1976 Review

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

NUMBER ONE

JANUARY/FEBRUARY 1977

EPRI JOURNAL is published by the
Electric Power Research Institute.

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

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EPRI JOURNAL

Volume 2, Number 1 January/February 1977

1976 REVIEW ISSUE

About This Issue

Recapping EPRI's 1976 achievements for this special issue of the JOURNAL involved coincidence and surprise for our writers and editors, as well as the division directors and program managers who discussed their work with us and then checked what we wrote.

The coincidence is that EPRI's Planning Staff sought to characterize the Institute's major accomplishments at about the same time we did, but in the much more focused form needed for presentation to the Research Advisory Committee in mid-December. Our technical management staff was thus able to "think once" and serve two communication purposes. The distillation of accomplishments was so effective that we adapted it for this JOURNAL (pages 4-7), where it can serve as a summary, or perhaps as a selector of topics to be read in more detail in subsequent pages.

The surprise lies in the intensified feeling of accomplishment so many EPRI people have experienced as they reviewed the manuscript for this issue. The feeling is shared by our writers and editors, too. It's something that happens only when you're able to rise above the daily routine, among the trees, so to speak, and look at the whole forest.

The main features this month are four articles that review the 1976 work of EPRI's technical divisions. Planned by the editorial staff, they share a single purpose, and they might therefore be expected to have great similarity. Happily, not. The perceptions of our division directors are different, their temperaments are different, and their principal staff members are different too. All these factors subtly influenced the selection of accomplishments and the tone in which they were presented by our writers and editors.

A word about the JOURNAL. Even when on an editorial deadline, it is rewarding to stand aside from that deadline—and all others—to review purposes. We have two objectives: to report on the progress of EPRI's research sponsorship and to illuminate some of the technological issues, programs, and disciplines with which EPRI is involved.

Judging from what we hear, the JOURNAL is progressing nicely. "You're too technical!" tells us that the intricacies of complex physical, chemical, thermal, mechanical, electrical, and even logical processes are being preserved for those readers who can understand and benefit from them.

"You simplify too much!" tells us that the JOURNAL is serving another intended audience: men and women of management or scholarship apart from a given topic who need or want a contemporary summary of it.

We will continue to respond to both needs, perhaps with an even sharper distinction of subject matter, in 1977. The March issue, which will resume the JOURNAL's regular editorial mix, will show you what we mean.

1976 in Perspective

A year ago—in the first issue of the EPRI JOURNAL—I said that we expected the JOURNAL to be a major element in a "cohesive communications program" from EPRI, bringing its readers monthly accounts of technical program progress. Now we devote this special issue to a recapping of the 1976 accomplishments of the technical divisions and the highlights of developments of general interest.

The technical progress chronicled here falls into two general categories: specific projects that have the likelihood of resulting in commercially available hardware in the near term; and encouraging movement in those programs that require significant front-end effort now if they are to result in new or improved technical options.

The developments summarized on the following four pages (and discussed in greater detail in the division reviews) fall mostly in the first category. Many are so near commercial availability that anticipated dollar benefits can be roughly foreseen. Program progress that is expected to produce a long-range payoff is more difficult to chart, but such progress is described in the division presentations.

Even less susceptible to "charting" is EPRI's developing organizational capability, which is only partially reflected in the accomplishments summarized in this issue. Three years ago the Electric Power Research Institute had a skeleton staff, a modest technical program (largely inherited from the Electric Research Council), and a long list of expectations. Staffing began in earnest, and with the help of the industry advisory structure, the outline of a comprehensive R&D program began to take shape. We can now say to our supporters that in the space of a few years we have moved from an emphasis on analyzing, planning, and staffing to one of active pursuit of solutions to the existing and anticipated technical problems of the nation's electric utilities.

With a technical staff largely in place and with Board approval of R&D targets and funding guidelines, EPRI has taken shape as a productive research and development organization consistent with the vision of its founders. However, we need to recognize the early stage of EPRI's programs. We cite our 1976 accomplishments in this issue because it is timely to do so, not because we have reached anything approaching a plateau of success. One of the chief accomplishments in EPRI's formative years has been the development of an understanding of the magnitude of the task we have before us. It is a task that requires progress that will be measured in decades rather than in years, as well as by ongoing current contributions.

The proper perspective on the past year, then, is one that acknowledges the value of our early accomplishments but sees the real promise in the years ahead from a more matured EPRI.

Chauncey Starr, President
Electric Power Research Institute

Highlights of 1976 Research Progress

The visibility of R&D success is not apparent from organization charts or budget allocations. You find it when you assess specific accomplishments against an ever-evolving background of needs.

The 38 R&D accomplishments reported here are examples chosen by the EPRI editors and technical staff. They are marked by the time of their compilation, as well as by the perceptions of those who chose them. The list is not all-inclusive, nor is it presented in priority order. The intent is to illustrate instances where we feel that EPRI's 1976 technical findings are already making a difference in the course of research or in commercial application.

FOSSIL FUEL AND ADVANCED SYSTEMS

Energy storage Energy storage potential defined: seen capable of filling as much as 5% of total electricity needs and meeting up to 17% of peak demand. Because technologies are established, early edge goes to underground pumped-hydro, compressed-air, and thermal storage.

Raises capacity factors for efficient baseload generators; cuts use of oil-fueled peaking equipment. If dispersed, may defer need for new transmission line capacity.

Geothermal energy A 50-MW capacity and a southern California desert site picked for low-salinity hydrothermal power generation, and utility syndicate formed to sponsor demonstration plant. Decision followed studies of 16 geothermal fields, 9 process-reservoir combinations, and 3 plant sites.

Combinations of subterranean steam and hot water resources might provide up to 40,000 MW of geothermal generating capacity in the West and Southwest by 2000.

Solar energy Methodology established for designing optimal residential solar heating and cooling systems. Demonstration systems and their monitoring instrumentation designed for 10 houses to be built in 1977 in Long Island and New Mexico.

Three-year evaluation of demonstration houses uses several systems and operating modes to reveal energy need and cost experience for both users and utilities.

Coal gasification Fixed-bed slagging gasifier tests with U.S. coals yielded gas output and thermal efficiency markedly better than today's Lurgi gasifier.

Linked to a combined-cycle plant, the new technology should use fewer resources (coal, water, land), produce fewer emissions (SO_2, NO_x, particulate, thermal), and be cost-competitive with a coal-fired plant using scrubbers.

New distillate process New coal-derived liquid fuel process invented, combining steps from liquefaction, gasification, and methanol synthesis processes. End products, methanol and low-boiling distillates, suited for gas turbine and fuel cell operations to generate electricity.

Advanced stage of most process steps encourages expectation of success in developing an integrated process to produce high-quality distillates from coal.

Particulate emission control New, separate ionizer for electrostatic precipitator fully tested at 5000-ft^3/min flow rate, being scaled up for 280,000-ft^3/min commercial retrofit application. Device uses a 15-fold increase in gas velocity and high field strength to impart 5-times-greater charge to fly ash particles.

The 280,000-ft^3/min retrofit cost is equivalent to $6/kW. Small size and high efficiency enable potential benefits up to 30% in capital cost for new installations, 50–70% for retrofitting.

Demister and reheater design Critical engineering data published for site-specific design of stack-gas demisters and reheaters used with scrubbers. Demister and reheater equal in importance to scrubber in designing for reliable overall operation.

Better reliability of demisters and reheaters means better availability for scrubber systems. Payoff is in more effective air pollution control at lower operating cost.

NO_x reduction Two-stage combustion in the furnace of a 550-MW coal-fired power plant proved far more effective than windbox gas recirculation for cutting NO_x emissions. (Tests performed in anticipation of future NO_x control standards.)

Research results narrow the field of useful NO_x

control methods and point to capital cost savings by avoiding windbox recirculation fans and ductwork in coal-fired plants.

Dry-cooling design Conceptual design completed for dry-cooling tower, using isothermal phase change to reject heat from ammonia-filled transport loop. Novel system seen more effective than conventional dry cooling in high ambient temperatures.

Study results indicate phase-change system cost to be half that of conventional design and justify pilot-scale test.

Coal-oil fuel mixture Coal-oil emulsion tested in oil-fired boiler as possible means to stretch fuel oil supplies. Slurry character, flame stability, ash removal, and stack emissions studied.

Technically successful, but tests showed limited economic advantage for utilities.

Heat treatable alloy Strength and fracture toughness required for retaining rings on generators achieved by heat treatment of nonmagnetic austenitic Fe-NiTi alloy.

Heat treatment potentially costs less than cold working now used and should be more reliable.

H-Coal H-Coal process operated at 3-ton/d to produce both liquid boiler fuel and syncrude. Construction started on 250–600-ton/d pilot plant.

Successful operation of large pilot plant will provide technical basis for H-Coal commercialization by utilities.

NUCLEAR POWER

Nuclear plant tornado safety Full-scale tests with rocket-launched projectiles demonstrated that nuclear plant walls are structurally safe even if struck by tornado debris driven to improbably high speeds.

Modification of regulatory design criteria could save about 17% in wall construction costs.

New software Five new analytic computer codes developed that give utilities independent capability to perform reactor fuel management, to evaluate operations safety, and to conduct structural analyses.

Estimated $30 million savings to utility industry.

Blowdown heat transfer Engineering test program provided basic information on BWR system performance and thermal response characteristics under LOCA conditions, including several inherent cooling mechanisms for which no regulatory credit is taken in current LOCA evaluation methods.

Expected 1% increase in BWR capacity factors could bring savings of $100,000–$600,000 per plant per year.

BWR pipe cracking Research on nature, extent, and consequences of intergranular stress corrosion cracking in BWR piping helped to establish a consensus supporting the methodology currently required for crack arrest analysis and to increase confidence in it.

Research results minimize probability of increased regulatory action, thus reducing off-line delays and inspection costs by at least a factor of five.

LOCA pressure suppression Scale-model tests quantified two-dimensional pool swell phenomena in Mark I BWR containment structures. Three-dimensional tests conducted on Mark II suppression pool containment.

Early Mark I work made significant contribution to regulatory decision allowing Mark I plants to continue operation.

Steel fracture toughness Safety and conservatism of present methods for measuring fracture toughness of pressure-vessel steels demonstrated, thereby averting potential forced outages because of NRC regulatory action.

Reduction of outages could mean savings averaging $250,000–$300,000 daily at a single plant.

Reactor coolant oxygen Method to reduce free oxygen content of reactor coolant water demonstrated at Vermont Yankee plant. Free oxygen is an agent in the intergranular stress corrosion cracking of stainless steel piping.

Avoidance of even one crack and the resulting unscheduled outage could be worth several million dollars.

Structural flaw analysis Comparison of the finite element method (used today) and the influence function method for analyzing postulated circular cracks in feedwater nozzles or similar components showed superiority of the latter in both accuracy and cost.

Total savings of $150,000–$200,000 predicted for each occurrence of a flaw needing analysis to meet code and license requirements.

Nuclear plant reliability Improved power plant network information system developed: now being implemented to correlate data for better plant design, operation, and availability.

A 1% improvement in capacity factor of all nuclear plants expected to be operating in 1985 would eliminate the need for three 1000-MW units costing $3 billion.

ELECTRICAL SYSTEMS

Utility pole preservation New fir-pole fumigants demonstrated 6-year effectiveness in controlling groundline decay, which now requires replacing some 500,000 fir poles annually at an estimated labor and materials cost of $500/pole.

Assuming that 100,000 fir poles last an additional 10 years because of new fumigant treatment, utilities save about $9 million annually.

Revenue metering accuracy Mobile unit developed for field calibration of coupling capacitor voltage transformers (CCVTs) to 0.05% accuracy. Several hundred CCVTs are used in bulk power substations for revenue metering, where gradual drift up to 2–3% is costly

Assuming 20-mill power and a 500-MW transfer with a 60% load factor correcting even a 0.5% error is worth $250,000 in annual billing.

Closer phase spacing Reduced (3-ft) phase spacing reliability demonstrated for 138-kV transmission; estimated to save 5–20% in construction and right-of-way (or in uprating of present lines). Design data being published; utilities already using data and extrapolating for 230-kV application.

For 52,000 miles of new 115–138-kV line by the year 2000, estimated $3.6 billion cost could be cut by 10%.

System stability Program developed to compute dynamic equivalent of much larger system, thus drastically cutting the size and computation complexity of system stability studies.

Full use in utility systems analysis estimated worth $300,000 annually, with research benefit-to-cost ratio of 17 1 over 10-year period.

Simplified cable splice Molded splice components developed for 138-kV rated extruded cable. One standard size elastomer sleeve and two pairs of adapters that snap together inside it can be combined for different cable diameters and lower voltage ratings.

Simplified splice assembly cuts field labor from 30–70 man-hours to only 10 man-hours. Factory testing ensures reliable performance

Three-conductor gas cable Three-conductor gas-insulated 345-kV cable successfully fabricated and tested. Segmented design of enclosure sections preserves extrusion economy at large diameters.

New design estimated to cut 15% from installed cost of rigid gas cable systems for short-distance bulk power transmission.

HVDC transmission data Overhead dc transmission design criteria established for lines up to ±600 kV; criteria will be published and are being applied to new line construction where generation and load centers are unusually far apart.

Documented criteria will build confidence in dc transmission and cut design time for future projects.

Polymer concrete insulation Polymer-impregnated concrete costing significantly less than porcelain passed extensive electric and weathering tests for insulators. The material has twice the dielectric strength and half the dielectric constant of porcelain.

With only 5% adoption of polymer concrete insulators, electric utilities could save up to $7.5 million annually.

Conductor motion in wind Simple spacers at irregular intervals shown to reduce wind-induced motion of bundled conductors. About 5000 miles of new line in next five years may be subject to oscillation. Spacers adopted by five utilities and a computer program devised to calculate patterns.

Spacers at \$10–\$25 will cost about one-third as much as the special dampers earlier thought necessary.

ENERGY ANALYSIS AND ENVIRONMENT

High-voltage effects Preliminary results from a major study of biological effects of electric fields from high-voltage overhead transmission lines indicated no adverse effects. Utility industry leads in this field of research.

Data will be a scientific guide in designing and constructing electricity delivery systems that are not hazardous to public health and safety.

Air pollutant monitoring Regional sulfate monitoring program begun. It is designed to measure ambient sulfate concentrations in northeastern U.S., to calculate local SO_2 emissions, and to define any relationship that may exist between local SO_2 emissions and regional ambient sulfate concentrations so that change in the latter can be used to predict change in the former.

By determining the relationship between SO_2 emissions and ambient sulfate concentrations, some present costly control strategies could prove unnecessary.

Energy modeling Energy Modeling Forum established. This group of major energy modelers and model users from private industry and public agencies will evaluate large energy-economic models by applying them to specific energy issues.

Identifying modeling strengths and weaknesses and appropriate applications will help to avoid questionable public and private policy decisions based on models.

Energy forecasts Studies completed to serve as a basis for availability and price projections of conventional fuels to the year 2000. First set of energy demand forecasts released and work completed on second forecasts of energy consumption for all sectors of economy and for conventional fuels. Updated supply and demand forecasts to be published early in 1977.

Sound, long-range planning will result from reliable forecasts of fuel prices and availability plus projections of the range over which total energy and electricity consumption are expected to vary.

SO_x health effects Critical survey completed on health effects of sulfur oxides. Indications are that although data are adequate for SO_2 plus particulates, little is known about other forms of sulfur and other compounds that may be the most harmful air pollutants.

Provides important data useful in drafting EPA updated criteria documents to serve as a basis for new air pollution regulatory policies and in designing new combustion control technologies.

