumer. To understand the economics of energy supply, the role of these functions must be clear. Although historically they have received less attention than energy production and conversion, the characteristics and cost of these services and their future evolution will condition, if not limit, the applicability of various conversion technologies. Transmission and transportation technologies also play an important role in determining interregional differences in the energy-economics picture.

Manalytics, Inc., is assessing the capability of rail and water networks to haul projected quantities of coal (RP437). In this research a set of sources and hypothetical consuming centers for coal was defined. The sources corresponded to approximately 30 mining states; some states were divided to facilitate the study. The coal consuming areas were basically the Federal Power Commission power supply areas. For both the production and the consumption areas, a centroid was designated. Coal forecasts for the consuming areas were used to estimate shipping volumes. Using a linear programming technique, a set of coal flows was then defined. Flows for all other bulk commodities were also forecast for the year 1985, constructed through the use of the 1972 Waybill Sample. In addition, Manalytics projected growth rates for bulk commodities.

The result of the above activity was a measure of the total bulk commodity shipments by rail and barge between two points. These commodities were then routed over the existing rail and barge network. Assistance was provided in this phase by the Federal Railroad Administration, which furnished a detailed computerized routing model. Manalytics examined these shipments and routes and drew the following preliminary conclusions: A large portion of western coal production is destined for the coastal states. Some parts of the rail network will be overloaded with these projected increases. Although there are alternative rail routings, they can be used only at a higher cost. Great Lakes and coastal waterways have seasonal capacity to handle part of the traffic. The inland waterways are almost blocked to additional traffic at some points now, and at other points they are reaching the practical capacity limits. Only a few waterways can handle the large additional tonnages that may be required under increased coal usage scenarios.

The Manalytics report is expected to be available late this summer. The results indicated above are the conclusions of the contractor and have had only preliminary review by EPRI. *Project Manager: Rex Riley*

DEMAND AND CONSERVATION

The Demand and Conservation Program has two projects on commercial energy consumption currently underway and is commencing work on two transportation energy consumption projects.

Forecasting Energy Use in Commercial Industries

Data Resources, Inc., of Lexington, Massachusetts, is working on a forecasting model of energy consumption, disaggregated by region and industry for U.S. commercial industries (RP662). Criterion Analysis, Inc., of Dallas, Texas, is a subcontractor for data development. This project will, for the first time, attempt to disaggregate commercial use by standard industrial classification (SIC) code.

Traditionally, the commercial class of service reported by electric utilities has included both substantial residential consumption in multiple dwellings and consumption in small manufacturing industries, as well as demand by the bulk of the commercial industries. Compounding the problem is the fact that some of the larger commercial establishments are included in the class of service commonly called industrial.

Criterion Analysis will survey a number of utilities in various regions to determine industrial consumption by SIC code and, if possible, construct corresponding data on the capital stock of buildings and equipment held by these commercial industries. From these new data, Data Resources will construct a forecasting model for energy use that accounts for both the short-run utilization decision and the long-run capital acquisition decision of commercial industries.

The disaggregated nature of this project will make it amenable to the consideration of specific scenarios for the introduction of energy-conserving design and construction of new commercial buildings. For example, the model will be capable of analyzing the energy impacts of solar-heated public buildings, such as schools. The commercial forecasting model developed by RP662 is part of a larger effort within the Demand and Conservation Program to develop models that forecast for all uses and types of energy in the U.S. economy.

The second project currently underway in the commercial area concerns solar energy and the heat pump in a northern climate (RP385). The contractor is Atmospheric Sciences Research Center of the State University of New York at Albany.

In this project, data are being gathered and analyzed on the technical specification, performance characteristics, capital cost, operating cost, and load requirements of a hybrid solar heating and storage heat pump system installed in the newly constructed 5000-ft^2 Alumni House at the university. This study will provide much needed information on the economic and engineering feasibility of hybrid solar storage and heat pump systems in small-size commercial buildings in northern climates. The study will also provide needed information on the potential impact of both solar heat and the heat pump system on the commercial load by time of day and season.

Forecasting Energy Use in Transportation

A forecasting model for energy used in transportation services has been initiated by Wharton Economic Forecasting Associates of Philadelphia (RP757). Wharton will develop the first full-scale model of energy used in transportation services, which will link energy use to demand for freight and personal transportation and to the existing supply of capital equipment for different transportation modes.

This transportation energy forecasting model is of interest to EPRI for two major reasons: First, it is necessary to know the energy required for transportation services in order to complete our total forecasting effort for national energy needs on which many of our R&D decisions will ultimately be based. Second, it is necessary to analyze the structure of transportation supply and demand in order to evaluate the impact and likelihood of the widespread use of electric transportation technologies, such as electric road vehicles or intercity rail electrification.

Freight transportation demand will be disaggregated by SIC code. Using an abstract modal choice model, each SIC's freight demand will then be allocated among the various transportation modes. The modal choice model explains a share of each mode based on the characteristics of the commodity being shipped and the characteristics of the mode, including its cost and the stock of cooperating social overhead capital.

For example, the share of the steel industry's output being transported by truck would be explained by truck freight rates, the total mileage of limited-access highways, other characteristics of transportation by trucks, and the characteristics of steel, such as its relatively high weight per unit value, relatively low bulk per unit weight, and lack of fragility.

On the supply side, the model will have behavioral investment equations and a vintage capital stock model for the equipment used by each transportation mode. The model for energy used in personal transportation services is technically similar to the model for energy used in freight transportation services. Personal transportation demand will be disaggregated into urban and suburban demand and intercity demand.

The second project in the transportation area that has been recently initiated is a study of the impact of electric automobiles on the utility system loads. In this study (RP758), Mathematica, Inc., will model the demand for electric automobiles in various classes of size, use, and location; the supply price of electric vehicles; and the rate of market penetration by electric automobiles. The supply analysis in this contract will analytically decompose the various electric automobile designs into their component engineering subsystems. Estimation of the total supply cost of electric vehicles with various technical performance and efficiency characteristics will be based on empirical cost-estimating relationships for the subsystems of the vehicle.

The impact on utility system loads will be computed under a variety of alternative battery recharging scenarios. This project will provide a framework for the further consideration and analysis of new electric automobile technologies and will allow us to estimate energy use by electric automobiles under explicitly stated assumptions on the state of battery technology and the performance characteristics of the vehicles.

Continuing Research

In the commercial area, we anticipate projects involving the development of better data, both of energy consumption and of energy-using equipment by SIC code, to the extent this is not accomplished by RP662. We will also look at the energy implications of land use planning and community development practices and will attempt to assess the market potential for both solar and heat pump heating and cooling systems by industry and by region.

In the transportation area, further work is planned on market potential for electric automobiles and electric commercial vehicles, including mass transit applications and intercity rail systems. The impact of these systems on electric utility loads will be analyzed. Also, as our forecasting effort becomes more regionalized, the transportation limitations and costs of interregional energy transfers will have to be more fully explored. *Project Manager: Anthony Lawrence*

Division Report
Fossil Fuel and Advanced Systems

Richard E. Balzhiser, Director

CLEAN GASEOUS FUELS

Combined-Cycle Systems

Coal gasification has several potential applications in power systems: as a clean fuel for steam boiler and combined-cycle systems and as a source of feedstock for methanol or hydrogen production. Of these, the greatest potential is in the gasification combined-cycle system. Its advantages over other coal-based systems include superior resource utilization for both coal and water, markedly reduced emissions, and (with advanced systems) the possibility of reduced capital investment and power cost.

Last November a conference was held at EPRI's Washington office to formulate and coordinate a broad-base national R&D program for the commercialization of gasification combined-cycle systems. Participants included representatives of companies active in gasifier development, turbine manufacturers, engineering contractors, power utility architect-engineers, fuel processors, and technical staffs from EPRI and ERDA.

The operation of two or more gasification units in conjunction with combined cycles at 150-Mw or greater by 1985 was suggested as a major goal. A balanced program of two separate but complementary and parallel parts was recommended. One part of this program would include projects specifically goal-oriented to the 1985 date, and the other would comprise those projects that are likely to improve the technology but will not reach the commercial stage until after 1985.

The conference participants concluded that parallel efforts on future process improvements were essential to achieve more economically competitive systems. It was emphasized that while gasification and turbine advances should be expedited, caution must be exercised to ensure that the goals of one project are consistent with the constraints of complementary endeavors. For example, it would be counterproductive to develop an advanced gasifier to produce 90-Btu/scf gas in the absence of a complementary program to develop a suitable combustor.