Time-of-day pricing Technology and costing approaches to time-of-day pricing examined and a progress report identifying issues released. Major report of findings in Electric Utility Rate Design Study will be published early in 1977, and work will continue during the year

Will provide utilities, regulatory commissions, and the public with information for weighing alternative load management techniques through pricing and load control devices.

Water data access Water data base management system developed, with implementation for Colorado River Basin nearing completion. Exchange agreement made with National Water Data Exchange. Evaluation completed of capability of crucial links in rail and barge transportation networks to handle large increases in coal.

Provides greatly improved access to federal and state water data bases and enables analysis of nationwide water supply problems; indicates where rail and barge transportation bottlenecks may occur as coal movements increase and aids in projecting coal transportation costs.

Model development Wharton model of national economy expanded to give more detailed description of energy sector DESOM, a dynamic optimization model of national energy system, developed by Brookhaven team. PILOT, a model designed to study the impact of different energy supply conditions on the economy's ability to provide goods and services, devised at Stanford University.

Gives industry planners analytic tools for assessing the effects of interfuel substitution and new technologies and the effects of energy options on the standard of living so that policies resilient under a range of economic futures can be formed.

Coal: The R&D Pivot for New Energy Fuels, Cycles, and

Coal must become a bigger item in our energy supply mix, especially to cut U.S. dependence on oil and gas. Increased electrification with both nuclear and coal-produced power is inevitable, despite the difficulties now experienced by utilities in using either of them. This is the "bottom line" in Richard Balzhiser's opinion.

Balzhiser came to EPRI in June 1973 from the White House Office of Science and Technology, where he played a primary role in energy R&D policy planning. As director of EPRI's Fossil Fuel and Advanced Systems Division, he heads the largest and most diverse of the technical divisions.

"Coal is the one fuel for which we know the resource base is adequate and the technology established," he maintains. "Unfortunately, coal-fired power plants have been a major source of effluents in the past," he concedes, "but emission levels have been reduced so that plants today are complying with primary air quality standards throughout the nation." However, with coal use projected to increase by a factor of 4–6 during the rest of the century, still further improvements must be made. In Balzhiser's words, "That's what EPRI is all about."

In just three years, Balzhiser points out, EPRI has produced R&D results. "Utilities and their vendors are already using EPRI research findings to improve the operation of feedwater heaters, electrostatic precipitators, scrubber mist eliminators, and reheaters." He adds, "EPRI studies are helping utilities make decisions about subjects as diverse as fabric filtration for better control of fine particulates and the impact of solar heating and cooling on load curves."

But Balzhiser says these examples are only the tip of the iceberg. "The really exciting developments in new fuels and generating options should reach the demonstration stage during the 1980s," he states. "Fluidized-bed combustion is one. Coal gasification with combined-cycle generation is another. They both offer lower emissions, lower heat rates, and lower water and land use—all attractive for baseload operation.

"For cycling and peaking generation, fuel cells and load-leveling batteries are being pursued at the national level. The 4.8-MW fuel cell demonstration and the Battery Energy Storage Test Facility, both shared with ERDA, are two excellent examples of projects that wouldn't have happened without EPRI."

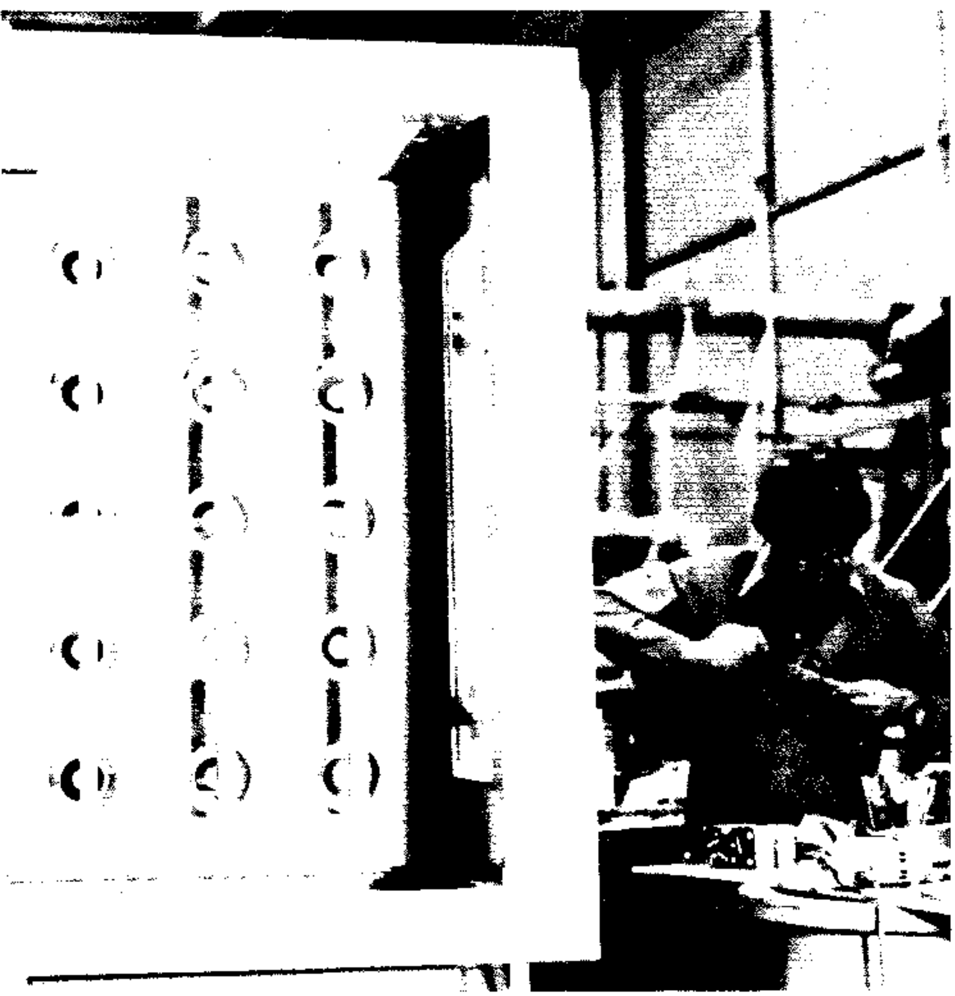
Balzhiser knows that utilities will need clean liquid fuels well into the future, hence EPRI's involvement in coal liquefaction research. "H-Coal is the only significant pilot-scale development now going on," he observes. "ERDA and four oil companies are supporting it, but I don't think a facility would be under construction if it weren't for EPRI's commitment."

EPRI's Wilsonville solvent-refined coal pilot project with Southern Company Services, Inc., is another example. It has been a prolific producer of data, Balzhiser notes, and its importance in the national effort to produce a clean boiler fuel is evidenced by ERDA's support, which began in 1976.

EPRI's modest funding of solar, geothermal, and fusion programs also enables the Institute to play a meaningful role in ERDA's activities in these areas. As Balzhiser explains, "We have given ERDA constructive and necessary contributions as to the criteria new generation technologies must meet if they are to be accepted and provide maximum benefits to the consumers. For instance, EPRI's early commitment to a residential solar heating and cooling demonstration—one that is optimized for capacity as well as fuel displacement—has already produced useful data for ERDA and the utilities."

Balzhiser acknowledges that EPRI expects to be held accountable by the utilities and their regulators for the substantial commitments they have made. "Of course," he cautions, "R&D can't be expected to pay off overnight. But much to my amazement, it may in one case. Our high-intensity ionizer—now under test by TVA—could save the utilities more than their entire investment in EPRI to date. But that's peanuts compared to the possible impact of other developments, when you consider the growth potential of the utilities over the next several decades."

Storage



Array of 15 high-intensity ionizers shows configuration of a novel electrostatic precipitation device. Vertical strips are busbars for energizing high-voltage cathodes in ionizer passages. A prototype four times this size will be tested this year on a 35,000-ft^3/min gas flow.

Fossil Fuel and Advanced Systems Division embraces a diverse set of technologies that share a common objective: allowing the United States to make fuller use of more domestic energy resources. Over the next quarter century the emphasis must be on more extensive and more reliable use of coal and uranium to produce electricity.

Projected growth in electricity use, coupled with the decreasing availability of oil and natural gas, will require at least a fourfold increase in the use of coal by electric utilities at the turn of the century. (Any slowdown in the deployment of nuclear plants can only increase this requirement.) This will challenge the industry's ability to design and construct coal-fired power plants, to ensure adequate and secure fuel supplies, and to meet increasingly stringent environmental regulations.

Division research emphasis in the near term (to 1985) is on improved environmental control technology, better plant performance and reliability, and more efficient end use of electricity. Research targeted at the 1985–2000 time period is concentrating on technologies that remove the emission-forming constituents from coal before or during combustion, such as coal cleaning, fluidized-bed combustion, and the conversion of coal to clean liquid and gaseous fuels. Advanced power systems to use these fuels, notably gas turbines and fuel cells, are being pursued in parallel, as are load-leveling storage technologies. Longer-term research is aimed at solar electric power generation, controlled fusion, and the more widespread use of geothermal energy.

Comparing the coal options

In order to sharpen R&D priorities, the division recently completed a first-cut economic comparison of 10 major options for using coal, each of them engineered to meet new-source performance standards. This analysis is the first one to produce a busbar-cost ranking of the major options for coal utilization.

The analytic process and major conclusions were covered in the November 1976 issue of the JOURNAL. Direct-fired, low-sulfur coal resulted in the lowest busbar cost for both baseload and intermediate operation, and direct-firing of higher-sulfur coal with limestone scrubbing was the second most attractive baseload alternative. Only slightly more expensive than the latter were direct-fired steam plants employing regenerative scrubbers, advanced gasifiers, and fluidized-bed combustors. Significantly, the combined-cycle systems of the 1985–1995 time period showed promise of being less costly than low-sulfur coal—those integrated with advanced gasifiers being used primarily for baseload operation, and those using coal-derived liquids, for intermediate service.

Testing finer particulate controls

Until a few years ago, particulate emissions control was considered a relatively mature technology. Electrostatic precipitators (ESP) could readily collect about 95% of the fly ash. In recent years, however, a number of factors have forced a reappraisal of the conventional ESP approach. Regulatory emphasis is now being placed on respirable particles—those in the submicron range most likely to be retained in the lungs. The implied health hazard has resulted in tighter environmental standards, requiring new and many existing power plants to achieve 99.5% collection efficiency. At the same time, there has been a shift toward increased use of low-sulfur, western coals that generally have a low-conductivity ash. This ash reduces the collection efficiency of the ESP. The combination of these two factors requires the use of exceedingly large and more costly precipitators with lower reliability. There is a clear need for innovative approaches to particulate collection.

Many new and improved concepts have been forthcoming, and EPRI has extended its support to a major new test facility for advanced devices. An advanced particulate control development and test center is presently under construction at the Public Service Co. of Colorado's Arapahoe power station in Denver. Operation is scheduled for May 1977, and initially the center will be capable of testing particulate control devices at temperatures between 150°C and 980°C and at flow rates from 150 to 1500 m^3/m.

One of the first devices to be tested will be a high-intensity ionizer. Developed by Air Pollution Systems, Inc., with EPRI funding, this highly promising device imparts up to five times the charge of a conventional ESP at gas velocities of 30 m/s and works well with both high-sulfur and low-sulfur coal. It promises benefits of up to 30% in capital cost for new installations, and 50–70% in retrofit installations. In the past year, it underwent five months of testing at TVA's John Sevier Power Plant with very encouraging results. By the fall of 1977, large-scale testing at the new Arapahoe facility should give a clear indication of its commercial applicability.

Bag filter efficiency verified

EPRI has also been evaluating the technical and economic performance of the fabric filter for particulate collection. EPRI tests at the Nucla Station of Colorado-Ute Electric Association, Inc., over the past year have shown the bag filter to have the highest collection efficiency of current particulate control technologies. It is particularly effective for low-sulfur western coals, is relatively independent of operating conditions, and is an excellent collector of fine particulates. Collection efficiency for fine particulates did not fall below 99.9%. The Nucla results have already been used by several utilities in evaluating fabric filtration for new coal-fired boilers, especially for low-sulfur coals.

EPRI has sponsored research at Southern Research Institute on reentrainment, the process by which particles reenter the emissions stream when the collector plates of a precipitator are rapped to remove the dust. The majority of the fly ash emitted from a precipitator results from reentrainment during the rapping cycle. Placing the precipitator on the cold side of the air heater appears to minimize reentrainment losses.

Over the past year, EPRI has supported the development of a number of instruments to improve the data base and performance prediction for particulate control devices. Of particular significance is the low-pressure cascade impactor, which can measure fine particles that are an order of magnitude smaller than those measurable by conventional cascade impactors. This development is particularly important as regulatory agencies begin to specify standards in terms of size rather than mass. The impactor has been built and tested at the University of Washington, and a commercial prototype will be evaluated in the near future. The device avoids the need for complex extractive and sample handling procedures for the 0.03–0.3-μm particle diameter range, and it compares with conventional cascade impactors in its simplicity.

Perfecting scrubbers for sulfur oxides

So far, the only positive emission control option with which the industry has had significant operating experience and which is capable of meeting new-source performance standards is lime/limestone scrubbing. Despite that experience, many problems remain. As a result, the focus of the EPRI subprogram in sulfur oxide control is to develop and disseminate design and operational data for lime/limestone scrubbers.

Over the past year, EPRI has evaluated a number of flue gas desulfurization (FGD) subsystems (including absorbers, reheaters, and demisters) at TVA's Colbert 1-MW pilot plant and has closely monitored other FGD testing installations, including those at TVA's Shawnee power plant. Based on this work and on other utility industry experience, in 1977 EPRI will compile and publish a guidebook on the specification, evaluation, design, and operation of lime scrubbers.

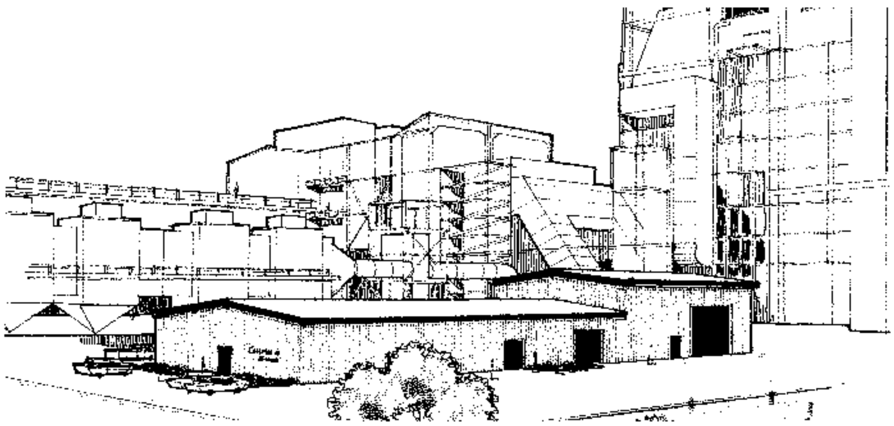
In 1976, Battelle Memorial Institute completed a study for EPRI that analyzed the reasons for the wide variations in the cost of FGD systems from one utility to another. Costs ranged from $50/kW to $150/kW and varied according to the system used, physical space limitations, equipment delays, redundancy requirements, height of the stacks, construction overtime, and disposal techniques. The final report will be issued early in 1977.

In the operation of a wet scrubber section, flue gases subsequently pass through a demister (to remove excess moisture) and then through a reheater (to avoid condensation in the stack, to avoid a visible plume, or to enhance the plume rise for dispersion of pollutants). Demisters have serious reliability problems due to plugging, and reheaters suffer from erosion and corrosion. Battelle recently completed an EPRI-sponsored study that provided engineering data on the 15 or so critical variables to be considered in any site-specific demister design. Battelle has also provided a detailed evaluation of several different types of reheaters: in-line reheat, indirect hot air reheat, and direct combustion reheat. The study provides data for the proper design of the reheater, which could help reduce the operating and maintenance costs of the entire scrubbing system.

Sludge versus salable sulfur

A major problem with lime/limestone scrubbing is disposal of the calcium

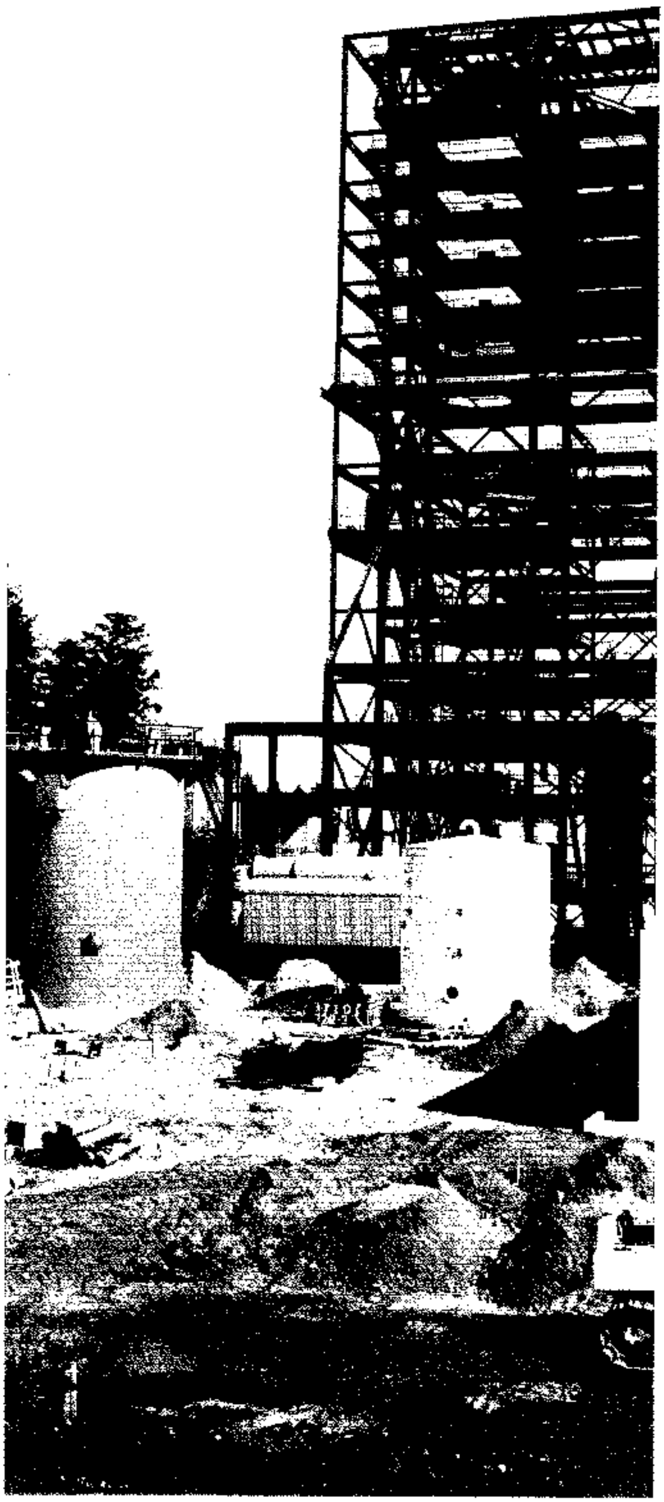
An advanced particulate control facility is now being built alongside the Colorado Public Service coal-fired Arapahoe power plant. Fabric and granular filters, advanced electrostatic precipitators, and high-intensity ionizers will begin prototype performance evaluation this year.



Fabric filters are efficient for particulate removal from stack gases, but many are required. For reliability in a large installation (~500 MW), the baghouse may be divided into 30–50 compartments like this one, each containing 200–600 bags.

Pilot plant for atmospheric, two-stage entrained coal gasification is under construction by Combustion Engineering, Inc., at Windsor, Conn., with startup planned for June 1977. Stretford process sulfur removal facilities are in place, with 150-ft reactor structure behind.

Sensor being located on induced-draft fan bearing is one of 200 transducers instrumenting New England Power Service Co. power plant for a study of acoustic and vibration patterns. Recorded "signatures" will be analyzed to differentiate abnormalities.



sulfate sludge. Typically, it is concentrated into a pond from which salts and toxic trace metals may, under certain conditions, leach into the groundwater. The ponding problem could become massive. Between 1976 and 1990, utilities will invest about $30 billion for 200,000 MW of FGD systems. This implies that over the next 15 years an estimated 1.5 billion tons of sludge will be accumulated — enough to cover 50,000 acres to a depth of 20 feet. As a result, EPRI has been assessing a number of second-generation FGD systems that have the capability to regenerate the absorption solution and produce a by-product such as sulfur, gypsum, or sulfuric acid, which can be either stored or sold on the commercial market.

Over the past year, an assessment of 12 regenerative processes was completed by Radian Corp. The processes were compared on the basis of energy consumption, material requirements, and process development, as well as operating cost. A final report, to be issued shortly, indicates that none of the developing processes has overwhelming advantages over the commercially demonstrated Wellman-Lord and magnesium oxide (mag-ox) systems. None of the developing systems can be taken directly from the current small scale to commercial use with any assurance of reliability. While no entire system shows great advantage over the two commercial processes, two of the more promising developmental FGD subsystems are the aqueous carbonate process regeneration step (Atomics International Division, Rockwell International Corp.) and the redox direct reduction step (Foster-Wheeler Energy Corp.). Both processes use coal as the only reductant necessary to produce sulfur and could be used with many regenerative scrubber systems.

The study also found that sludge regeneration is generally economically unattractive for FGD installations except when its use is justified by site-specific conditions, such as prohibitions against dumping or the proximity of a plant using sulfuric acid.

EPRI has been engaged in a continuing assessment of regenerative FGD systems development throughout the country and is supporting the 20-MW test program of the Foster-Wheeler–Bergbau-Forschung, Chiyoda, and Combustion Equipment Associates–Arthur D. Little, Inc., systems by Southern Company Services, Inc. Evaluation of bids from 15 vendors may lead to the detailed design of certain of these processes.

Combustion controls for NO_x

Research goals set by EPA for the control of NO_x may foreshadow substantial control requirements for electric utilities in the future. NO_x can be adequately controlled now in oil- and gas-fired boilers by staging the combustion upward from a fuel-rich zone to an air-rich zone or by recirculating the flue gas back into the boiler through the windbox. An EPRI-sponsored test on a coal-fired unit at Allegheny Power Service Corp. found that windbox gas recirculation was relatively ineffective compared with the staged-combustion process. However, serious questions about boiler corrosion and slagging associated with staged combustion on high-sulfur fuels must still be resolved.

EPRI has also been exploring alternative approaches to NO_x control, including postcombustion techniques. In laboratory tests, the injection of small quantities of ammonia or other suitable compounds into combustion gases at temperatures between 1300°F and 2000°F resulted in NO_x reductions exceeding 90%. Preliminary research indicates that such techniques may be the lowest-cost means of postcombustion control since they require no catalytic agents. However, they do require very tight temperature control and may yield by-products of ammonia–sulfur oxide compounds, including ammonium sulfates. EPRI is exploring further work with Exxon Research and Engineering Co.

Better use of water

Electric power generation requires water as a working fluid and as a medium for cooling, cleaning, and materials transport. Fresh supplies are now less abundant, and EPA has moved to restrict direct thermal and chemical discharges into natural waterways. As a result, EPRI has initiated a number of projects designed to conserve water by recycling and by alternative technologies, such as dry cooling. Over the past year, efforts have been directed toward the development of an advanced dry-cooling tower, the use of agricultural waste water for power plant cooling, and improvements in the performance of evaporative cooling systems.

A design study was recently completed for a dry-cooling tower that uses ammonia in the condenser–cooling-tower loop, together with high-performance heat-transfer surfaces. The study, performed by the Linde Division of Union Carbide Corp., indicated the system's cost at less than half that of conventional dry cooling. A pilot-scale test is now planned that will provide the design detail for a full-scale demonstration.

The use of agricultural drainage water for wet cooling has been successfully demonstrated in the laboratory, and pilot-scale tests are under way at a San Joaquin Valley Irrigation District facility. A water-softener approach was developed that will economically reduce scaling by the makeup water.

The performance of an evaporative cooling system can be significantly reduced by recirculation of the plume, which is caused by improper tower siting. EPRI is using field data to validate a physical modeling (water tunnel) technique to determine how mechanical-draft cooling towers should be sited relative to other power plant structures. The results are expected in 1977.

EPRI has also been extensively involved in ways to predict and mitigate the emission and dispersion of water vapor and drift from cooling towers. To date, two sets of comprehensive field data have been obtained from the Chalk Point cooling tower project in Maryland. Predictive, analytic models are now being developed that will eventually be used by utilities to satisfy environmental impact statements.

Biofouling films, which collect on condenser tubes and reduce heat transfer, have traditionally been controlled by chlorination. Discharge limitations on chlorine necessitate a search for alternatives, and EPRI has been supporting a project in which ozone is dissolved into the cooling water for biofouling control. A model system has been constructed recently and is ready for testing.

New ways to clean coal

During 1976 EPRI was involved in advancing both physical and chemical coal-cleaning technologies. Pyritic sulfur can be separated from coal by gravity or by flotation before the coal is pulverized. These techniques are commercially established. Organic sulfur can be removed only by chemical means, which are in the research and development stage.

Last summer EPRI organized a meeting of the most knowledgeable people in the field of coal preparation research and engineering. Broad objectives for an R&D program to clean coal were mapped out by the participants, and specific agreements for cooperative funding are expected to be reached in the near future. As a result of this new level of coordination, research duplication should be minimized and the development time scale to commercial chemical and physical coal-cleaning processes enhanced. This will allow a much larger fraction of U.S. coal reserves to be utilized.

EPRI has been supporting a proprietary technique developed by Atlantic Richfield Co. that has the capability to remove organic as well as pyritic sulfur. Laboratory work at the bench-scale level has been quite successful thus far and has resulted in the design and construction of a pilot plant. Initial operation is scheduled for early 1977. The principal objective is to equal or undercut the cost of flue gas desulfurization techniques. Even at the same cost, such a process might be preferable to FGD because it decouples the cleaning from the plant operation.

In 1976, EPRI was one of 18 cosponsors to test the feasibility of firing a boiler with a coal-oil slurry. The demonstration was technically successful but indicated no economic advantage. Nevertheless, the research was considered significant because the process would provide an emergency measure for east coast utilities to reduce oil consumption in the event of another oil embargo.

Fluidized-bed demonstration in 1977

The energy conversion alternatives study recently completed by General Electric Co. indicates that fluidized-bed combustion (FBC) shows promise of being less expensive than conventional steam plants with scrubbers for baseload and intermediate generation. In addition, it offers environmental incentives, including SO_2 absorption by limestone during the combustion process (which occurs at temperatures low enough to reduce NO_X formation).

EPRI and ERDA have both joint and parallel efforts to bring this technology to full-scale commercial development before 1985. They have begun planning a 100–200-MW atmospheric fluidized-bed power plant to be in operation by the early 1980s. Engineering data for this demonstration unit will be derived from the 30-MW Rivesville unit funded by ERDA and from the EPRI-funded development facility at the Babcock & Wilcox Co. laboratories in Alliance, Ohio. The latter facility is under construction, is ahead of schedule, and will begin operation in 1977. It should improve knowledge of the fundamental process and guide development of full-scale hardware for utility application.

Some of the research findings over the past year, although negative, are useful in directing the R&D focus. A study by Babcock & Wilcox, which evaluated existing FBC design information, concluded that insufficient data were then available to design a full-scale FBC unit with a high probability of successful operation. Many significant design gaps and unknowns were identified in the study, and the general result has been to delay the immediate scaling to large FBC power plants until these problems can be resolved. One of the more troublesome areas involves boiler tube materials. In a series of EPRI-sponsored materials tests on a small unit in England, some of the normal boiler materials held up adequately under the FBC operating conditions, while some of the advanced materials did not. As a result, EPRI will continue its evaluation of alternative alloys and is planning a second test in an existing unit that is much larger, where operating conditions would be more representative of a full-scale power plant.

The fundamental processes of FBC are not yet sufficiently understood, and EPRI has been developing new instrumentation to assist in the measurement and modeling of coarse-particle fluidization and heat transfer. The hope is to elevate FBC technology from the time-consuming and costly process of trial-and-error design to one of predictable science.

Boosting power plant availability

U.S. coal-fired power plants larger than about 600-MW have appreciably lower average availabilities than the smaller, older plants. Building on the historical work done by the Edison Electric Institute (EEI), by individual utilities, and by equipment suppliers, the Federal Energy Administration (FEA), EPRI, and ERDA are now formulating R&D programs to attack generic engineering, design, and operational problems that adversely affect plant availability. EPRI has sponsored a series of workshops with individual utilities to help define the most significant problems. EPRI has also initiated a similar activity to improve the reliability of gas turbines used in utility peaking service.

A project to improve the reliability of feedwater pumps has corrected generic design problems, with savings of about $10 million a year. In another project, a new material for generator end rings is being developed that can be heat-treated to the necessary strength at less cost than by cold working.

Converting coal to clean fuels

Clean liquid and solid fuels can be produced by reacting coal with hydrogen. The liquid fuels are intended to be used primarily as petroleum substitutes in intermediate and peaking equipment, and current EPRI estimates indicate a maximum market potential reaching 2–3 million bbl/d in the 1985–1995 time period, when the technology becomes commercially available.

EPRI has been supporting fundamental research, bench-scale operations, and process development unit operations, which will lead to large pilot plant demonstrations over the next decade for four major process alternatives: solvent-refined coal (SRC), H-Coal, Donor Solvent Process, and fuel-grade methanol. The product quality and cost ($2.50–$6.00/10^6 Btu) vary for each alternative, increasing in the order that the products are listed above.

SRC is a solid, low-sulfur, low-ash fuel that has been under development since 1974 at a 5-ton/d level at the EPRI-sponsored facility at Wilsonville, Alabama. Processing tests over the past few years on most major U.S. coals indicate that SRC can meet the new-source performance standards, and combustion tests indicate that SRC can be used in conventional coal-fired plants with only minor modifications. In just the past year, further tests have correlated the results at Wilsonville with those from the 50-ton/d ERDA-sponsored SRC unit at Tacoma, Washington. Through most of 1976, the Tacoma facility was producing a 3000-ton batch of SRC for a large-scale combustion test to be conducted early in 1977 on a 22-MW boiler of the Georgia Power Co. In support of this future test, EPRI has been sponsoring the development of a special burner at Babcock & Wilcox.

In mid-1976, ERDA agreed to provide two-thirds of the funding for the Wilsonville operation through 1977, with EPRI

Solvent-refined coal pilot plant at Wilsonville, Ala., has been run since 1974 to study processing steps with various feed coals. During the past year, operations of the 6-ton/d unit have been closely integrated with ERDA's 50 ton/d plant at Tacoma, Wash.

International Agreements Signed

EPRI signed energy exchange agreements last year with the Federal Ministry for Research and Technology of the Federal Republic of Germany, the Swedish State Power Board, and the Central Research Institute of the Electric Power Industry in Japan. The agreements call for the quid pro quo exchange of research information and are similar to previous agreements made with the Central Electricity Generating Board in England and Electricité de France.

The exchange can be in the form of technical reports, experimental data, correspondence, newsletters, and joint meetings. The agreements also establish the necessary mechanism for assigning personnel of one group to the facilities of the other for certain periods of time.