Another very important conclusion of the conference was that the potential control problems of operating such an integrated system for power production must be identified and solved as early as possible. The need for a national test center to investigate integration problems and for component testing at an early stage was clearly defined. The gasification combined-cycle test facility planned by EPRI and Commonwealth Edison for Commonwealth's Powerton station, which has been submitted to ERDA for support, is such a center. This facility will have two Lurgi gasifiers (one operating and one spare), with associate gas cleanup, feeding clean fuel gas to a 25-Mw gas turbine equipped with a heat recovery boiler.

A definitive cost estimate for the facility will be available in June 1976, and if ERDA support is forthcoming, the plant should be ready for the initiation of a three-year test program in May 1978. The knowledge gained from this project should prove invaluable for larger demonstration units of 150-Mw or greater capacity, which will probably be the next step toward commercialization. *Program Manager: Neville A. Holt*

Demonstration Plants

One of the most promising of several gasification pilot plants is the slagging fixed-bed gasifier being developed by British Gas Corp. at Westfield, Scotland (RP407). This project is sponsored by EPRI and 14 U.S. oil and gas companies. The anticipated improvements in throughput and thermal efficiency over a conventional fixed-bed, dry ash Lurgi have been demonstrated successfully in several runs. Two runs of seven days each have been achieved with production of up to 25 million scf/day of synthesis gas (equivalent to about 380 million Btu/hr). This output is about four times that of a same size dry ash Lurgi gasifier. Further work will cover a variety of coals and will examine methods for fine coal gasification and tar elimination. In response to a recent ERDA proposal request for high-Btu gas demonstration plants, a team of the sponsoring companies, headed by Conoco, is designing a project based on this technology.

With their ability to handle all U.S. coals without tar formation, entrained gasifiers are prime candidates for development. Supported by EPRI and ERDA, site work has been initiated on Combustion Engineering's 5-t/hr atmospheric pressure pilot plant at Windsor, Connecticut (RP244). Startup for a two-year test program is scheduled for June 1977. C-E's atmospheric design is expected to effect low cost and good reliability. The two stages of gasification should give superior thermal efficiency over commercial single-stage designs. The firing of the gas in both boiler and combined-cycle applications is being considered.

Babcock & Wilcox Co. has recently completed a detailed design and cost estimate for a 20-t/hr unit to operate at 50 psig (RP266). The site selected for this design was the Seward station of Pennsylvania Electric Co., where the gas can be fired in a modified existing boiler.

Pilot-scale work on a downflow devolatilizer–upflow gasifier is being done by Babcock & Wilcox at its Alliance, Ohio, laboratories (RP523). The goal of this project is to improve the heating value of the product gas and the overall thermal efficiency of the process. Although conditions have been established that permit the gasification of caking coals, tar formation has not yet been completely eliminated.

Char Gasification Tests in a Commercial Unit

FMC Corp.'s char oil energy development (COED) is a multiple fluidized-bed pyrolysis process developed through the pilot plant stage with government funds. The products of the process are gas, oil, and a char. The char represents more than half the energy in the feed coal. However, if the feed is high-sulfur eastern caking coal, the char product is higher in sulfur than can be burned in boilers under the EPA New Source Performance Standards. Gasification of the char is one solution to this problem, and EPRI has contracted with FMC for the testing of high-sulfur char in an existing commercial Koppers-Totzek gasifier in Puentes, Spain (RP264). About 1000 tons of char derived from West Kentucky and Pittsburgh seam coals were shipped to Spain early in 1975, and a series of successful tests was completed last August. The chars showed good reactivity, and carbon conversions over 90% were consistently achieved over a range of process conditions. Still better conversions in more modern gasifiers are predicted by Koppers. These tests also produced information of interest in the gasification of other coal pyrolysis residues, such as those from Coalcon hydrocarbonization.

Component Development

General Electric Co. is developing an extruder feeder for feeding fine caking coals to a pressurized fixed-bed gasifier (RP357). Successful extrusion tests against a back pressure of 400 psig have been accomplished with a 2-in extruder. The large 6-in-diam unit will be ready for full testing shortly. This unit is connected to a 2-ft-diam (approximately 1 t/hr) pilot plant gasifier designed to operate at 300 psig, which has been built by General Electric. The first gasification tests on the extrudates are anticipated early in 1976.

A panel bed filter for the removal of particulate from hot gas streams is being developed at City College of New York (RP257). The first phase of the project completed in 1975 focused on the "puff back" technique for removal of accumulated material and was mostly conducted with cold gas. The emphasis in the current work is on using hot gases and on initiating conceptual designs for a larger test unit. The resultant device may also permit the use of solid absorbents for hot H_2S removal.

Gasifiers require materials to withstand highly erosive/corrosive conditions at high temperature and pressure. Westinghouse Electric Corp. has recently begun a 30-month program to develop the design criteria for new refractories capable of withstanding these stringent conditions (RP625). Particular attention will be placed on the slagging regions where the possibility exists to alternate reducing and oxidizing atmospheres.

Engineering Economic Studies

Fluor Engineers and Constructors, Inc., is continuing to provide engineering economic studies on both advanced and current gasification processes (RP239). The work being reported covers the relative economics of air and oxygen gasification for pressurized fixed-bed, pressurized fluidized-bed, and two-stage entrained pressurized and atmospheric systems for the production of clean fuel gas. The design basis is 10,000 t/day of Illinois No. 6 coal. Results to date indicate that the advanced gasifiers could reduce the cost of gas to as low as 50% of current costs. Engineering work is currently underway on using these gasifiers in integrated combined-cycle systems. An oxygen-blown slagging fixed-bed gasifier, a conventional fixed-bed gasifier operating on western coal, and entrained gasifiers at various pressure levels have also been added to the scope of work. The cost of additional processing to meet possible future pollution control standards will also be assessed.

Stone and Webster, Inc., is investigating the relative economics of hot and cold gas cleanup for both particulate and H_2S removal in a range of gasifier types (RP243). This study will help to establish the relative importance of the development of hot gas cleanup in an overall gasification program. One interim conclusion is that the techniques for regeneration of H_2S absorbents used in hot gas cleanup are not well understood and engineering schemes are necessarily tentative at this time. *Project Manager: M. Gluckman*

One method of increasing the applicability of gasification to power systems is the coproduction of gas and storable liquid fuels. Most of the gas would be for base or intermediate loads and the liquids would be used for peaking. Fluor Engineers and Constructors, Inc., has conducted a screening study comparing load-leveled and non-load-leveled gasification systems (RP522). Although the costs were found to be similar, other considerations such as increased reliability from having a storable liquid fuel and avoiding cyclic operation of the gasifier would favor the load-leveled system. Both methanol and SNG/LNG were studied as possible liquid fuel options and were found to be similar in cost.

FOSSIL PLANT PERFORMANCE AND RELIABILITY

Well over two-thirds of the electricity produced in the United States is generated by fossil-fired steam plants. The amount of power generated by this method is expected to increase for many years. Raising the tremendous amount of capital to purchase the required new plants will be very difficult, and the interest costs on the debt will be high.

Minimizing the capital investment for new plants consistent with providing reliable service to their customers is a major objective of utilities. One way to minimize the investment is to achieve higher operating availability. (Operating availability is defined as the ratio of the number of hours a unit is available for service divided by the total number of hours in the time period.) According to Edison Electric Institute (EEI) the operating availability of fossil units 600 Mw and larger was 73.3% during the 10-year period 1965–1974. If this figure could be raised by 1%, the need for new capacity would be reduced by the equivalent of four 1000-Mw plants.

EEI (through the Equipment Availability Task Force of the Prime Movers Committee) has been collecting equipment availability statistics from the utilities for many years. The information is tabulated and issued in annual reports that are available to EEI members and to EPRI. These reports are useful resource documents in managing the improved steam plants projects. Although the statistics indicate which pieces of equipment are the major contributors to plant outages, they do not provide specific information on the cause of the equipment breakdown. For EPRI to initiate relevant research projects, it must develop more detailed information about equipment failures.

In cooperation with the Improved Steam Plants Working Group, it was decided that the most feasible method of obtaining the required information would be to hold meetings with the utilities that operate the large units and determine as well as possible the underlying causes of forced outages. Twenty-six companies operating 600-Mw and larger units were invited to attend one-day meetings held in six regions of the country. The discussions were technical and therefore budgetary, fiscal, regulatory, and management problems were not considered, although it was recognized that these problems may also significantly influence plant operating availability. Attendance was limited to the invited utilities, the Utility Working Group, and EPRI staff.