Although the agreements do not attempt to set up joint programs or projects, they do provide a starting point for identifying projects that might be appropriate for joint sponsorship.

In addition to bilateral flow of information, the temporary exchange of technical staff between EPRI and organizations in other countries has helped to promote the dissemination of international research.

EPRI presently has a technical representative stationed at the Halden Reactor Project in Norway, and in 1976 six foreign energy experts from England, France, Australia, and Israel worked at EPRI. The average length of stay has been one year, and the new insights these individuals brought to EPRI's research, especially in areas such as environmental control technology for fossil fuel power plants and combustion, have proved very valuable. An additional benefit is the understanding of EPRI's objectives and research programs that these experts take back to their own countries.

covering the balance. EPRI will probably concentrate future efforts in SRC on concepts that have the potential to improve the process economics, particularly short residence time dissolution and solvent precipitation or extraction for ash removal.

Sharp focus on coal liquids

The two primary options for coal-derived liquid fuels are H-Coal and the Donor Solvent Process. In an effort to concentrate its funding, EPRI eliminated two other alternatives this year. EPRI recently agreed to participate with ERDA, the state of Kentucky, and four major oil companies in the construction of an H-Coal pilot plant at Catlettsburg, Kentucky. Due for completion in 1978, the plant will process 250 ton/d of coal when producing a distillate oil, and 600 ton/d when producing a heavy fuel oil. Over the past year, EPRI and the other participants supported an extensive experimental program at Hydrocarbon Research, Inc., to evaluate key process concepts that will be demonstrated at Catlettsburg.

EPRI, ERDA, and Exxon Research and Engineering Company are supporting an intensive program to develop the Donor Solvent Process. A 1-ton/d process development unit commenced operation in January 1976 at Baytown, Texas. Operations to date have been quite successful on Illinois coal. After the experimental basis is established, detailed design of a 250-ton/d pilot plant will begin. Current expectations are that the large plant will begin a two-year operating program in 1980.

EPRI has developed a new concept that will lead to a lower-cost, fuel-grade methanol. Methanol is considered an ideal turbine fuel, but its use has been limited by high cost. The EPRI staff-conceived process would produce equal amounts of methanol and clean distillate fuels by combining advantageous elements of liquefaction, gasification, and synthesis gas conversion processes. A comprehensive engineering analysis is now under way, and if the results support the preliminary estimates, a pilot plant will be designed in 1977.

One of the highlights of the past year was EPRI-sponsored research at Mobil Research and Development Corp. into the basic reaction chemistry in coal. Mobil gained new understanding of the fundamental structure of coal and how it relates to coal conversion and coal-derived products; for example, product properties can be altered by manipulating process variables, rather than being predetermined by the chemistry of the coal feedstock. Mobil was recently awarded the Bituminous Coal Research Award for its innovative work for EPRI.

Under another contract, Mobil finished the first phase of a study on upgrading coal-derived liquids for use in gas turbines. Among the findings: present coal liquids are too deficient in hydrogen and too abundant in nitrogen and trace metals for use in today's gas turbines. Mobil is developing processes that will upgrade these liquids to turbine fuel quality at minimum cost. At the same time, EPRI is considering combustor–gas turbine modifications that may allow the highly aromatic coal-derived fuels to be burned directly without upgrading.

Coal gas for combined cycles

Another high-priority EPRI research area is the integration of second-generation coal gasifiers with gas turbine–steam turbine combined cycles. Recent studies suggest that such systems offer overall efficiencies of 40–43%, and under current emissions standards, they would compete economically with coal-fired plants equipped with stack gas scrubbers. If standards are tightened, as would seem likely, gasification–combined cycle (GCC) systems would tend to be further favored. EPRI has been instrumental in the development of all the GCC power train: advanced gasifiers, advanced gas turbines, and systems integration and control. GCC power systems may become commercially available by the late 1980s.

The first test of integration will take place at the 25-MW scale at a test facility near the Powerton Station of Commonwealth Edison Co. in 1979. Agreement in principle on project management and cost has been reached among EPRI, ERDA, and Commonwealth Edison; contract details will be finalized early in 1977. Much of the detailed design has been completed and quotes have been received on about 80% of the major procurements. The Powerton facility will incorporate a conventional gasifier, the Lurgi, because it is commercially available. Future systems will use advanced gasifiers now under development, such as the British Gas Corp. (BGC) slagging fixed-bed gasifier and the Texaco partial-oxidation gasifier. The information and data derived from Powerton on integration, operation, and control will lead directly to the design of a 200-MW integrated system in the 1983–1986 time period.

EPRI, together with 14 oil and gas companies, has been supporting the BGC slagging gasifier development at Westfield, Scotland. The system is extremely promising—it can yield gas at three times the rate of the conventional Lurgi, and recent results confirm that dramatic improvements in the economics will be achieved. Two very successful 8-day runs were completed last spring on a unit processing 360 ton/d of coal, and a 30-day run was initiated in November. The system is probably one of the two leading contenders for future integrated GCC power trains. The Texaco partial-oxidation, medium-Btu gasifier has also been identified as an attractive alternative due to its technical simplicity, flexibility, and promising economics. A full investigation of its potential for integration has been initiated by EPRI, and a firm assessment will be available in 1977.

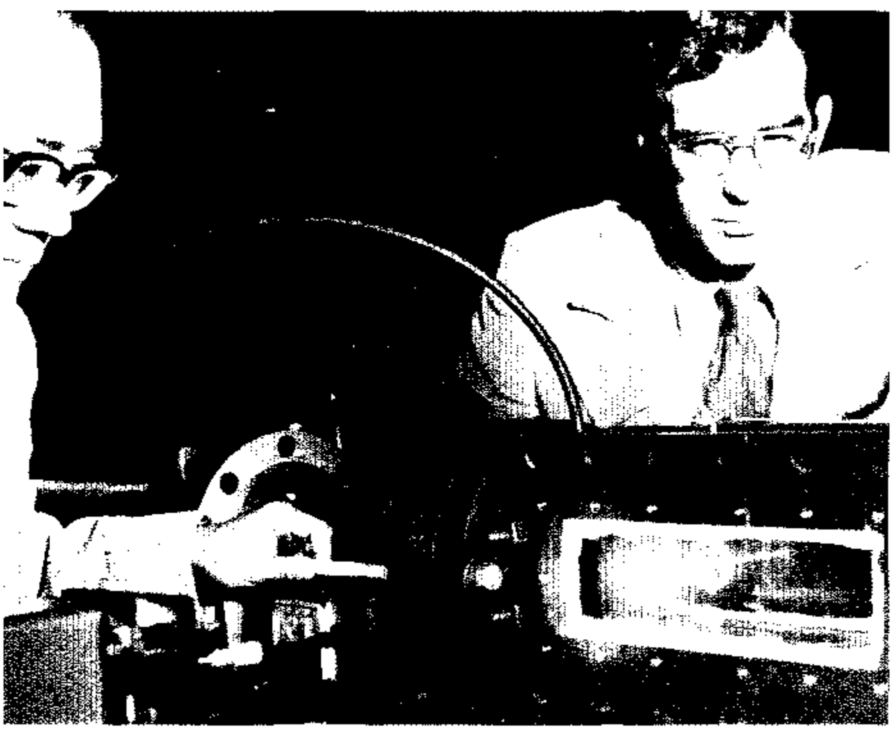
The EPRI Board of Directors has recently approved a project to investigate the dynamic and environmental effects of operating a Texaco gasifier in the mode required for power generation. This will be carried out at a 15-ton/d pilot plant at Montebello, California. This facility includes particulate and H_2S removal equipment, and the clean gas will be fired in a full-scale gas turbine combustor can so that most aspects of a power system are represented.

Other gasification research

EPRI has also been supporting work on the Combustion Engineering, Inc., two-stage entrained gasifier at Windsor, Connecticut. This particular system operates at atmospheric pressure, which allows the product gas to be used for direct boiler firing. A 5-ton/h pilot plant is now under construction, cosponsored with ERDA, and is due to begin operation in mid-1977.

A General Electric Co. study completed in 1976 identified control of an integrated GCC system as one of the keys to its successful operation. Essentially, such a system is a train of specialized components, and where and how to apply control to follow sudden changes in electric load presents a major challenge. A much larger study to develop the preferred mode of control for quick response is just starting.

Several other studies were completed in the past year whose results have been of major significance to the overall program. For example, contradicting earlier assumptions, a study by Stone & Webster Engineering Corp. showed that hot gas cleanup systems offer very little improvement in the cost and efficiency of advanced gasifiers. (However, it also indicated that hot cleanup would significantly improve the economic performance of dry ash Lurgi systems.) In Spain, a project using a Koppers-Totzek gasifier demonstrated the ability to gasify char-type materials. General Electric built and successfully tested a small-scale dry coal feeder for high-pressure operation that employs a screw device for extruding a solid bar of fuel. The bar is then chopped into 2-inch pieces for feeding to the gasifier. A larger version of the same feeder has been tested against hydrostatic back pressure; it will soon be mounted on the pilot gasifier for online testing.



Laser beam is scattered by condensing steam in this simulation of expansion turbine conditions. Data from a range of temperatures and pressures are being used in developing more efficient turbines that are less susceptible to blade erosion by water droplets.

Helping gas turbines run hotter

Because of their low capital cost and ease of installation, gas turbines in simple cycle have been widely used to provide peaking service. With the potential of their future use in gasification–combined-cycle systems to provide baseload generation as well, R&D efforts have been stepped up to improve turbine efficiency and reliability, as well as capability to use coal-derived fuels.

EPRI and ERDA are funding the development of higher-temperature gas turbines, including General Electric's water-cooled machine. Higher-temperature operation provides more power per unit of airflow, thereby improving efficiency; however, blade corrosion increases markedly above 1100°F. To resolve this dilemma, General Electric has added water channels in the blades and vanes, which effectively hold the metal temperatures below 1000°F at the same time that turbine inlet temperatures run as high as 2600–3000°F. Corrosion is thus minimized, while combined-cycle efficiencies approach 50%. A small-scale prototype of the water-cooled turbine has recently been run, successfully demonstrating a scheme for collecting spent cooling water. A full-scale prototype is expected to be tested in 1982.

Preliminary tests on ceramic turbine components have been recently completed at Westinghouse Electric Corp. with favorable results. Ceramics, unlike metals, demonstrate high strength and high corrosion resistance at 2300–2500°F and therefore might be used in high-temperature, high-efficiency machines burning low-quality fuel. However, they have no ductility and no resistance to thermal and mechanical shock, creating a severe design problem at metal-ceramic interfaces. Special blade root forms and a compliant layer have been used to attach ceramic blades to a metallic rotor. The blade-rotor combination survived spin-test stresses twice the nominal values expected in an operating machine.

Relatively dirty or coal-derived fuels can be burned when a turbine is driven by gases in a closed cycle with a heat exchanger. EPRI research is focusing on high-temperature ceramic heat exchangers to maximize efficiency. Results to date show that silicon carbide can operate in a coal ash environment with acceptable corrosion. By early 1977 tests now under way should determine whether these heat exchangers can work without cracking from the thermal shock of sudden turndowns.

In 1976, EPRI initiated a major program in gas turbine reliability. Several workshops were held with manufacturers, suppliers, and utility representatives, which resulted in a survey that attempted to match utility needs and priorities with new directions in turbine design.

The workshops also led to the identification of sulfidation (corrosion from sulfur and salt) as a widespread problem. A project that will ultimately result in an automated system to monitor the salt content of the entering air and fuel has been initiated. The system would trigger an alarm before severe damage occurs in the turbine.

Monitoring MHD research

In magnetohydrodynamics (MHD), very hot, ionized combustion gases (plasma) pass between powerful magnets; interaction of the plasma with the magnetic field extracts the kinetic energy of the gas as dc current. Efficiencies from the coal pile to busbar might reach 55% with advanced designs in combined cycles.

EPRI has a small but significant program in coal-fired, open-cycle MHD technology in order to provide maximum utility industry input at minimum funding to a large ERDA program. The ERDA-sponsored program will move from a component test facility (now under construction) in 1980 to a 25–50-MW engineering test facility in 1984. Commercial systems that are likely to emerge by the turn of the century will be capital-intensive and their market penetration is questionable at presently assumed rates of fuel inflation. However, given rapid fuel escalation, their market capture would be quite favorable; MHD thus represents a hedge against higher fuel inflation.

EPRI-sponsored research has demonstrated the interrelation of design between major MHD components, particularly the combustor, generator, and power conditioning and control units. Innovative design changes in the generator, a low capital cost item, has had major beneficial effects on the entire system, improving overall performance by minimizing coal slag carryover and aiding recovery of the seed material used to enhance ionization. By taking a comprehensive view and then focusing on the optimal generator design as the key, EPRI has helped to relax design requirements throughout the system. This should significantly influence the ERDA design philosophy and lead to a more flexible, comprehensively designed plant.

High performance goals for fuel cells

Over the last several years, progress in fuel cell technology has been rapid, and the prospects are favorable for multifueled, modular, dispersible power plants to be in operation by 1985. The utility-sponsored FCG-1 program at United Technologies Corp. has progressed to the point where ERDA and EPRI have entered into an agreement to demonstrate a 4.8-MW module in 1979. This important ERDA commitment to fuel cells is a direct result of utility industry and EPRI involvement in fuel cells. The 4.8-MW module of a 26-MW fuel cell power plant is to be tested with a host utility yet to be determined. If the project is successful, purchase options for commercial-scale units are expected to be exercised by a number of utilities.

First-generation fuel cells, such as the FCG-1, meet the requirements of a few utilities that have stringent environmental, land use, or transmission capacity restrictions. The increased performance goals of second-generation fuel cells would make them available to many more utilities. As a consequence, EPRI has focused significant development effort on second-generation fuel-cell technology, which would reduce capital costs by 20%, improve heat rates by 20%, and expand the range of fuels considerably. The target specifications for advanced fuel cells are a capital cost of $200/kW, 45% overall efficiency, and a 40,000-hour life.

In a recently completed study, the penetration of second-generation fuel cells into the utility market was determined to be quite large, even at a capital cost of $300/kW, if the proper fuels are available. In a major study on the suitability of fuels, it was generally concluded that fuel cells could use naphtha until the mid-1980s and then use low-sulfur oils until clean, coal-derived fuels become available in the 1990s. One exciting concept identified in the study was the potential for integrating fuel cells with coal gasification into a central power plant with attractive capital costs and efficiencies approaching 50%.

EPRI research in second-generation fuel cells includes both molten carbonate and advanced phosphoric acid technologies. Testing of 20-cell stacks of the former have been completed, and similar tests of the latter are about to begin. Depending on the results, one of these two technologies will be selected in 1977 for scaling up to a 40–100-kW test that is to begin in 1978 and terminate in 1979. At present, the research is well ahead of the original schedule.

Some of the research on second-generation technology has been transferred to first-generation hardware. For example, an advanced dc/ac power inverter progressed to the point where the equipment could be used as part of the first-generation fuel cell system. Similarly, a fuel desulfurizer was developed more quickly and more successfully than originally anticipated and offers a good opportunity for transfer in time to broaden first-generation fuel cell capability in the 1980s.

Solar test houses under way

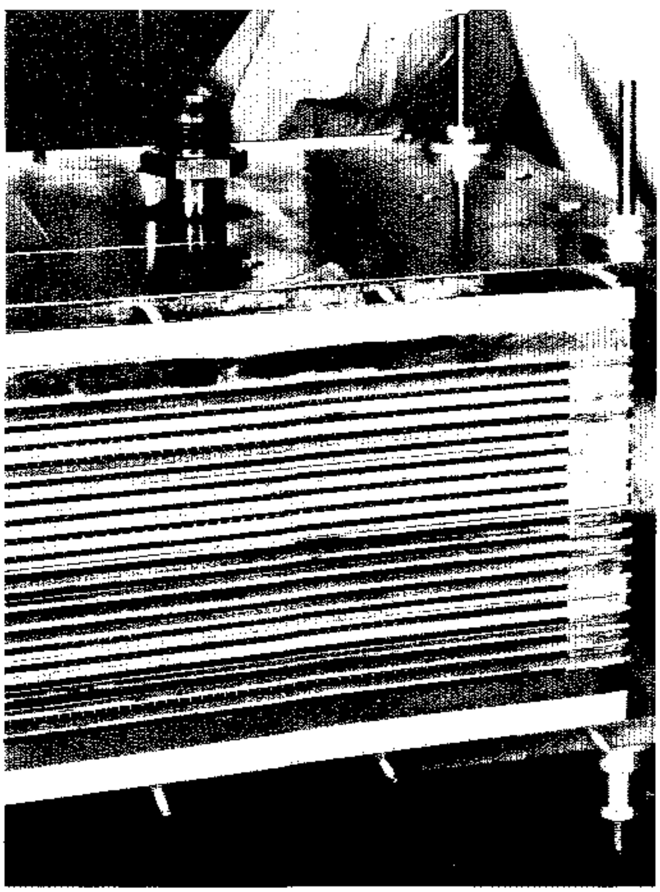
Solar heating and cooling of buildings will probably be the first use of solar energy in the United States. It could become competitive with conventional heating and cooling systems in the 1985–1990 time period and could penetrate 10% of the space-conditioning market by 2000. EPRI's primary emphasis in solar heating and cooling (SHAC) is in developing preferred systems that not only conserve energy but also minimize the adverse impact on the utility system load factor by storing off-peak energy and using solar-assisted heat pumps.

EPRI has undertaken a major demonstration program of preferred SHAC systems in residential and commercial buildings. Five houses will be built in the Long Island Lighting Co. service area and five in the area served by New Mexico Public Service Co. for the purpose of a three-year test and evaluation of residential SHAC system performance. Individual houses may have more than one system of different types, so that between 80 and 90 experiments can be conducted on the 10 houses. System development and preliminary design has recently been completed, as has the development of a consistent instrumentation, test, and evaluation plan. Detailed design and verification of component performance is under way. Construction of the houses and an evaluation of the SHAC system performance and cost for the next two years will also take place in 1977.

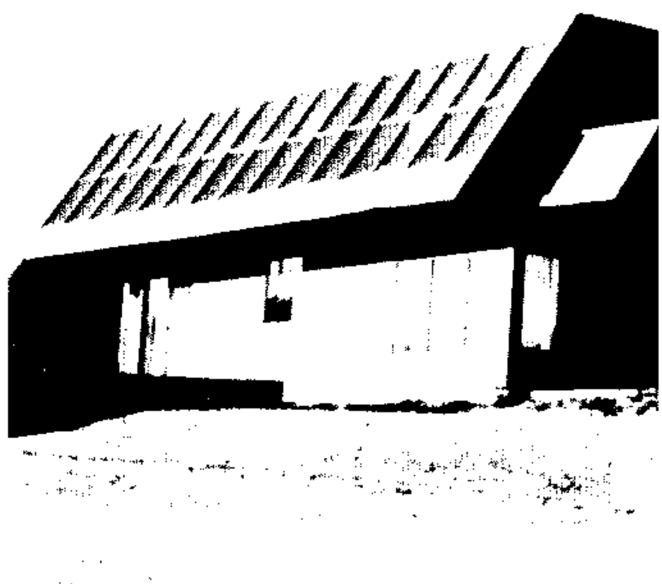
A computer program has been developed that permits determination of the preferred SHAC system for a specific utility service area. Originally developed for the two service areas of the EPRI program, it was later extended to 14 additional utilities. The program yields various system/subsystem options and their comparative performances and costs for specific areas. Results indicate that the program has wide geographic applicability. It will be available to utilities, together with a user's manual, in 1977.

Designing solar power generation

Recent analyses of solar-electric power plants indicate that central-receiver solar-thermal plants may become competitive with conventionally fueled intermediate load plants in the southwestern U.S. after 1985. EPRI is developing two high-temperature, gas-cooled central-receiver systems. These second-generation receivers will operate with conventional Brayton-cycle turbine generator units and have higher overall



Molten carbonate fuel cell stack (20 cells) has 3-kW output and operates at 1100°F without supplemental heating, demonstrating ability to scale up from laboratory cells to hardware size (1 ft²). A 40-kW demonstration (4-ft² area) is planned in 1978.



Solar collectors for heating and for thermal storage to assist a heat pump are elements of an instrumented energy-efficient house in Colorado Springs, Colo. Data from this installation are being evaluated to determine effects of its use on the consumer and the utility.

efficiencies and lower requirements for cooling water than the first-generation, lower-temperature, water-steam systems now being developed by ERDA.

The first EPRI concept is a closed-cycle helium system being designed by The Boeing Company, and the second is an open-cycle air system being designed by Black & Veatch Consulting Engineers. The preliminary design of a 1-MWt bench model of the Boeing receiver has been completed; the preliminary design of the Black & Veatch receiver is under way. Detailed designs, materials procurement, and fabrication for both receivers are scheduled for 1977. Testing will begin in 1978 in a radiant heat test facility, and it is hoped that further testing will be performed at ERDA's 5-MWt solar-thermal test facility at Albuquerque, New Mexico.

Photovoltaic devices convert solar energy (photons) directly to dc electricity. Their large-scale use will require improved performance and considerably reduced costs. EPRI is also assessing the potential of silicon cells for thermophotovoltaic conversion, an approach that has high theoretical efficiencies. Stanford University has recently completed the fabrication and testing of a thermophotovoltaic bench model using silicon cells. After several experimental runs, cell conversion efficiencies of 12% were recorded. The results were considered encouraging even though efficiencies in excess of 30% are required for large-scale utility application. Future efforts will focus on optimization through cell processing.

EPRI has also been assessing the use of thin-film photovoltaic devices. Though lower in efficiency, thin-film devices have potential manufacturing costs considerably lower than silicon crystal devices.

Geothermal brine to be tapped

The U.S. has raw geothermal resources sufficient to provide roughly 142,000 MW-centuries of electricity if the cost can be made competitive with other energy options. By the turn of the century, the geothermal generating capacity in the U.S. might reach about 40,000 MWe. At present, however, the capacity is only 502 MWe and originates exclusively from the Pacific Gas and Electric Co. dry steam fields at The Geysers in California. Since dry steam fields are extremely rare, most of the U.S. expansion over the next quarter century must utilize hydrothermal (hot water) reservoirs.

A low-salinity hydrothermal demonstration plant, the key project in EPRI's Geothermal Program, will have a nominal capacity of 50 MWe. Scheduled for operation in 1980, it will be the first major hydrothermal plant in the U.S. The feasibility analysis and conceptual design studies have been completed and approval has been given to proceed with the next phase. The geothermal field near Heber, California, was determined to be most representative of the total hydrothermal resource base, as well as the best location to study the problems associated with a moderate temperature (300–400°F) reservoir at the least total cost. Analysis indicates that the field can produce in excess of 200 MWe, that scaling and corrosion problems appear manageable, and that adequate cooling water is available for the demonstration plant. However, cooling water could present a problem as further development of the field progresses. Binary-cycle technology, which uses a heat exchanger and a secondary working fluid (such as isobutane) was selected as the preferred design on the basis of its lower power costs and its broad applicability to a large segment of all hydrothermal resources. A 2000-hour test of heat exchanger performance at Heber is near completion.

Assessing geothermal fluid chemistry

One of the major problems associated with geothermal development is the precipitation of salt and mineral solids from the brine as it is cooled and the consequent formation of scale on equipment. EPRI is putting together a brine chemistry data base, developing laboratory and field experimental data, and developing computer programs that synthesize the chemical kinetics of geothermal fluids and the rates of scale deposition. This systems analysis capability will help to develop optimal design configurations, maintenance philosophy, and scheduling and operating procedures that can increase plant availability and reliability. The brine chemistry data base is nearly complete and the laboratory experiments are under way, as is the correlation with field data. Also, the major elements of the computer model are now complete and should be operational in the near future. The data base and computer models will be available to the utility industry.

EPRI has recently developed the requirements for a mobile geothermal laboratory and has completed the conceptual design studies. The laboratory will be used to sample, test, and analyze the characteristics of geothermal fluids at well sites and to determine the compatibility of materials and components with the thermal and chemical properties of geothermal brine. It will provide real-time, standardized measurements, allowing a quick assessment of commercial interest in the fluids from hydrothermal wells. The mobile laboratory will first be used to establish a data base on the similarities and differences of geothermal fluids at a number of sites. These data will be used to assist in both the custom design of power plants (where appropriate) and in developing standard designs for fields and similar characteristics.

Seeking fusion "breakeven"

The EPRI fusion program represents a small fraction of the total U.S. fusion budget. It is designed to continuously assess the national program from the utility industry's perspective, including the need for acquiring operational experience on adequately sized, economical, reliable, efficient, and maintainable power plants. EPRI also has been exploring modifications of existing fusion reactor concepts, as well as alternative concepts, that would enhance the practicality of fusion for utility use.

EPRI has recently completed assessments of various magnetic plasma confinement options and of laser-fusion and their implications for the utility industry. Laser-fusion may allow smaller power units and greater redundancy of critical elements; nevertheless, it is in an earlier stage of scientific development than magnetic confinement. It appears that fusion ignition conditions cannot be reached with the currently available fuel pellets, but pellet designs held under security classification do hold promise. Continued classification serves to hinder but does not necessarily preclude commercial development.

In addition to assessing fusion approaches, research on alternative fusion reactor concepts has been carried out under the EPRI program. The physics are typically less advanced than the ERDA main-line tokamak effort, but some of the concepts have features that are particularly attractive to the utility industry. A conceptual design of a laser-solenoid fusion reactor system has been completed, and its inherent modular construction appears to offer the advantages of short construction time and ease of maintenance. The Tormac experiment at the Lawrence Berkeley Laboratory, funded by EPRI, uses a variation on toroidal plasma confinement that could offer substantial reductions in the size and cost of fusion power plants.

In addition to the use of fusion for the production of electric power, EPRI has evaluated other uses of fusion energy, including synthetic fuel production, fission waste transmutation, and fission fuel production, to see what these applications might mean to utilities.

Priorities in energy storage

EPRI recently completed a major assessment of energy storage techniques, which indicated that storage could eventually provide up to 5% of U.S. electric energy consumption and up to 17% of the electric utility generating capacity if sufficient coal and nuclear baseload capacity for charging storage becomes available. The study also concluded that underground pumped hydro (UPH), compressed-air storage (CAS), and thermal energy storage (TES) are the technologies most likely to become feasible in the near future; and that batteries, if present development trends continue, were likely to represent an attractive storage option after 1985. Hydrogen energy storage systems also have some prospects for becoming competitive, but flywheels and superconducting magnetic storage will require major advances in materials and/or reductions in materials cost before they can be seriously considered for use by electric utilities.

Several conceptual design studies have been completed on the more promising thermal-mechanical energy storage techniques, including UPH, CAS, and TES. Preliminary engineering design and cost studies of UPH and CAS are now beginning; these will establish an information base for specific utility assessment. The data base, which will be completed within a few years, could be used by utilities to make decisions on demonstration projects and to identify areas requiring additional R&D.

Each of the EPRI contractors engaged in the development of advanced batteries has made significant progress toward the design, construction, and life of cells that use technically and economically feasible materials. There are presently four or five advanced battery systems that promise practical performance and acceptable cost. The technical and economic feasibility of these batteries will be established in the next three to five years, first on the level of prototype single cells, and subsequently with the building of 5–10-MWh prototype batteries for testing in the Battery Energy Storage Test (BEST) Facility.

Conception and implementation of the BEST Facility have already become the focus of a truly national discussion of battery technology and its application for energy storage. When completed in 1979 as a joint EPRI–ERDA effort, the BEST Facility will begin testing advanced batteries that have a target capital cost of \$20–\$35/kWh, a 70–75% round-trip efficiency, and a 10-year life with 2500 cycles.

An emphasis on conservation

A new program was established in May 1976 to provide a focal point for EPRI's R&D of technologies for the conservation and wise use of electric energy. From internal discussions and a recent workshop, three broad goals have emerged for the Energy Utilization and Conservation Technology Program. The first goal is the development, demonstration, and acceptance of technologies and practices for more efficient use of electric energy in the major consumer sectors. The second goal, closely related to the first, is utility load management to achieve more economic production and use of electric power. The third goal is new uses of electric energy that are compatible with the first two goals. This recognizes the large potential for electric energy to substitute in functions and processes currently supplied by gaseous and liquid fuels.

The general approach will be to develop an information and data base that can assist in EPRI's planning decisions and those of individual utilities: set priorities for projects on the basis of probable magnitude of energy utilization and conservation potential; and carry out interrelated projects on technology and system development, demonstration, and impact analysis.

Many R&D needs and project opportunities have already been identified by EPRI staff and workshop participants. A few projects of agreed high residential/commercial priority are currently under way or are soon to be initiated. One project, an investigation of methods to improve heat pumps for northern climates, has pointed to reliability rather than performance as the key to improved heat pump acceptance by 1980. Another study, just begun, will provide a technical assessment of cool storage and identify the R&D needed to develop such storage into a feasible component of air conditioning systems that could operate on off-peak power.

Focus on Greater Reliability and Verified Safety for

The Nuclear Power Division is headed by Milton Levenson. There were only about 10 people on the EPRI staff when he arrived September 1, 1973, bringing with him a quarter of a century of nuclear experience at Argonne National Laboratory.

Looking back on 1976, he says, "The year just ended really represents the first full year of the EPRI nuclear program. In 1975 we began approaching full staff and completion of the program planning necessary for the start of significant work. So I feel 1976 was our first year of substantive progress.

"Although the nuclear industry continues to encounter new problems, it must be recognized that these are characteristic of any new technology, and all other new energy technologies will have to run the same gauntlet before they reach stability.

"It is encouraging that the decisive results of seven state nuclear initiatives during 1976 clearly indicate that the public perceives that any significant hazards of nuclear power are clearly outweighed by its benefits.

"The continued increase in oil imports indicates that the basic objectives of Project Independence are not being met, and new nuclear plants coming on-line continue to be among the few restraints on the growth of oil imports. Nothing in 1976 changed any projections showing nuclear power to be one of the most stable and cheap energy sources."

A primary objective of EPRI's Nuclear Power Division can be simply stated: to help assure and demonstrate the safety of nuclear power plants. Other objectives are to improve existing nuclear power options and develop newer, better ones; to make nuclear power more cost-effective; and to contribute to the design of the next generation of nuclear power plants—the fast breeder.