The response of the utilities to the regional meetings was very gratifying. The 26 companies invited sent highly qualified people to discuss the problems with equipment in their plants. Descriptions of equipment breakdown and information on probable causes were presented that would not have been obtainable by any other means. The information from these meetings will be correlated to determine if there are failure patterns in any component that could be reduced.

Boiler Feed Pump Survey

Boiler feed pumps have been a significant contributor to forced outages. Feed pump capacity has become so large that pumps cannot always be tested over the entire load range before installation. Experience indicates that problems can be caused by many circumstances. For example, service conditions may differ widely from specifications; piping connections to the pump are inadequately sized or supported so that vibrations are generated; hydraulic instabilities develop at certain flow rates; and lubrication systems breakdown. EPRI has sponsored a project to investigate feed pump failures that have occurred over the past several years (RP641). The circumstances and underlying cause for each failure will be determined, along with the temporary and permanent solutions used to overcome the problem. The results of the study can be used by the industry in several ways: to warn if failures are likely in certain types of pumps; to assist in establishing maintenance and operating procedures that reduce risk of failure; to recommend actions for repairing failures; and to provide guidance in writing specifications. The results may also indicate areas where further research would be beneficial.

Slagging and Fouling of Utility Boilers

As boilers became larger and as lower-grade coals were used, outages due to slagging and fouling increased. Past research correlated the elemental analyses and fusion properties of the ash with the slagging and fouling characteristics, and these correlations have been used with some success in boiler design. However, occasionally a coal will exhibit anomalous behavior by causing unexpectedly severe slagging and fouling in a boiler. The problem may be related to the molecular structure and distribution of mineral constituents in the coal.

A laboratory technique called low-temperature ashing has been developed that oxidizes the carbon and hydrogen in a coal sample at a temperature of approximately 160°C, leaving the mineral matter in its original molecular form. The mineral matter species can be identified by analytic techniques such as infrared analyses, X-ray diffraction, atomic absorption, spectrochemical analyses, and electron microscopy.

In this project (RP736), five different coals will be examined by the low-temperature ashing technique and the mineral matter analyses. The slagging and fouling behavior of the five coals will then be determined by burning each coal under closely controlled conditions in a utility boiler. Efforts will be made to correlate the slagging and fouling behavior of each coal with the laboratory analyses of its mineral matter.

Water Induction into Steam Turbines

Entry of water into steam turbines can cause turbine blading damage, rotor distortion, and other thermally induced stress conditions. On the basis of laboratory studies it is believed that these irregular episodes can be detected in utility steam power plants by using ultrasonic sensors properly located in the piping system and correlated with other plant conditions. The objective of RP637 is to determine the operating conditions that may produce water carryover from the boiler or feedwater heater system and by employing computer control techniques, to provide remedial action before turbine damage can occur.

Laboratory work on ultrasonic sensors will be done to establish feasibility before the installation of the system on utility plants.

Acoustic Emission and Vibration Monitoring

Advance warning of failure in rotating equipment is often given by changes in the acoustic and vibration signatures. If warning of impending failure can be detected far enough in advance, it may be possible to take corrective action and avoid a forced outage.

In RP734, acoustic and vibration sensors will be installed on equipment in a power plant. These will provide on-line readings to the operators so they can observe changes in the acoustic or vibration signatures and decide whether action is necessary. *Program Manager: V. Cooper*

At the Institute

FFAS DIVISION REORGANIZATION

In an effort to meet the changing needs of the utility industry, the Fossil Fuel and Advanced Systems Division (FFAS) was reorganized May 1 into four departments, one of which is responsible for a new EPRI program area.

In commenting on the reorganization, Richard E. Balzhiser, division director, explained that the move reflects the division's efforts to recognize in its formal organizational structure the changes in emphasis that have occurred in the R&D program over the last three years.

"The division is three years old and in those years we've learned a lot about the needs of the utility industry, the breadth of our technology, and the scope of our responsibilities," Balzhiser explained. "We've been restructuring the details of our programs and feel it is now time to recognize these changes in emphasis in the formal organizational structure."

As a result of the reorganization, a much greater emphasis is placed on the integrated systems approach to power generation and management. "We have to treat a power-generating system as an integrated whole," Balzhiser said, "from the coal pile to the electric busbar, for example. The reorganization reflects our thinking along these lines."

The four departments created by the reorganization are the Fossil Fuel Power Plants Department, the Advanced Fossil Power Systems Department, the New

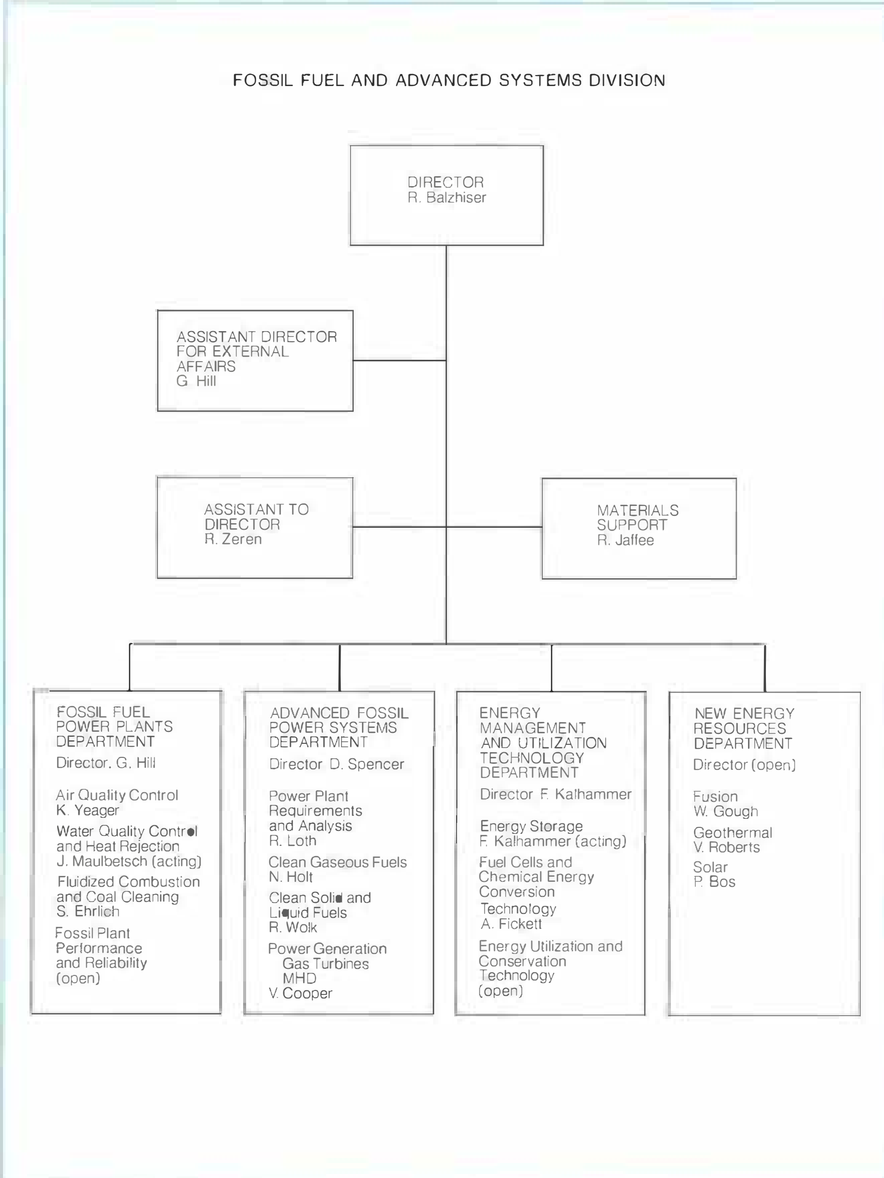
Hill Spencer Kalhammer

Energy Resources Department, and the Energy Management and Utilization Technology Department.

Heading the Fossil Fuel Power Plants Department as director is George R. Hill, formerly director of the Fossil Fuel Department. Hill is also serving as assistant division director for external affairs with responsibilities for coordinating the division's participation in EPRI's international exchange program, university relations, and memoranda of agreement with federal, state, and local governments.