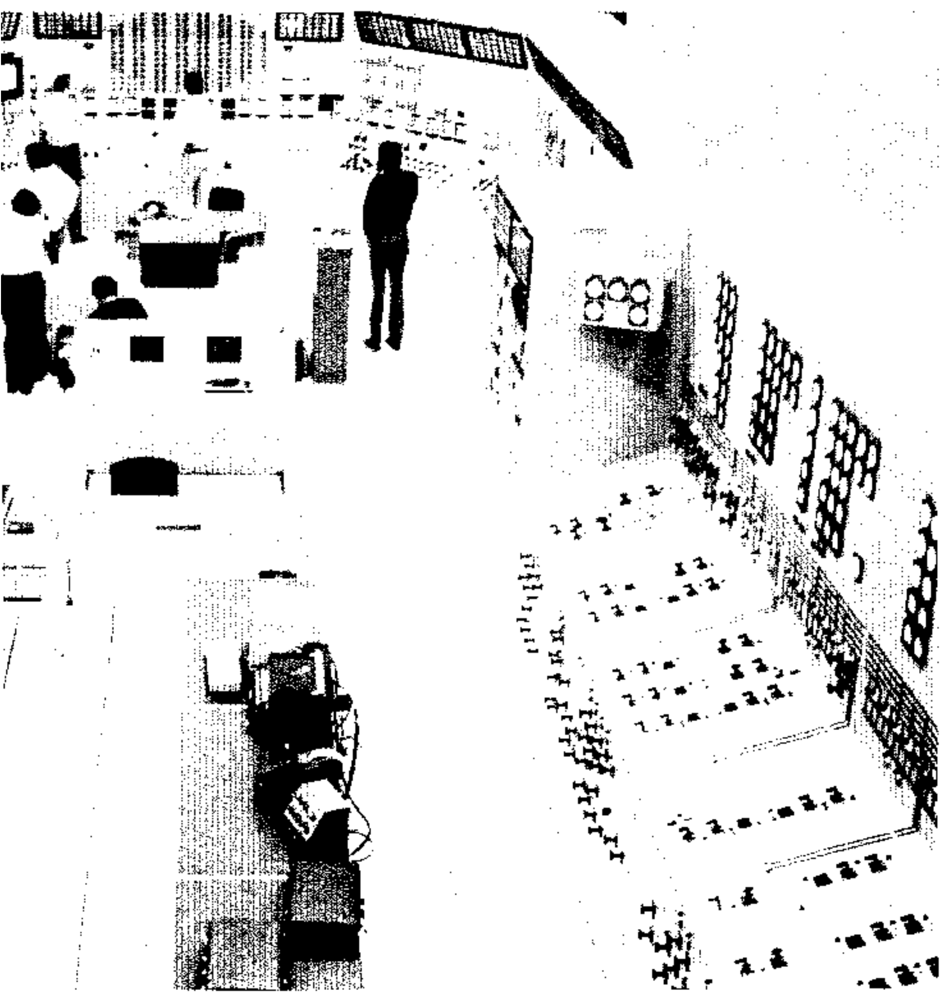
The division is organized into three departments: Safety and Analysis, Engineering and Operations, and Systems and Materials. Safety and Analysis is the largest of the three in terms of the size of professional staff.

In 1976, which Director Milton Levenson feels was the first year of full operation, the division has chalked up an impressive list of accomplishments—many are already available for use by the industry; many others are in the preparatory stages. Some highlights from the first of these two categories follow.

Tornado missile tests

Among the most spectacular (in the literal sense of the word) were the full-scale impact tests carried out on a rocket range in the Nevada desert. Large objects, such as utility poles, were hurled against concrete test panels at speeds of 140 mph and higher to investigate what might happen if a tornado picked up and threw such

Today's Nuclear Plants



As may be gathered from this simulator, which reproduces the control room of the three-unit Browns Ferry nuclear station, the sheer size and complexity of modern power plant control rooms demand that human factors be considered in their design. EPRI has evaluated this problem.

heavy debris against the walls of nuclear power plant auxiliary buildings. When the rocket-launched poles struck the panels, which were 12 inches or 18 inches thick, the first 6 feet of the poles literally disintegrated in a shower of matchwood. Effect on the panels was either nil or negligible. Other objects, such as heavy steel pipes and steel reinforcing bars, yielded analogous results in terms of damage to the panels, showing graphically that even the reinforced-concrete walls of auxiliary buildings in nuclear plants, which are relatively thinner than those of the reactor buildings themselves, are proof against tornado-borne flying debris. This is true even when assuming tornado wind speeds higher than any recorded by the National Severe Storms Laboratory, or direct perpendicular strikes rather than randomly angled ones, or even that objects weighing up to 1500 pounds could be picked up and accelerated to very high speeds by tornadoes.

Additional work on these problems involves aerodynamic analysis and probability analysis. This is of immediate value to utilities, architect-engineers, and regulatory bodies in working toward realistic and conservatively safe design standards without going to excess—such as, figuratively, duplicating the Great Wall of China to fence in a schoolyard.

EPRI has recently produced a 12-minute, 16-mm documentary sound film, "Full-Scale Tornado-Missile Impact Tests." Utilities or other interested organizations may obtain a print on loan—with option to purchase—by contacting George Sliter at EPRI.

On a broader front, both in subject scope and in time (embracing near-term, mid-term, and long-term research), is the division's work in nuclear fuel performance and alternative LWR fuel cycles, in power plant reliability, and in steam generator reliability.

Fuel performance

The fuel performance program is on three levels: the fuel rod itself, the fuel assembly, and the entire core. It has as near-term objectives the minimization of plant availability restraints required by fuel power charge restrictions and the reduction of fuel failure rates. In the long term, the aim is the virtual elimination of fuel distortions and failures, even with load-following operation.

The 1976 results from the destructive examination of power reactor fuel rods have provided basic data on the stress corrosion aspects of Zircaloy-cladding failure. Using these data and related information from out-of-core fracture studies, an analytic understanding has evolved that separates the failure processes into a crack initiation event, which requires a critical stress level (or local strain), and then a phase of chemically assisted flaw growth.

The 1977 efforts will obtain the specific data needed to confirm and quantify the main parameters of the failure mechanism. These data are expected to support improved specifications for cladding tubing to make it substantially more resistant to failure.

The reactor operational (duty cycle) aspects of failure have been further quantified by using an analytic technique that assesses the change in failure probability with changes in overall and local core power conditions. Backed up by the data from EPRI's Halden Reactor Project experimental rig, this analysis of commercial reactor power maneuvers is being used to develop a manual of preferred power-maneuvering strategies that can enhance nuclear plant availability.

The fuel performance effort also covers near-term problems, such as obtaining the additional data needed on fuel behavior in a hypothetical LOCA. Such data are needed to avoid or to minimize plant derating that may result from uncertainty.

In 1976, two results of related research were obtained that are of immediate use: (1) The oxidation rates of fuel cladding were found to be significantly lower than the correlation used by NRC. (2) The preoxidation of Zircaloy has the effect of lowering the total oxidation reached at the end of a LOCA transient. These results will be key elements of a paper to be submitted to NRC with the object of seeking relaxation of current licensing criteria on allowable peak cladding temperature and oxidation levels. The results also provide the basis for data on oxidation of both the inner and the outer surfaces of the cladding tube.

Another major area of work is fuel deformation or failure due to interaction between the uranium pellet and its Zircaloy tube cladding and the tendency of fuel rods to bow under certain conditions.

The complex interrelationships of these and other discrete fuel rod behavior mechanisms are analyzed by the fuel rod modeling codes, which project the conditions resulting from any one variable. By using six existing codes (with common sets of input data and similar materials properties) to evaluate the results, a preferred interim code for utility use has been selected. This code will be used as the basis for the failure model and for developing sensitivity tables to aid in preparing fuel specifications and for guiding plant core operation decisions.

Other topics being covered include the effect of increased internal pressure in the fuel rod from fission-product gases at high burnups in PWRs and fuel channel wear in BWRs.

Thorium utilization in LWRs

Comprehensive analyses of various thorium-based fuel cycles for deployment in a standard-lattice LWR were carried out last year, and the technical and economic feasibility of such deployment was determined. It was found that the ^{235}U–Th–^{233}U recycle scheme could save about 18% in uranium resource requirements over the life of the reactor in comparison with the ^{235}U–^{238}U–Pu cycle. Such cycles are not of economic interest now, but may become practical and economical in the mid- to late 1980s, after present questions on chemical reprocessing have been resolved. The economics are also favored if uranium prices continue to rise, and/or if isotope separation costs stabilize or go down. Effects of small modifications in the lattice spacing on the uranium and the separative work requirements were determined. Some scoping calculations were performed to evaluate the resource savings potential in the spectral shift control concept using the thorium cycle. It was found that both Pu–Th and ^{235}U–^{233}U–Th fuels can easily be introduced into a standard-lattice PWR with no significant changes in the power distributions, the reactivity coefficients, and the transient behavior.

The increase in the price of uranium fuel eventually may make it attractive to consider using cycles that give higher conversion ratios. Thorium–^{233}U cycles offer the best prospects for higher conversion ratios in thermal reactors—LWRs, HTGRs, and heavy water reactors. The results obtained by this research show the potential of the deployment of thorium fuel in already existing or currently planned LWRs. The work has also helped in analyses of future uranium requirements with different advanced reactor deployment strategies.

Plant reliability data systems

Power plant information systems that potentially have an effect on improving plant design, operation, and availability were developed in 1976 and are in the early stages of implementation. Efforts are under way to perform in-depth analyses of the three major power plant data banks and of approximately 25% of the licensee event reports collected by NRC to discern whatever insights may be

Comprehensive Planning Document Published

A five-year R&D program plan for 1977–1981 was published by EPRI last December, marking the Institute's first comprehensive planning document. Two years of R&D planning are reflected in the plan, which covers 29 programs and over 130 subprograms in terms of objectives, key events, and estimated funding requirements.

The objectives outlined in the plan reflect the research needs of the electric utility industry and will guide the programs of the Institute. The plans were formulated through the interaction of EPRI's advisory committees and its technical staff and are based on estimates of future electric energy consumption, fuel needs, and utility plant additions.

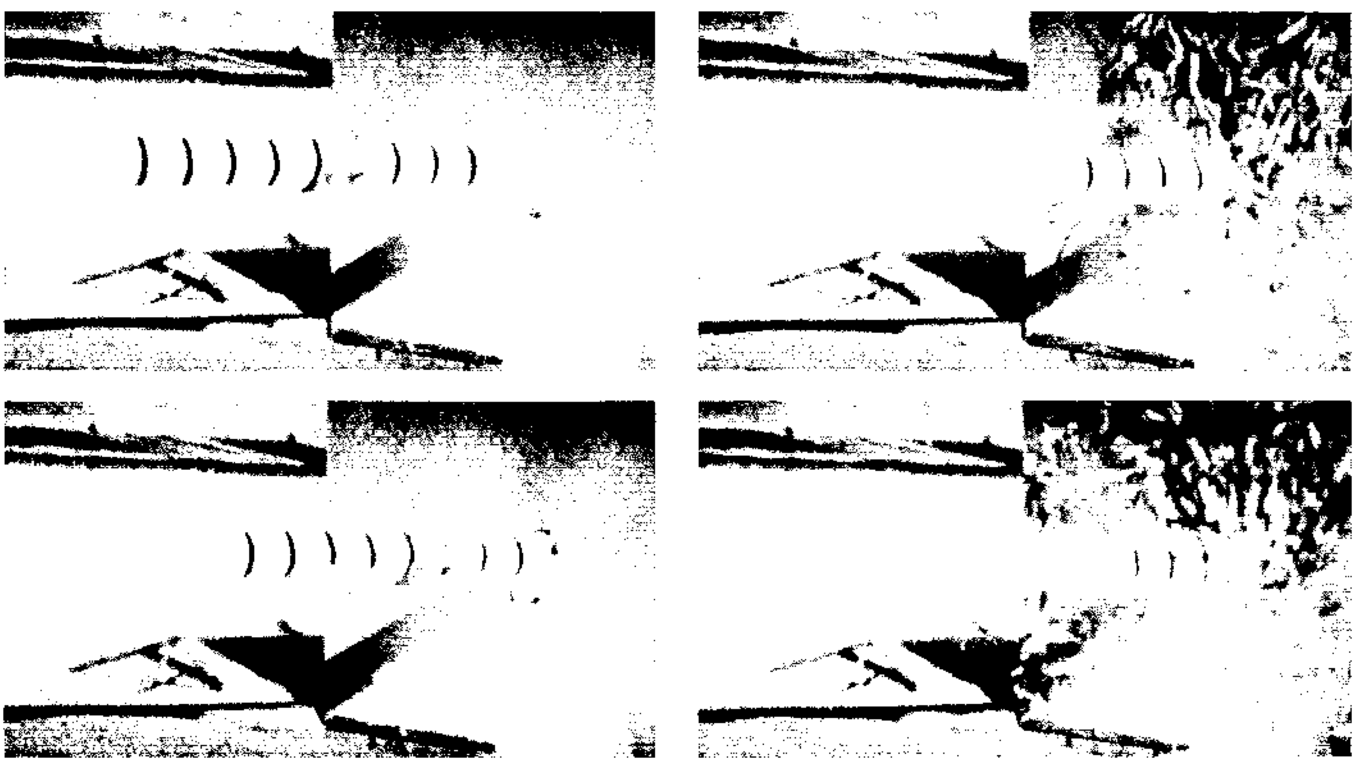
Both current and future technological needs of the industry are continually being evaluated as part of EPRI's planning activities to ensure that R&D dollars are wisely spent. At the beginning of each year, the five-year plan will be updated by the technical staff and then reviewed by more than 300 experienced utility people in EPRI's advisory committee system.

The following six major research areas are considered in the plan: primary energy resource processing; conversion systems; transmission and distribution systems; storage systems; environment and conservation; and energy R&D planning.

The development of the plan is the direct responsibility of EPRI's R&D Planning and Technical Assessment Department. In addition to the planning functions, the department's technical assessment group is involved in developing standard methods for use by EPRI's technical divisions in program evaluation.

It's important for EPRI to understand utility methods of economic assessment, system analysis, and the criteria by which utilities select new generation, transmission, and distribution technologies so that the methods used by EPRI in assessing new technologies will be consistent with those used by utilities. For this reason, an economic assessment workshop for EPRI staff and utility representatives was held in September 1975.

At the workshop, three groups were formed to explore R&D program evaluation procedures, economic assessment methods, and system analysis techniques. As a result of recommendations made by these groups, six models of hypothetical utility systems were developed—models that would be realistic but not duplications of any utility system, pool, or region. These models are being used in evaluation efforts by the technical assessment group. In September 1976, a follow-on workshop reviewed progress to date, as well as continued the exploration of ways to assess new technologies in the future.



An EPRI study of the resistance of walls of nuclear plant auxiliary buildings to damage from tornado-driven debris demonstrated that damage that might result from this source is not in fact a real risk. Various types of debris were driven by a rocket sled into reinforced concrete test panels built to government specifications. Here a standard utility pole is shown as it is propelled at 140 mph against a 12-in-thick wall test panel. The first 70 in of the pole literally disintegrated into matchwood, but there was no damage to the wall.

gained from these data that might aid in understanding the problems being encountered and determining the directions to be taken for their solution.

Another effort is identifying ways in which these information systems can be upgraded to serve more usefully the needs of all sectors of the power plant industry—the needs of equipment designers and architect-engineers in designing and building more reliable equipment and of utilities in operating and maintaining the equipment in ways that will result in improved reliability.

Projects are being planned that will:

□ Provide the means for collecting and disseminating information having generic significance on a rapid turnaround and by so doing, provide an early-alert communication system

□ Attempt to identify and ultimately to consolidate under a single software computer program all the diverse and sometimes duplicative power plant reporting obligations presently confronting the utility industry

Steam generator improvement

In recent years, various corrosion problems have been experienced in recirculating steam generators in PWR plants. The resultant tube thinning, pitting, or cracking has required extensive tube plugging. The occasional leakage of reactor cooling water into the secondary system has been a significant cause of plant outage. Attempts to control these problems chemically by changing from phosphate water treatment to all-volatile treatment appear to have contributed to another type of corrosion-induced damage (denting) in some plants. Denting is caused by the accelerated corrosion of carbon steel support plates in the crevice region between tube and plate. This has distorted both steam generator tubing and support plates, which in turn has increased the frequency of tube leakage. Several utilities are exploring the possibility of having to replace some steam generators.

The root cause of steam generator corrosion damage is the local concentration within the steam generator of trace impurities in the recirculating water, which can become aggressive when concentrated. This situation is difficult to control in some operating plants because of limited flow and recirculation rates, the presence of sensitive materials, and the limitations in capabilities of auxiliary systems for maintaining feedwater and recirculating water composition.

At present there are 10 EPRI projects under way that address one or more aspects of this problem area. These will provide basic information on high-temperature water technology, as well as operating plant surveillance and diagnostic data. Plans have been worked out to expand this activity in 1977 by 10 additional research efforts that will focus on remedies to current plant operating problems and on technology needs to upgrade secondary system design. In addition, the EPRI-sponsored Corrosion Advisory Committee—a 40-member panel of technical experts on corrosion technology—held several meetings in 1976 to determine the specific causative factors involved in steam generator corrosion damage, as well as to help define remedies and preventive measures. An extensive series of meetings has been held with the affected utilities, with those potentially affected, and with vendors in an effort to define the most urgent tasks.

There are several specific accomplishments of this EPRI-sponsored effort. Quantitative measurements of chemicals and corrosion products in five operating plants have shown:

□ Condenser leakage and plant layups are the major sources of chemical upsets that result in large inventories of corrosion products. One means for effective reduction of sludge accumulation in steam generators is the use of low-temperature or high-temperature filters. Such tests are scheduled.

□ Corrosion-product removal from steam generators by blowdown is ineffective, particularly for copper, zinc, and lead corrosion products, which may be aggressive under some conditions.

□ Carbon dioxide and sodium appear to accumulate in certain secondary system loops and therefore can be present at unexpectedly high concentrations. This observation may indicate a need for consideration of system design changes.

□ Hydrazine, which is added to boiler water to control oxygen, appears to be consumed during cold layup conditions. Chemical reduction of copper oxides may be the cause of this behavior. Iron oxide itself can be aggressive to iron support plates under some conditions.

Tests have been initiated in model boilers to reproduce accelerated carbon steel corrosion. This test method will subsequently be used to identify causative factors, as well as possible ways to arrest this form of corrosion damage.

Model boilers will also be used to evaluate the effectiveness and consequential effects of chemical cleaning.

The attention of the engineering and scientific community has been focused on the detailed issues of steam generator corrosion damage. Many valuable comments and recommendations have been received that ensure that meaningful and useful information will be obtained from current and future EPRI programs in this area. Users' groups have been organized to supplement the EPRI Steam Generator Subcommittee. These groups represent the different needs of plants with different operating histories, different designs, and varying cooling-water conditions.

Steam generator data survey

With the assistance of a utility ad hoc advisory group, a steam generator data survey and history questionnaire has been developed and mailed to 22 U.S. and 17 overseas utilities. The survey includes detailed steam generator design data and operating histories at 29 U.S. nuclear plants and 17 overseas plants that are larger than 400 MWe and have been operating for at least one year. In addition, 6 U.S. stations will be visited by a utility-EPRI team to obtain detailed information on steam generator performance. The first two site visits to San Onofre and

Zion were completed in mid-December and the remainder are scheduled in early January. The data survey and histories should contribute to the overall definition of steam generator problems and should assist in identifying future research efforts. Successful operating and maintenance practices will be identified and distributed to PWR owners.

Computer code development

An area of technical research that inherently has one of the widest and most immediate payoffs is the development of new computer codes for use in design, design-verification, performance, and safety analysis of nuclear power systems. EPRI is active in this area and in the past year has made available five new or updated major code packages, some already in use by the industry–utilities, reactor suppliers, nuclear consultants, architect-engineers, and the government agencies concerned (NRC and ERDA). True to the customary mysterious acronymic titling of computer codes, they are designated STEALTH, ARMP, MEKIN, RETRAN, and RELAP/E.

In the evolution of computation methods in mechanics, tradition has separated the effort into distinct combinations, such as solid or fluid, steady state or transient, linear or nonlinear, and so on. The formulation for solids has been biased to the finite element method, while the treatment of fluid mechanics has leaned toward the finite difference technique. Recently there has been a trend to unify the solid and fluid formulations into a common general form known as continuum mechanics. Here a problem is delineated by its material specification, while sharing common conservation laws.

There has been a void in the public domain for a general, modular, user-oriented, explicit finite-difference computer program to address transient, nonlinear events. Although this technology exists in the defense community, it is limited by narrow applications, unfamiliar terminology, and a high degree of sophistication required of the user. EPRI has transferred this technology with

Guidelines for Advisory Groups

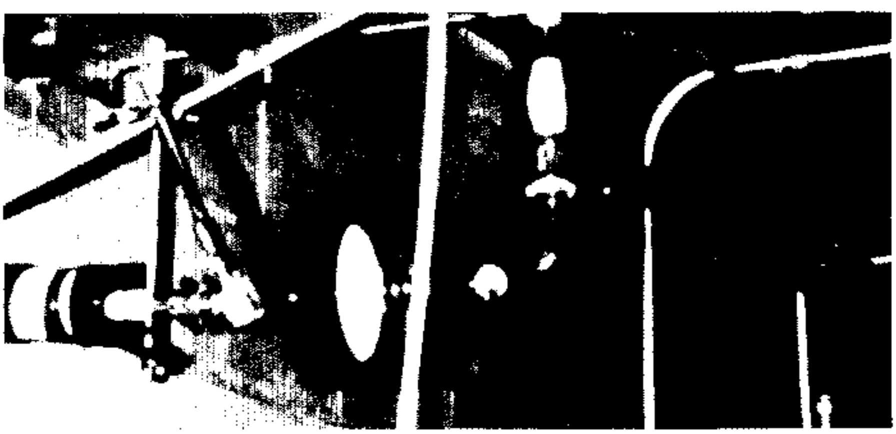
The role of EPRI's industry advisory groups in reviewing projects and planning programs was formally approved at the May EPRI Board of Directors meeting.

The current responsibilities of the Research Advisory Committee (RAC), the four division committees, and the various task forces, remain basically the same. However, RAC, the senior group in the EPRI industry committee structure, has been assigned the added responsibility of reviewing certain research projects, such as those that pose technical policy questions, prior to their review by the Board. The Board or the president of EPRI may also request RAC to review ongoing projects.

Beside managing the organization and operation of the industry committee structure, RAC members work with EPRI's president and the Board to identify and rank the R&D needs of the utility industry.

The four division committees, corresponding to the four EPRI technical divisions, advise the division directors. They have major responsibilities relating to the preparation and review of program plans. Task forces work in more detail with the EPRI staff in specific program areas, both in the preparation of program plans and in the review of individual projects proposed to implement the plans. Subcommittees and other advisory groups are formed at the option of the task forces and function similarly at the program and project levels.

RAC members are generally appointed for terms of three years, approximately one-third of the terms expiring every year. In 1976, eleven new RAC members were appointed: James M. Cain, president and chief executive officer, Middle South Services, Inc.; John A. Casazza, vice president for planning and research, Public Service Electric and Gas Company; Ellis T. Cox, executive vice president and chief operating officer, Potomac Electric Power Company; Ralph S. Gens, manager of planning, research, and development, Bonneville Power Administration; Sidney H. Law, director of research, Northeast Utilities; Francis M. Staszesky, executive vice president, Boston Edison Company; Ruble A. Thomas, vice president for nuclear power, Southern Company Services, Inc.; Russell C. Youngdahl, executive vice president, Consumers Power Company; D. E. Simmons, vice president, environmental and interutility affairs, Houston Lighting & Power Company; Charlie F. Jack, chief engineer, Buckeye Power, Inc.; and Everett D. Smith, group vice president for construction, production, and engineering, The Dayton Power and Light Company.



The possible release of radioactive iodine in nuclear power plants has been a major source of controversy in government regulation of the industry. EPRI has isolated prominent release points and shown how the problem can be controlled. Here a species sampler for various chemical forms of iodine is sampling the in-plant ventilation air from a BWR ceiling duct.

the distribution of STEALTH (Solids and Thermal-hydraulics code for EPRI Adapted from Lagrange Toody and Hemp).

One- and two-dimensional versions of STEALTH are already available to interested parties. A three-dimensional version will be available by the second quarter of 1977. Current extension includes coupling with finite elements to address fluid-structure interaction. The general code architecture allows a high degree of flexibility so users can either treat it as a component code or build it to a systems code.

Applications of the STEALTH code include the BWR pressure-suppression system, seismic wave propagation in a free field, residual stress from welding, and certain two-phase phenomena.

MEKIN (MIT–EPRI Kinetics code) is sponsored by EPRI to provide the nuclear industry with a publicly available, benchmark, computation capability for analyzing reactor core transients in PWRs or BWRs.

This computer program provides a solution in three dimensions for the time-dependent, two-group, neutron diffusion equations and corresponding thermal-hydraulic equations that model the transient behavior of an LWR. It accepts initial steady-state power level and the inlet coolant temperature and flow rate; it first computes the initial steady-state flux and power distributions throughout the core and then the response to a user-specified transient (change in inlet flow, temperature, or control rod pattern).

It provides options to treat the following effects: one or two neutron energy groups; zero to six delayed neutron families; equilibrium xenon; motion of control rods entering the core from top or bottom to simulate drive-in and scram; feedback to neutron cross sections due to coolant density and temperature and metal temperature; heat produced by fission and by radioactive decay processes; heat deposition in metal and in coolant; neutron cross-section perturbations as largely arbitrary functions of position and time; thermal-hydraulic core boundary conditions as functions of time.

MEKIN is available in both IBM and CDC versions and is being distributed (without charge) to those who request it for experimental use—it is still only a developmental tool. NRC and a number of utilities, reactor vendors, and consultants now hold MEKIN.

ARMP (Advanced Recycle Methodology Program) is intended to benefit the numerous utilities that are finding an increasing need for an analytic capability for reactor fuel management and operations analysis. Unfortunately, up to this time such a capability—one that can be used with reasonable confidence—has not been widely available to the industry.

ARMP has undergone extensive development over the past two years. It has also been subjected to initial testing and benchmarking to establish a level of confidence in its use. The computer code package is now available with its documentation and has been distributed to the utilities that have requested it.

As a result, the utility industry now has available a full reactor analysis capability. This provides utilities with both a fuel management and an operations support analytic tool, as well as a mechanism for the effective exchange of information and experience. Such a unified system lays a foundation for greater utility engineering capability and increases confidence in its use.

ARMP is also available in both IBM and CDC versions. A workshop to acquaint utilities with its use was sponsored by EPRI in August at Rockville, Maryland, and a second workshop will be held early in 1977.

RELAP/E, sponsored by EPRI, is a new system of codes based on the extensive amount of analytic and experimental work that has already been done on RELAP-4 and its predecessors.

The majority of nuclear power plant safety analyses are concerned with postulated accidents, occurrences, or operating conditions that require calculational modeling and simulation of the performance of the nuclear system, including the reactor core. Many such analyses

Eighty-four Utilities in Data Bank

When an individual utility considers sponsoring research on coal conversion, solar heating, or any other electric energy concern, how does it find out if similar projects are already under way at other utilities? What resources are available to save electric utilities time and money by helping them to avoid needless duplication of research efforts?

EPRI established one such resource in 1974 with its Research and Development Information Service (RDIS). Through RDIS, EPRI offers utilities a resource for obtaining up-to-date information about in-progress or recently completed R&D projects sponsored by the electric utility industry in the U.S.

RDIS is an on-line computerized data base currently containing approximately 2300 records on R&D projects. Beginning as a pilot program with only seven utilities, RDIS now includes information contributed by over 84 utilities in the U.S., with another 34 currently preparing data for inclusion. The data base is updated on a quarterly basis to include new projects and reflect changes in progress, objectives, and funding of existing projects.

For each entry in the data base, the following information is available: project title, sponsor, cosponsors, contractor, funding, project duration, list of publications resulting from the project, and a 250-word abstract.

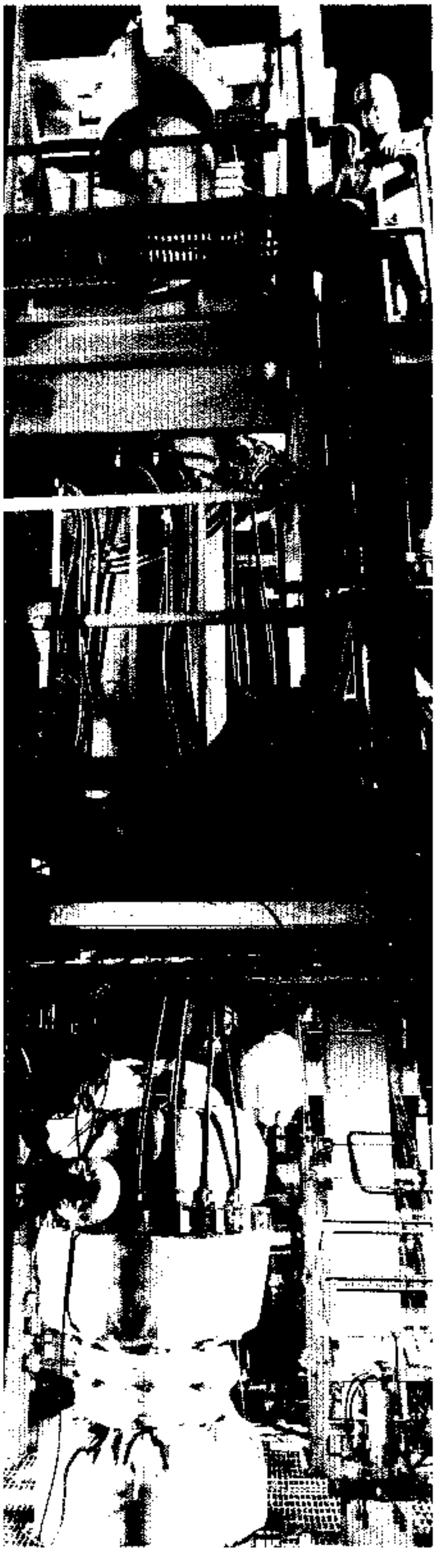
The RDIS system can be accessed in two ways. First, a utility or another organization may make a telephone call or write to the RDIS staff and request a search. There is no charge for this service to EPRI member utilities or to utilities reporting R&D projects to RDIS. Nonmembers and nonparticipants are charged $25 for the first 25 project records or fraction thereof, and 50¢ for each additional record. Second, the utility may access RDIS directly over local telephone lines, using an interactive computer terminal or a teletype.

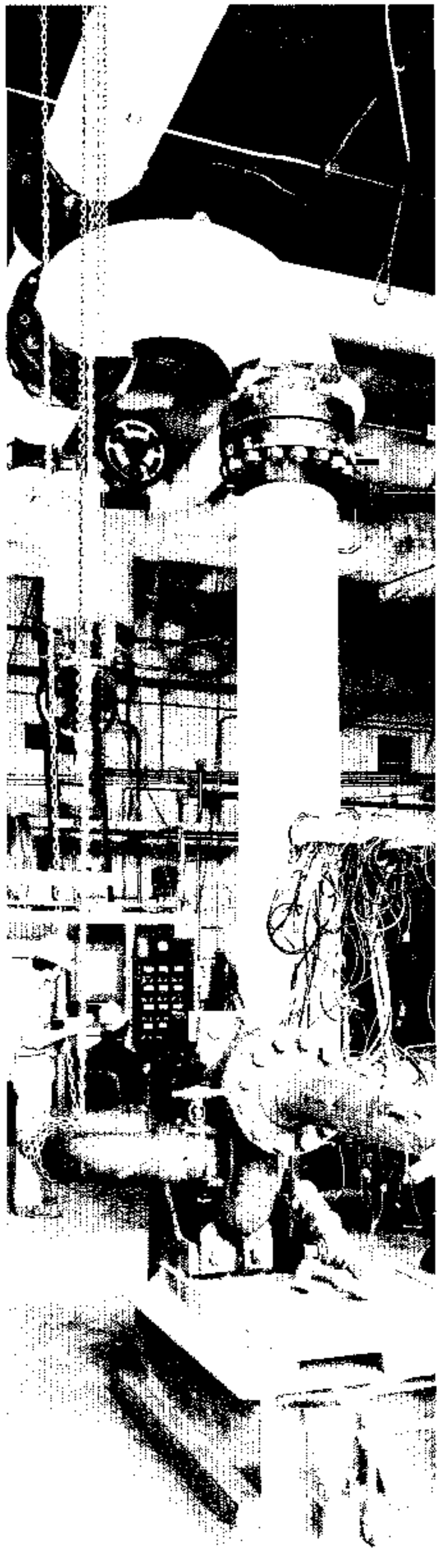
An annual *Digest of Current Research* is photocomposed from the data base and available free to all interested parties. Electric utilities wishing to participate in the RDIS are encouraged to contact Kenton Andrews at EPRI.