Dwain F. Spencer (formerly technical manager, Planning) and Fritz R. Kalhammer (formerly program manager for Electrochemical Energy Conversion and Storage) have been promoted to department directors. Spencer is now director of the Advanced Fossil Power Systems Department, and Kalhammer is director of the Energy Management and Utilization Technology Department. The director of the New Energy Resources Department has not yet been named.

Three of the newly formed departments are concerned with the production of electricity. Both the Fossil Fuel Power Plants and the Advanced Fossil Power Systems departments will share the responsibility for researching and developing environmentally acceptable technology for converting coal and other currently available fossil fuels into electricity. The Fossil Fuel Power Plants Department will focus on improving current technology and developing new direct coal-fired systems. The Advanced Fossil Power Systems Department will be concerned with systems further down the road to commercialization, including coal liquefaction and gasification integrated with combined cycles. The third department concerned with energy production, the New Energy Resources



Department, will be examining more advanced technologies and resources, including solar, geothermal, and fusion.

Energy storage, dispersed generation, and improved end-use efficiency of electricity are the responsibilities of the fourth department, the Energy Management and Utilization Technology Department. This department will be concerned with fuel cells and will be seeking ways to reduce energy costs to the utility industry, the consumer, and the environment. Assigned to this department is a new EPRI program, the Energy Utilization and Conservation Technology Program, which will explore residential, commercial, industrial, and transportation applications of electricity. "This new program reflects the division's understanding that the goal of the utility industry is not only to produce more electricity but to use it in a more efficient way," Balzhiser explained.

Ways to Conserve Energy Detailed in New Publication

By the end of this century, Americans could make significant advances in the efficiency with which they use electricity if existing techniques are practiced, according to the authors of a new EPRI handbook, *Efficient Electricity Use.* The handbook is the result of an 18-month research project conducted for EPRI by Applied Nucleonics Co. of Los Angeles.

Published by Pergamon Press, the 996-page book details conservation techniques that can be adopted by any type of electricity consumer, from the design engineer to the homeowner.

Efficient Electricity Use begins with an overview of the energy-related problems now confronting an energy-constrained world. The handbook provides data on world and U.S. energy consumption and makes projections for the future. It focuses on each of the major energy-using sectors of the economy: industry, commerce, residential property, agriculture, transportation, and communications.

Efficient energy practices in regard to heat sources and electrolytic and electronic processes will be of special interest to equipment and process designers. Energy use in urban and suburban dwellings, in nonresidential buildings, and in cities is viewed from the system planner's perspective.

Highlighting the book are more than 50 detailed case studies demonstrating the implementation, economic savings, and environmental benefits of the suggested energy-saving techniques. One study, for example, describes an energy audit in an integrated steel plant, while another details total energy systems for commercial buildings. A third study demonstrates the measurement of direct energy use in residences.

To quantify the benefits of more efficient use of electricity, the authors discuss the potential electricity savings that could be achieved in the U.S. if the prescribed techniques were implemented in industry, commerce, residential properties, and transportation. According to their calculations, within the next several years the energy used in all types of operations could be reduced by 10% if available techniques were employed. Many of those techniques could be implemented with modest capital expenditures. Over a longer time and with greater capital investment, the authors project even larger energy savings.

Certain sections of the book are technical, while others are geared to the lay audience. The handbook has been organized so that it may be read in part, for specific information, as well as in its entirety.

Copies of *Efficient Electricity Use* can be obtained from Pergamon Press, Inc., Maxwell House, Fairview Park, Elmsford, NY 10523. Single case-bound copies are $45 and flexicover are $20, with a 25% discount for orders of 10 copies or more.

Starr, Hill, Spencer Testify on ERDA Budget

EPRI officials testified in late February before congressional units holding hearings in Washington, D.C., on 1977 ERDA budget requests. Chauncey Starr, president of EPRI, appeared before the House Subcommittee on Energy Research, Development, and Demonstration. George Hill, director of the EPRI Fossil Fuel Department, testified before the fossil fuel unit of the same subcommittee; and Dwain Spencer, EPRI technical manager for planning in the Fossil Fuel and Advanced Systems Division, testified before Senator Henry Jackson's Committee on Interior and Insular Affairs.

Starr stated that U.S. foreign oil and gas needs could be greatly reduced by increasing electrification and energy conservation and by concentrating on national resources of coal and uranium. By the year 2000, according to Starr, coal and nuclear may each account for as much as 43% of the electricity demand, with hydroelectric sources providing 5%, oil and gas 4%, geothermal 3%, and solar-thermal 2%.

Hill confirmed EPRI support in developing technologies for advanced coal combustion systems, "particularly atmospheric pressure fluidized-bed boilers, clean fuels from coal, specifically low- or intermediate-Btu gas, low-sulfur solid fuels, and synthetic petroleum and methyl fuels for boilers and gas turbines." Hill further emphasized that none of these systems presently approaches the low cost of power from pulverized coal-fired plants that use either low-sulfur coal or flue gas control.

Hill concluded his testimony by stating, "The uncertainties in future environmental control requirements are a major factor in selecting and developing clean fuels from coal and coal combustion alternatives. An extensive public health research program should be undertaken before environmental standards of uncertain value are established that could minimize the development of complex technology."

Spencer's remarks emphasized the importance of continued close cooperation between EPRI and ERDA. He stated the importance of electric utility development, testing, and demonstration of improved energy storage technologies—ranging from compressed air to battery storage systems—and how they eventually may be coupled with baseload coal or nuclear power plants. Spencer further pointed out that advanced energy conversion technologies could significantly improve overall power plant efficiencies, and he called for improvements in all elements of the electric system, including transformers, underground transmission systems, generators, and other components. At the same time, Spencer cited the importance of developing alternative energy sources, such as solar and geothermal.

Underground Transmission Offers Important Energy Option, Says EPRI Official

"With the electric utility industry hard pressed to deliver larger blocks of power because of increasing demands, fewer rights-of-way, and more strict environmental standards, underground transmission systems will someday be a major alternative to overhead lines," predicted EPRI program manager for underground transmission, Ralph Samm, addressing a meeting of the Institute of Electrical and Electronic Engineers in Tucson, April 8.

Samm cautioned his audience on the many problems to be overcome before underground systems can approach the lower costs of overhead lines. He said that the underground cables, not being subject to the elements, "are more reliable than overhead lines, but also very expensive and time-consuming to repair." According to Samm, underground cables are just beginning to carry the larger amounts of power required to make them more practical as extensions of, or alternatives to, overhead lines.

"Components of the underground system cannot withstand the higher temperatures inherent in transmitting large blocks of current," explained the transmission specialist. "And this is one of the key areas which EPRI, in cooperation with ERDA, has been working to resolve. Possible solutions might be the advent of synthetic tapes, advanced forced-cooling techniques, and cryogenic systems."

Concerning the potential impact of cable systems during the next ten years, the EPRI spokesman was optimistic. He said that taped cable systems, now rated 500 kv, will be uprated to 750 kv and above and will be more efficient, more economical, have a higher capacity, and be just as reliable as present systems.

Samm also remarked that extruded cable systems could be available shortly in transmission voltages through 345 kv, compared with today's 138-kv ceilings. "Their reliability and cost would approach that of a taped cable system," he stated.

At the same time, he said, flexible compressed-gas cable systems will be developed to 345 kv, and possibly even higher. "Less expensive, rigid gas cable systems may be attained by the three-in-one designs, with such designs eventually being converted to flexible cable technology."

The EPRI spokesman also predicted that resistive cryogenic systems may be commercially available by 1985, depending on the economics of equipment development and the scenarios of the particular installations involved.

EPRI Representatives Discuss Current Research at Power Conference

A wide range of energy topics was covered by members of the EPRI technical staff at the annual meeting of the American Power Conference late in April.

EPRI officials presenting papers at the Chicago conference included Louis J. Martel, speaking on the EPRI program to study PWR secondary water chemistry; Piet B. Bos, discussing both perspectives and prospects for solar energy; Paul Anderson, on research needs in power system long-term dynamics; Vance R. Cooper and Joseph W. Pepper, on the rationale for the EPRI thermal-mechanical energy storage program; and James W. Beck, on power conversion equipment.

James W. Beck and James R. Birk discussed features of the design and testing program for the Battery Energy Storage Test (BEST) Facility; Edwin L. Zebroski spoke about EPRI programs in nuclear systems and materials that bear on component design; E. Robert Perry delivered an update on transmission and distribution technology; Milton Levenson discussed the capital cost of the liquid metal fast breeder reactor; and Edwin L. Zebroski and Melvin E. Lapides spoke on developing methods for establishing improved plant reliability.

Plutonium—Major Energy Resource

"Plutonium should be considered a resource, like coal and natural gas," Walter Loewenstein, director of the Safety and Analysis Department, Nuclear Power Division, told an audience at the University of Puget Sound in Tacoma, Washington, recently.

Addressing a student-faculty seminar on the breeder reactor, Loewenstein said that studies at this time "indicate that plutonium, a by-product of light water reactors [LWRs], could be safely and economically used as fuel in LWRs." The nuclear energy specialist stated that plutonium would also be a major source of fuel for breeders. He warned, "Unless plutonium is considered a resource and used to its full potential, this country is going to experience serious uranium shortages."

As it generates electricity, the breeder transmutes uranium into plutonium, which can then be used to fuel other breeders. U.S. development of the breeder is being sponsored by EPRI and ERDA.

In Tacoma to receive the Alumnus Cum Laude Award from the university's Alumni Association, Loewenstein told his audience that breeders would have less environmental impact than conventional reactors because there would be less need to explore and mine for new uranium deposits. In fact, the energy specialist pointed out, "The uranium already mined in this country is adequate to fuel breeder reactors for several hundred years."

Although emphasizing the importance of treating plutonium "with respect," Loewenstein commented that the dangers of plutonium are frequently overstated. He cited the well-documented history of 25 workers, exposed to 100 times the allowable amount of radiation from plutonium during the Manhattan Project (1942–1946), who have undergone physical examinations each year since then without the discovery of biological aftereffects from the exposure.

Energy-Economy Relationships Explored

How do changes within the energy sector affect the general economy?

Although extensive information exists on how the economy influences energy, few data exist on how energy affects the economy, according to J. Daniel Khazzoom, a visiting professor of energy-economic modeling at Stanford University, in referring to a recent EPRI-sponsored workshop on this subject.

Held in Washington, D.C., the workshop helped to define the status of modeling between the energy sector and the rest of the economy and identified further research needs.

"Until the energy crisis," explained Khazzoom, "oil and natural gas were readily available, and energy prices were low and fairly stable. So information on how changes in energy cost and availability affect the economy was not considered essential.

"It took the oil embargo to dramatically illustrate just how important this information could be," stated Khazzoom. "At the time of the embargo, there were no models designed to determine adequately what the effects would be on the economy."

A leading U.S. model in this area is one developed by Edward A. Hudson and Dale W. Jorgenson as part of the Ford Foundation Energy Policy Project. Hudson is affiliated with Data Resources, Inc., and Jorgenson is a professor of economics at Harvard University. One of the main conclusions of this model is that a substantial reduction in energy use could be achieved without seriously affecting economic growth.

"This conclusion has been the subject of extensive debates in Congress, in the energy industry, and in the academic community," commented Khazzoom, who added that while several aspects of the Hudson and Jorgenson model were discussed at the workshop, other models were also explored.

Project Highlights

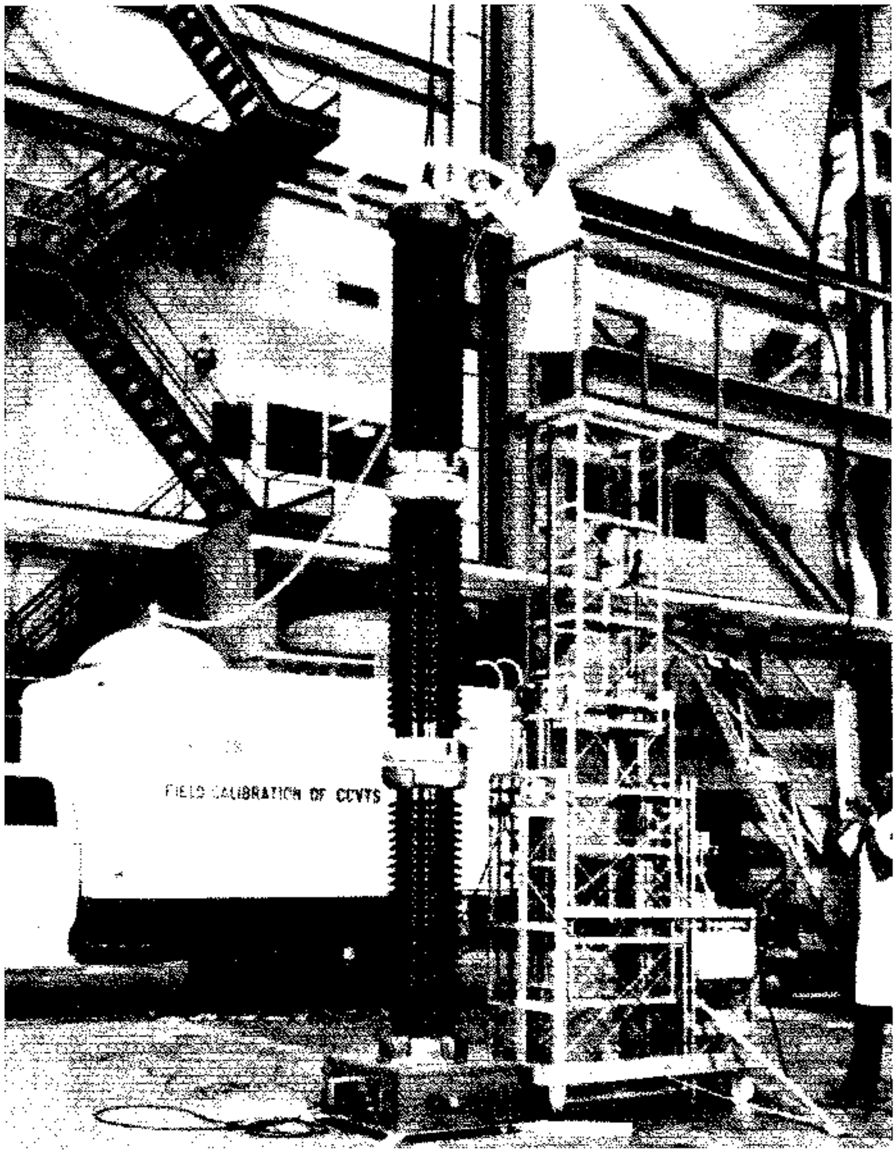
Truck-Mounted Calibration Unit Developed for Reading Verification of CCVTs

Under EPRI sponsorship and in close cooperation with the Edison Electric Institute, the U.S. Department of Commerce, National Bureau of Standards, recently developed a prototype of a portable calibration system for on-site verification of the voltage ratio and phase angle of coupling capacitor voltage transformers (CCVTs) used for metering.

Announcing the development of the truck-mounted calibration unit, EPRI's Walter Johnson, a project manager in the Transmission and Distribution Division, stated that the unit will soon be ready for commercial application. "Precise voltage metering is critical to the electric utilities," stated Johnson. "When there is, for example, a routing or emergency exchange of power between utilities, they have to know exactly how much was bought and sold. There's a good deal of money at stake."

When used commercially, the calibration unit will be connected to the high-voltage substation bus in parallel with the utility's CCVT and the outputs from the two devices will be compared to calibrate the CCVT.

CCVTs are widely used for voltage metering and power line carrier coupling at EHV and UHV voltages. The CCVT with metering accuracy, however, has especially critical requirements, and prior to this project, it has not been feasible to routinely verify long-term field performance.



Technicians at the National Bureau of Standards assemble a mobile CCVT calibration unit in a final laboratory checkout prior to field tests. The unit was developed under EPRI sponsorship and with the close cooperation of the Edison Electric Institute.

More Efficient Power Generators Under Development

Marketing and design studies are now underway on a new type of power generator that is much more efficient than conventional steam generators and may, in certain cases, eliminate the need for expensive sulfur removal devices, such as scrubbers.

In announcing the three new projects on magnetohydrodynamic (MHD) generators, Paul Zygielbaum, EPRI project manager for MHD studies, commented that although the energy conversion process by which MHD generators produce electricity has been known for over 100 years, it has been actively developed during only the past 20 years.

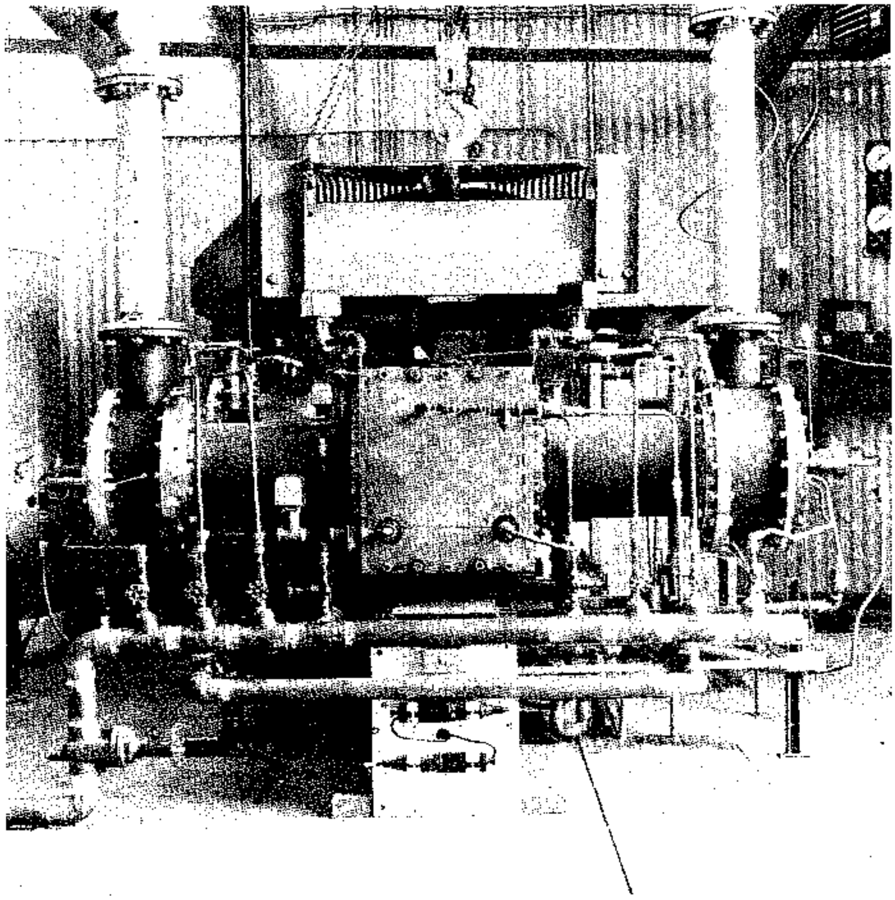
"The potential ability of these generators to directly use our country's large high-sulfur coal resources and their extremely high projected energy efficiencies when used in combination with steam generators are the main reasons for today's interest in their development," the energy specialist stated.

"Control of sulfur and nitrogen oxides in plant emissions has been a major development objective in recent years," commented Zygielbaum. "The latter problem is potentially more serious because of the extremely high temperatures at which the process operates."

The most popular scheme for sulfur control in MHD plants envisions the burning of coal gas seeded with potassium, which would then form potassium sulfate in the generator exhaust gas. The potassium and sulfur could later be chemically recovered, with the potassium being reused and the sulfur possibly sold for other industrial applications.

STD Research Corp., Arcadia, California, and Westinghouse Electric Corp., are performing system design studies under the new projects, with Westinghouse also identifying the most marketable type of design. As part of the systems studies, STD will determine the most effective method of controlling or using the nitrogen oxides produced in the combustion process. STD will also assess the trade-offs associated with ash carryover from the coal combustor.

In related MHD tests for ERDA, Westinghouse is operating a 50-kw MHD generator at the company's energy systems site in Waltz Mill, Pennsylvania. Shown here is the burner of this generator, which burns a simulated coal fuel composed of benzene with coal char and ash added.



The MHD process works by passing a hot conducting fluid, such as combustion gases from coal, between the poles of a powerful magnet. The motion of the conducting fluid passing through the magnetic field creates an electric current.

With MHD generators, combustion temperatures up to 4500°F could be reached as compared with temperatures of 3000°F normally found in steam generators. After electricity has been produced in the MHD generator, there would still be enough heat remaining in the fluid to make steam in a steam generator. The benefit: more power with less coal.

There are dozens of ways in which these power plants could be designed. "One of the main reasons for the studies is to identify a basic design that is not only technically good but also attractive to a large group of utilities," said Zygielbaum. "It's critical that the MHD plant design selected for the first U.S. demonstration plant be one that can accommodate the needs of as many utilities as possible."

Scheduled for 1989, the demonstration plant should be followed soon after by the first U.S. commercial MHD power plants. The USSR will probably have its first commercial MHD power plant sometime in the early 1980s. Instead of using coal, however, it is being designed to use natural gas. The only other countries with major MHD development programs are Japan and India.

Technique Developed for Measuring Voltage of HVDC Systems

A new way of measuring the high voltages of HVDC transmission lines without using a resistive voltage divider was recently reported by Stig Nilsson, a project manager in the Transmission and Distribution Division.

The devices presently used for ac measurements are not able to reproduce a steady state dc quantity, since this would saturate the transducer. A dc measuring device must, of course, provide the dc information, but must also accurately reproduce all transient information, which makes the measuring problem more difficult. For gas-insulated systems, it is also necessary to have a compact device.

The new device (called a voltage transducer) uses the static voltmeter principle, sensing capacitive displacement currents from the dc bus and producing an ac voltage proportional to the electrostatic field. (The bus is the link between large power components in a substation.)

The measuring device is compatible in size with other gas-insulated components of the compact terminal. All electronic equipment is at ground potential. Its reliability and performance predictions are promising, with an accuracy that is applicable also to metering requirements.

Utilities must know the direct voltage output of HVDC converters for fault recording, power control, line protection, metering, and operator display of the line voltage.

The development of this measuring technique was termed a side benefit of EPRI's largest dc transmission project, according to Nilsson. Being performed by the General Electric Company, the $21 million project calls for the design and construction of a prototype compact HVDC converter at Consolidated Edison Co.'s Astoria Station in Queens, New York. The 400-kv, 100-Mw dc system now being designed is a step toward the development of smaller HVDC substations.

EPRI Negotiates 39 New Contracts

No	Title	Duration	Funding ($000)	Contractor
Fossil Fuel and Advanced Systems Division				
RP114-2	Advanced Technology Fuel Cell Program	38 months	7,200.0	United Technologies Corp.
RP255-2	Battery Energy Storage Test (BEST) Facility	3 months	150.0	Public Service Electric and Gas Co.
RP533-3	Development of Agglomerator and New Collector for Electrostatic Precipitators	1 month	7.8	Time Data Corp.
RP627-1	Design Properties of Steels for Coal Conversion Vessels	2 years	250.0	Westinghouse Electric Corp.
RP629-1	Improved Fuel Evaluation Procedure and Testing Facility for Characterization of Fly Ash and for Prediction of Electrostatic Precipitator Performance	18 months	351.1	Babcock & Wilcox Co.
RP630-1	Evaluation of Improved Control Capability for Flue Gas Desulfurization Processes	5 months	32.0	Radian Corp.
RP637-1	Detection of Water Induction–Steam Turbines	15 months	257.0	Westinghouse Electric Corp.
RP639-1	Operational Analysis of Open-Cycle MHD Power Generation	1 year	249.6	Westinghouse Electric Corp.
RP640-1	Open-Cycle MHD Systems Analysis	1 year	167.5	Westinghouse Electric Corp.
RP640-2	Open-Cycle MHD Systems Analysis	1 year	151.0	STD Research Corp
RP644-1	Design of Improved Materials Systems for Coal-Fired Boiler Superheater and Reheater Tubes	2 years	192.3	Foster-Wheeler Energy Corp.
RP651-1	Requirements Assessment of Photovoltaic Electric Power Systems	14 months	399.0	General Electric Co.
RP730-1	Evaluation of Beta Alumina as a Fuel Cell Electrolyte	1 year	87.6	General Electric Co.
RP787-1	Capital Costs of Advanced Batteries for Utility Energy Storage	5 months	35.0	Arthur D. Little, Inc.
RP788-1	Technical and Economic Assessment of Phase Change and Thermochemical Advanced Thermal Energy Storage Systems	5 months	49.8	Boeing Engineering and Construction
RP790-1	Thermophotovoltaic Energy Conversion	1 year	84.4	Stanford University
Nuclear Power Division				
RP218-2	Field Evaluation of In-Service Strain Monitoring System for Power Plant Piping	1 year	200.0	Southwest Research Institute
RP230-2	Decay Heat Program	8 months	35.8	General Electric Co.
RP306-3	Radioactivity of Recycle Fuel: Effect of Fabrication on Mixed-Oxide Fuels	10 months	99.2	Babcock & Wilcox Co.

Improving Underground Power Transmission

A new way of moving oil through underground power cables, which may increase the efficiency and reliability of such cables, is now being examined by EPRI, according to the project manager for the study, Thomas Rodenbaugh.

In announcing the selection of the University of Illinois, Urbana, as the contractor for the $151,000 study, Rodenbaugh said that researchers will evaluate a novel concept that uses the electrons from a high-frequency electric field to pull molecules of oil along the underground cable system. The oil cools the cable's insulation, preventing overheating and power failures.

Most electric utilities rely on the natural convective properties of the cable's heat meeting the cool oil to circulate the oil. However, if the oil could be forced through at a faster pace, larger amounts of power could be transmitted without the insulation overheating.

The only method currently available for forcing oil through the pipes is by pumping. "But like all equipment, pumps require maintenance and repair," said Rodenbaugh, a technical staff member in the EPRI Transmission and Distribution Division. "At the same time," Rodenbaugh explained, "if there is a power failure in the cable system, the pumps are inoperable since they depend on the same electricity."

Underground cables seldom carry their rated amount of current because of the overheating problem. "If the concept we're investigating proves to be practical," stated Rodenbaugh, "the electrons would provide a constant, maintenance-free method of moving cable oil and also greater amounts of power."

The award marks the second phase of an EPRI study on free and forced convective cooling of cables. The first phase, also conducted by the University of Illinois under EPRI sponsorship, looked at different structural designs for underground cables in an attempt to enhance the transfer of heat from the cables to the oil.

No.	Title	Duration	Funding ($000)	Contractor
RP502-2	Reliability of Steam Turbine Rotors—Nondestructive Evaluation	2 years	350.0	Battelle, Columbus Laboratories
RP502-3	Reliability of Steam Turbine and Generator Rotors	2 years	200.0	Westinghouse Electric Corp.
RP502-4	Reliability of Steam Turbine and Generator Rotors	2 years	500.0	Westinghouse Electric Corp.
RP503-2	Sensor Time Response Verification	16 months	146.3	Babcock & Wilcox Co.
RP507-2	Analytical Fuel Rod Modeling in Support of the Studsvik Interramp Test Project	1 month	7.0	Science Applications, Inc.
RP601-2	Methodology for Plastic Fracture	35 months	895.0	General Electric Co.
RP603-1	Fundamental Study of Crack Initiation and Propagation	2 years	690.0	Lawrence Livermore Laboratory
RP708-1	Improvement of the ENDF/B Nuclear Data Base for Use in Thermal Reactor Analysis	1 year	110.0	Brookhaven National Laboratory
RP709-1	Improvement of Thermal Benchmark Analysis Procedures	1 year	40.0	Technion Research and Development Foundation, Ltd.
RP766-1	Measurement of Beta and Gamma Fission Product Decay Heat for ^{239}Pu	1 year	96.4	Intercom Rad Tech Corp.
RP768-1	Methodology Development for Statistical Evaluation of Safety-Related Engineering Analysis	3 months	25.0	Westinghouse Electric Corp.

No.	Title	Duration	Funding ($000)	Contractor
Transmission and Distribution Division				
RP655-1	Design and Development of a Prototype 500-kv Reactor/Capacitor Switching Device	2 years	256.4	Bonneville Power Administration
RP744-1	Frequency Domain Analysis of Low Frequency Oscillations in Large Electric Power Systems	1 year	350.0	Westinghouse Electric Corp.
RP752-1	Transformer Hot Spot Detector	10 months	248.5	Nucleonic Data Systems
RP798-1	Permanent Magnetic Fields in Superconductors for S/C Generators	1 year	70.0	Battelle, Pacific Northwest Laboratories
RP7849-1	Installed Cost Comparison for Self-contained and Pipetype Cables	7 months	72.0	Power Technologies, Inc.
Energy Systems, Environment, and Conservation Division				
RP434-2	Electric Utility Rate Design Study	1 year	103.3	Temple, Barker, and Sloane, Inc.
RP757-1	Analysis and Forecasts of Energy Used for Transportation Services	1 year	119.6	Wharton EFA, Inc.
RP759-1	Fuel and Energy Price Forecasts	8 months	145.0	Stanford Research Institute
RP802-1	Development of a Disaggregated Data Base for Industrial Energy Demand Models	1 year	57.4	Research Triangle Institute, Inc.

Each month the JOURNAL publishes summaries of EPRI's most recent reports. Supporting member utilities receive copies of reports in program areas of their designated choice. Supporting member utilities may order additional copies from EPRI Records and Reports Center, P.O. Box 10412, Palo Alto, CA 94303. Reports are publicly available from the National Technical Information Service, P.O. Box 1553, Springfield, VA 22151.

New Publications

Nuclear Power

EPRI 84-2 HISTORY AND SUMMARY OF GENERAL ATOMIC STUDIES OF HTGR PLUTONIUM UTILIZATION
Final Report
This report covers work performed over a seven-year period. During this time the problems of plutonium fuel analysis and design have come into sharper focus, and the theoretical basis for analysis has improved. The first part of this report is a historical review of work done by General Atomic Co. The second part describes recent probes into two alternative modes of HTGR plutonium utilization: one involving the use of uranium feed, either recycled ^{233}U or purchased ^{235}U; the other including only plutonium and thorium in the feed stream. The historical review reports past conclusions chronologically, without updating. The later work is thus an advancement over the earlier studies.

The work described in this report can be classed as conceptual fuel-management analysis rather than core design. Careful studies have not yet been made of the effects of reactor geometry, dimensionality, and regional heterogeneities. *Contractor: General Atomic Co.*

EPRI 220 IMPROVEMENT OF REFERENCE NUCLEAR DATA FOR COMMERCIAL POWER REACTOR ANALYSIS AND DESIGN
Final Report
EPRI's objective in the area of nuclear cross sections has been the development of a national standard data base. Since the Evaluated Nuclear Data File System (ENDF/B) has been found to meet most of the requirements as a standard from a fast reactor point of view, EPRI programs have attempted to improve the performance of this file in thermal reactor applications.

The present report, prepared by the National Neutron Cross Section Center (NNCSC), Brookhaven National Laboratory, describes the analysis of a series of critical experiments, using the latest version of the cross-section library (ENDF/B-IV). This work is of particular importance to the EPRI program because of NNCSC's key role as coordinator for the Cross-Section Evaluation Working Group responsible for developing the ENDF/B library. It is also important because information on how the present version of the library is performing in thermal benchmark experiments is needed to guide the preparation of the next version.

One particularly persistent problem, "the discrepancy between measured and calculated capture rates in ^{238}U rods," was the topic of a workshop organized for EPRI by NNCSC. The proceedings of the workshop are outlined in this report. *Contractor: National Neutron Cross Section Center, Brookhaven National Laboratory*

EPRI 306-1 MULTIPLE-CYCLE PLUTONIUM UTILIZATION NONDESTRUCTIVE TESTING
Interim Report
The report documents the results of the fuel examination that was performed at Big Rock Point on the two uranium fuel assemblies (referred to as the J-1 assemblies) during the March 1972 reactor outage. The objective of the fuel inspection was to obtain data that would characterize the physical condition of the fuel assemblies after one cycle of reactor exposure. The data obtained include bundle-sipping test results, profilometry of removable rods, results of eddy current tests of removable rods, results of visual examination and photography of removable rods, and rod growth measurements of removable rods. *Contractor: Exxon Nuclear Co.*

EPRI SR-23 A PROPOSED EPRI EXECUTIVE SYSTEM AND DATA BASE
Special Report
This report summarizes the long-range objectives of EPRI's Nuclear Power Division in developing a viable data base and interacting computer programs. The data base considered will contain both experimental and analytic data. The computer programs considered may be simple programs to reduce data or sophisticated computation systems for solving such problems as LOCAs or reactor physics calculations of an LWR. In addressing these problems, the types of computers available and the existing executive systems were studied. Of equal importance were the types and physical locations of the potential users—EPRI, the electric utilities, and the general nuclear community. The use of the proposed system should ensure an orderly and prompt transmittal of data from the researcher to the many different users in a simple, well-documented, and accessible form.

EPRI SR-27 ACCIDENT-MONITORING INSTRUMENTATION: STUDY OF THE IMPACT OF PROPOSED REGULATORY GUIDE 1.97
Special Report
This report is an assessment of the impact of proposed Regulatory Guide 1.97 (Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant Conditions During and Following an Accident) on the instrumentation provided at a typical Westinghouse pressur-

ized water reactor (PWR) nuclear generating station. This study was performed so that the probable impact of the proposed regulatory guide on the utility industry could be determined expeditiously.

At the outset it was felt that substantial amounts of new instrumentation and stiffer qualification testing of existing plant instrumentation would be required to meet the regulatory guide requirements. However, this study attempts to show that the requirements of the regulatory guide may be satisfied in a cost-effective manner. The probable effects of this cost-effective solution are identified in the report.

The necessary accident-monitoring instrumentation for a typical PWR is identified and compared with the proposed regulatory guide requirements in this report. Suggestions are given for resolving observed deficiencies.

For each utility applicant, this report should provide an effective starting point for a comprehensive review of the plant accident-monitoring instrumentation. Where significant differences of opinion have arisen among the reviewers of this report, the dissenting viewpoints have been included. *Contractor: Nuclear Services Corp.*

EPRI SR-30 PROCEEDINGS OF NDE EXPERTS WORKSHOP ON AUSTENITIC PIPE INSPECTION
Special Report
In late 1974 and early 1975 a series of intergranular stress corrosion cracking incidents occurred in some boiling water reactor systems. As a result of the concern about this problem, a workshop involving approximately 40 people knowledgeable in nondestructive examination (NDE) fabrication technology and materials was held.

The major problems encountered during in-service inspections of austenitic pipe welds were identified and potential solutions for the problems were offered. The recommendations included changes in fit-up procedures, design considerations, improvements to existing ultrasonic inspection procedures, code requirements, equipment standardization, new signal-processing concepts, alternative inspection methods, and operator training. The justification and detailed discussion of each of these recommendations is contained in this report.

EPRI TSA-16 GAMMA-RAY HEATING IN POWER REACTORS
Final Report
The techniques for calculating gamma-ray heating in LWRs are reviewed in this report. An effort was made to consider all techniques that provide insight into the methods used for calculating photon heating and to examine the range of applicability of each technique. Recommendations are made concerning basic data, cross-section libraries, processing codes currently used in the industry, and techniques that can be used to obtain working data sets.

Benchmark experiments and their use in validating calculations are presented. Typical gamma radiation fields in current-generation LWRs operating at power are considered. A review of methodology—including use of the recommended decay heat curve, gamma redistribution factors, and mixed-oxide fuel effects—is given for the fission product power generation following shutdown. *Consultant: Nuclear Services Corp.*

Fossil Fuel and Advanced Systems

EPRI 96-2 FUSION R&D ON ADVANCED FUELS, HOMOPOLAR GENERATORS, CIRCUIT BREAKERS, AND TOKAMAK DIAGNOSTICS
Final Report
This report describes fusion research and development work carried out by the University of Texas for EPRI. The general purpose of this program was twofold: (1) to investigate theoretically the potential for the use of advanced fuel cycles and direct conversion in tokamak systems and the development of automated data acquisition systems for tokamaks, and (2) to explore both theoretically and experimentally the potential of homopolar generators and inductive energy storage devices as power supplies for future fusion experiments. *Contractor: University of Texas*

EPRI 115-2 FUSION REACTOR STUDIES: KEY PHYSICS QUESTIONS USING THE DC OCTOPOLE
Key Phase Report 1
This report provides a brief history of octopole experiments and describes in some detail the work of the past year. This work involved an experiment using a divertor-tokamak system and developed plasma conditions capable of entering the trapped ion mode regime, an important parameter space useful for fusion reactor studies. *Contractor: General Atomic Co.*

EPRI 115-2 FUSION REACTOR STUDIES: POTENTIAL OF LOW Z MATERIALS FOR THE FIRST WALL
Key Phase Report 2
This report covers progress made in the past year on a study of the utilization of low atomic number ceramic materials for fusion reactor application with emphasis on first-wall problems and includes work in the areas of materials properties and engineering design for application of ceramic materials. *Contractor: General Atomic Co.*

EPRI 115-2 FUSION REACTOR STUDIES: DOUBLET III DESIGN
Key Phase Report 3
This report describes the physical and engineering design parameters for the Doublet III fusion experiment.

The Doublet III experiment has as its primary goal the test of confinement of noncircular cross-section toroidal plasmas in the regime where trapped ion effects may be operative. The importance of the experiment stems from the potential of noncircular cross-section toroidal plasmas for fusion reactors that will operate in a regime that may be dominated by trapped ion effects. The guiding principles for the design of the Doublet III device have been: (1) to minimize the physics risks in reaching the desired regime, i.e., to use the smallest possible extrapolations from existing experimental results, (2) to minimize technological risks, i.e., to use proven technology wherever possible, and (3) to minimize costs and time involved in achieving the goal. *Contractor: General Atomic Co.*

EPRI 202 THE ENVIRONMENTAL EFFECTS OF TRACE ELEMENTS IN THE POND DISPOSAL OF ASH AND FLUE GAS DESULFURIZATION

Final Report

This project investigated the disposal of solid wastes from coal-fired electric generating stations from the standpoint of trace element contamination of groundwater. Coal ash and lime-limestone flue gas desulfurization sludge are commonly disposed of by ponding. The trace elements entering the generating station in the coal will leave the station primarily in the ash and sludge. Contact with water in a disposal pond will dissolve the trace elements, and if pond leakage occurs, present a potential problem with groundwater contamination.

Samples of ash and sludge from five operating generating stations were exposed to leaching conditions to simulate ponding. In general, the levels of the dissolved trace elements were low, near the analytic detection limit. Selenium, chromium, boron, and in isolated instances, mercury and barium exceeded the proposed EPA Public Water Supply Guidelines.

Water leaking from a pond will pass through a soil layer before mixing with groundwater. A series of batch and column tests, using ash and sludge leachate in contact with natural soils, were conducted to determine the degree of removal of trace elements in pond subsoil. Passage of pond effluent through soil was found to provide significant protection against groundwater contamination by trace elements. *Contractor: Radian Corp.*

EPRI 265-1 RETROFIT OF GASIFIED COAL FUELS TO STEAM GENERATORS

Final Report

This study assessed the capability of existing steam generating units in electric utility plants when firing low-Btu gas (LBG). The objectives of the study were: (1) to determine the maximum generating capacity without modifying existing pressure parts or auxiliary components, (2) to establish the minimum heating value of LBG that could be used to obtain original maximum continuous rating, (3) to define the alterations and estimate the order of magnitude costs that would be required to achieve original maximum continuous rating, and (4) to provide performance data to make a comparative evaluation of LBG firing.

This report includes an evaluation of five different low-Btu gases with higher heating values of 105, 128, 179, 292, and 396, as well as a tabulation showing a complete chemical analysis of these gases.

In this project, six typical modern steam generating units were randomly selected. They ranged in size from 250 Mw to 900 Mw, included both subcritical and supercritical pressure steam cycles, and were originally designed with tangential firing systems to fire one of the predominant fossil fuels (i.e., pulverized coal, fuel oil, or natural gas). *Contractor: Combustion Engineering, Inc.*

EPRI 323 EXPERIMENTAL POWER REACTOR CONCEPTUAL DESIGN STUDY

Key Phase Report

This is an interim report that describes the work carried out during the first year of a two-year conceptual design study of a fusion experimental power reactor (EPR). The primary objectives of the program are to develop a conceptual design of an EPR, utilizing the concepts of noncircular tokamaks, and to carry out conceptual and analytical studies of critical problem areas.

The important plasma physics-related problem areas that have been examined during the past year are described. These studies have emphasized plasma scaling considerations, power balance and ignition conditions, α-particle effects, pellet fueling, plasma field-shaping requirements, startup sequences to minimize volt-second requirements, and plasma boundary problems.

Reactor design alternatives for various components and subsystems of the EPR are discussed, and an initial conceptual design developed early in the study is described in an appendix. The subelements of this initial conceptual design do not necessarily involve the optimum choice of each design alternative for the various reactor components. Rather, this initial design was used as a basis for identifying and developing technical information on the various alternative design concepts presented in the main body of the report.

During the initial months of the second year, a thorough evaluation will be made of the various design alternatives and the initial conceptual design will be modified as required. The resulting design will then be validated by analysis of the critical elements and a conceptual design will be generated for the overall EPR test facility, including remote handling equipment. Another report will then be issued (July 1976) to describe the revised conceptual design and the results of the various supporting studies. A preliminary cost estimate of the EPR will be included. *Contractor: General Atomic Co.*

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