As part of EPRI's effort to show the safety of nuclear systems even in case of a LOCA, GE built this blowdown heat transfer loop, which demonstrated new margins of safety.

Improvement of pumps and valves is an important key to improving power plant reliability. EPRI is working on both. Here a pump test loop instrumentation is checked.

The huge scale of a BWR pressure-suppression-pool torus is shown here. EPRI is investigating maximum structural stress loads in such components from hydraulic forces in a blowdown.



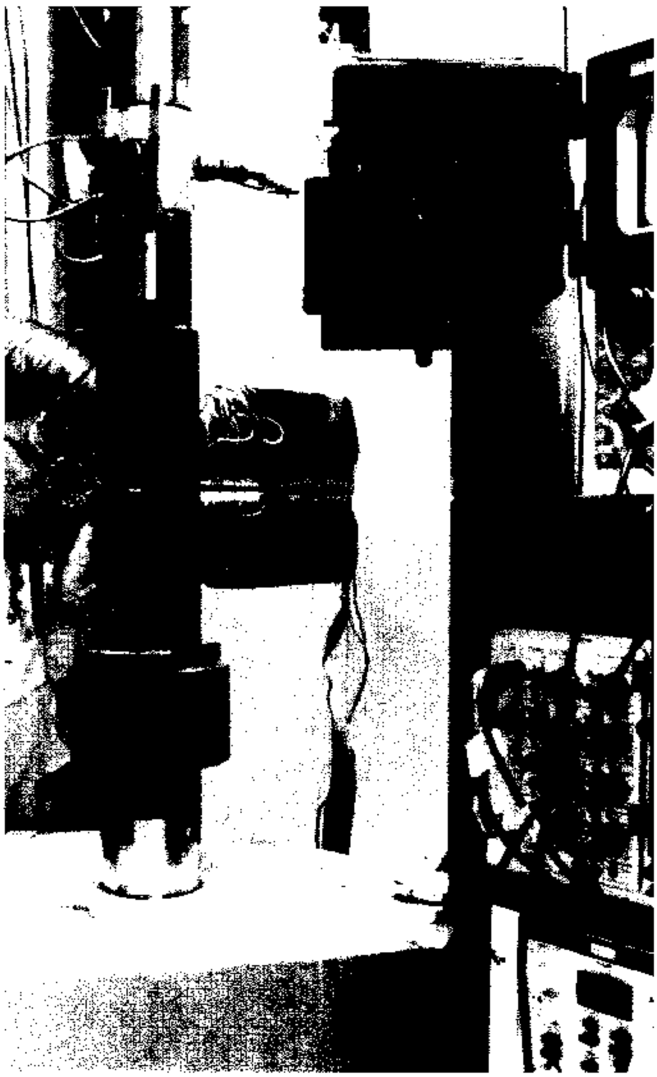


are directed toward determining the optimal approach to fuel design limits or design-basis hypothetical accidents, such as LOCAs. These analyses have usually been performed by reactor suppliers or fuel fabricators, but utilities are being forced into this area more and more.

Utilities that operate nuclear plants have found that backfits are becoming less the exception than a way of life. These backfits, which are very visible and expensive when hardware is concerned, are equally frequent in the area of safety analysis and can be almost as time consuming. Their sources are not limited to new NRC criteria but stem also from hardware problems, design changes, operational strategy changes, and development of improvements in the original safety analyses made by reactor vendors.

For utilities that have opted for reload fuel suppliers who are not also reactor suppliers, these problems are compounded by interface problems, proprietary information concerns, and diffusion of vendor responsibility. Clearly the concept of total reliance on the original safety analysis as an umbrella for fuel resupply has faded. Consequently, there is an increasing need for utility engineers to perform safety analyses at various levels of complexity. The need for flexible computer programs is thus apparent.

EPRI has been responding to this need by developing, improving, and validating the long-used RELAP code, which is a calculation tool for "best estimate" ECCS performance analyses of LOCA situations in LWRs. The code permits feeding



In designing steel pressure vessels, it is important to know and to be able to predict confidently crack initiation, propagation, and arrest. Here an EPRI investigator studies an instrumented steel sample (on right of vertical shaft) as it is literally pulled apart.

An assessment of the technological readiness of the high-temperature gas-cooled reactor has been undertaken by EPRI. Here one of the 1,482 graphite fuel blocks in the Fort St. Vrain reactor core is lowered into place. The fuel is in the small channels seen at top.

in the scores of reactor variables—dimensional, neutronic, temperature, pressure, coolant flow rate, fuel burnup, and the like—to simulate the reactor system realistically in all its complex interrelationships and interactions; the code then accepts the selected abnormal conditions and calculates the effects on each input variable millisecond by millisecond.

RELAP/E provides procedures for hooking together different RELAP modules to suit any given requirement. It is intended to be the most effective and sophisticated analytic tool available and at the same time, to be flexible and user-oriented.

RETRAN is a series of special codes to be used in conjunction with RELAP to permit calculation of the effects of reactor transients other than a LOCA, such as system trips, overpressurization, responses of various components, anticipated transient without scram, and other situations and hypothetical scenarios.

EPRI and its task force are setting up an ad hoc EPRI-utility system analysis working group to facilitate the transfer of these new computer codes to the utilities. An industrywide meeting was held early in December on this subject.

Radioiodine release control

A major subject of controversy in NRC rule making has been the control and prediction of the release of radioactive iodine from nuclear power plants. EPRI's program in this area has already isolated prominent release points of radioiodine and has shown that most of the iodine can be eliminated by treating a relatively small volume of air prior to venting from the reactor building; has provided designers with sufficient information to predict radioiodine releases with confidence; has shown how to make rational decisions (based on the effectiveness of commercially available filters) between alternative means of control, such as eliminating the source or treating the release.

EPRI completed its radioiodine studies on BWRs and expects to complete a corresponding study on PWRs this year.

Blowdown heat transfer

A major consideration in the design and licensing of power reactors is that sufficient cooling capability be available to ensure against fuel clad overheating (in terms of very specific NRC criteria), even in the event of a postulated break in the main coolant piping (the hypothetical LOCA). It is therefore necessary to be able to predict fuel and system response to various speculative LOCA conditions and to take accident-preventing or -limiting steps in designing the system.

As data for such purposes are not available from actual reactors, an engineering test program is required. For several years EPRI has funded research in LWR blowdown heat transfer to investigate core heat transfer performance under LOCA conditions.

In 1976 a project in BWR blowdown heat transfer was completed that demonstrated several important findings.

- Maximum measured cladding temperature, without forced cooling, was less than 1400°F for the peak power bundle tests, despite the fact that critical heat flux, causing excessive heat buildup in the bundle, was forced by the test apparatus to occur earlier than generally assumed.
- Maximum temperature for the average power tests was typically less than 900°F. NRC regulations require designers to demonstrate that in case of a LOCA, this temperature will not exceed 2200°F, which has been established as a conservatively safe level.
- A number of inherent cooling mechanisms were observed for which no safety credit is currently taken in NRC licensing: (1) bundle cooling due to residual fluid in the bundle; (2) steam updraft cooling in the upper bundle zone by steam generated from flashing due to depressurization and heat transfer to the fluid inventory in the lower zone; and (3) rod rewetting during the lower plenum flashing surge and fallback from the upper plenum of the fluid that had been deposited there during the lower plenum flashing surge.

In short, the tests showed that there is a substantial margin above calculated prediction of peak cladding temperature, using current LOCA evaluation methods for BWRs.

Single-parameter and multiparameter blowdown heat transfer studies are also being carried out for PWRs. Preliminary results indicate that the time to critical heat flux, an important blowdown behavior parameter, is generally between 1.0 and 2.0 seconds for average power conditions. This result is significant in that early speculations required consideration of shorter times (about 0.1 second) with more profound heat-transfer ramifications. More conclusive information on high power rod PWR core heat transfer performance is expected to be available soon from both EPRI and related NRC programs.

Decay heat

During a hypothetical LOCA, the nuclear chain reaction quickly comes to a halt, although residual radioactivity in the fuel continues to produce heat. This residual energy, referred to as decay heat, must be known accurately in order to verify that the engineered safeguards exist to assure the integrity of the fuel. Shortly after shutdown, the decay heat level is about 6–7% of the thermal power level of the reactor prior to shutdown, or about 60–70 MW for a typical 1000-MWe unit. This energy release rate rapidly decreases, so that after one hour it is only about one-tenth as large. For LWRs, the radioactive decay of the isotopes ^{235}U and ^{239}Pu is the primary contributor.

EPRI has sponsored several projects to measure decay heat with high accuracy and precision. Accuracy is important because the maximum operating power for some reactors (as determined by the NRC regulatory guides) is directly related to the decay heat. Each 1% decrease in the uncertainty about decay heat may potentially result in a 1% increase in maximum authorized reactor power. Together with other projects funded by NRC, EPRI projects helped to reduce the uncertainties in decay heat over short intervals to less than one-half that of two years ago.

Pressure boundary integrity

To ensure the continuing safe and reliable operation of the components that make up the pressure boundary of a nuclear steam supply system, it is necessary to understand how the materials behave under both normal and faulted conditions. Quantitative description of behavior, backed up by qualified data, is also essential for licensing. The goal of the Pressure Boundary Technology Program is to develop and upgrade knowledge of materials properties, fabrication processes, and analytic techniques in order to be able to predict and correlate the behavior of pressure boundary materials under realistic plant conditions.

Results to date include the refinement of a statistically based design curve for predicting the resistance to fracture of reactor pressure vessel steels. The results have been submitted for official adoption by ASME. If accepted, this will help to limit the continuing increase in design, analysis, and inspection requirements. Savings are expected from increased useful vessel life, reduction of forced and scheduled outages for vessel inspection, and avoidance of some repair operations through the improved definition of acceptable flaw criteria.

BWR pipe cracking

The discovery of intergranular stress corrosion cracks in BWR piping late in 1974 stimulated a great deal of utility activity. Most efforts by individual utilities were concerned principally with assessing the nature, extent, and consequences of the problem (by field inspections and stress analyses) and with implementing remedial action. EPRI initiated and is conducting a number of related research projects dealing with critical issues. Some of the highlights from completed research:

□ Measured levels of dissolved oxygen and hydrogen peroxide were higher than anticipated for plant startup transients. Because excessive quantities of these constituents can shorten time to initiate cracks, operational procedures to minimize such chemical transients have been devised. The effectiveness of such procedures has been demonstrated during actual plant startups.

□ Measured residual stresses generated on the inside surface of large pipes during welding were lower than comparable stresses in small-diameter pipes. Thus this major parameter influencing crack initiation and growth is shown statistically less likely in large-diameter pipe.

□ Heat-to-heat variability in welding has been shown to have a major influence on corrosion performance. A practical technique for screening "bad heats" has been evaluated.

□ The mechanical behavior of cracked piping has been shown to be dominated by predictable plastic flow conditions. Predictions have been substantiated by testing full-size, 4-inch-diameter pipe to failure. The agreement with predicted ductile behavior helps to confirm that desired safety margins are maintained even with cracks present.

BWR containment pool swell

Another group of projects aimed at solving an immediate need on the part of utilities has to do with predicting the behavior of water in a reactor pressure-suppression pool and the most severe hydraulic forces if a hypothetical LOCA occurred in a BWR.

All U.S. BWRs have a pressure-suppression system to condense steam that would be released if such a LOCA did occur, thereby relieving pressure on the inside of the reactor containment and thus preventing release of radioactivity. In a typical pressure-suppression system, the reactor vessel is surrounded by a large, pear-shaped drywell, which in turn is connected by massive vents to a torus-shaped (doughnut) wetwell or water tank. In the remote event of a break in the main reactor coolant piping, escaping steam would be conducted by vents from the drywell into the wetwell, where the water would act as condensing agent.

EPRI has been investigating the behavior of the wetwell pool and the maximum stress loads placed on the local structures from large bubbles, impacting water, or other perturbations in the event of such an air-steam blowdown.

In the past year, the EPRI projects in this area determined experimentally the pool swell surface shapes and velocities and developed a computer model to predict the pool motion, which obviously is of immediate help to architect-engineers and system designers.

Commercial breeder design

The jointly funded EPRI-ERDA project to design the country's first commercial-scale breeder reactor involves three reactor-vendor–architect-engineer teams. It proceeded through its first phase in 1976 and started on the second. Phase I covered the establishment of the basic plant characteristics of this large LMFBR, and Phase II will see the development of an overall conceptual design.

This prototype large breeder reactor (PLBR), as it is designated, will be a loop-type reactor with an output capacity of 1000-MWe gross, without sodium reheat and with the average temperature of the sodium coolant at reactor outlet limited to 950°F. These characteristics represent a fundamentally conservative approach in an attempt to assure the satisfactory performance and reliability of what is planned to be the first full-scale LMFBR in this country, one that is intended to be acceptable to utilities both economically and in terms of system reliability and availability.

Human factors in control-room design

A team from Lockheed Missiles and Space Co., Inc., and NUS Corp. reviewed the human factors in five representative control rooms of nuclear power plants that recently became operational. The review evaluated current nuclear practices in the light of knowledge developed in other industries and estimated the significance of the differences in terms of their potential effect on reactor safety and reliability. The study recommended that a detailed set of standards on applicable human factors be developed to stimulate a uniform and systematic concern for such factors in design considerations.

Eddy-current testing

An EPRI project working to improve the commonly used eddy-current technique of nondestructive testing of metal shapes and welds developed a two-frequency eddy-current system. This uses a multiparameter analysis to extract information on tubing defects and thinning, while discriminating against probe wobble and tube support signals. The system reduces reliance on operator interpretation of signal information and improves characterization of materials damage. Laboratory evaluation tests of the system were conducted in 1976 and a field evaluation will be carried out in 1977.

Assessment of valve problems

A year-long assessment of industry valve problems identified technical aspects and details of problems associated with valves and supporting equipment installed in commercially operating nuclear generating stations. These valves have been responsible for 12% of the forced-outage time for nuclear power plants.

The final report includes specific recommendations to the utility industry on obtaining acceptable functional performance and maintenance burdens when selecting, specifying, and purchasing valves for nuclear power plant applications. The report also proposes using these recommendations as the basis for a more detailed publication, such as a manual on the specification and verification of valve applications in the design phase and in valve maintenance after purchase and installation. Recommendations for further EPRI research to improve valve designs (especially in the areas of seat leakage, steam seals, and body-to-bonnet seals) are also contained in the report.

Condenser leakage study

Condensers are a critical component in the steam cycle of conventional and nuclear power plants. They are the interface between cooling water (seawater, freshwater, cooling-tower water) on the tube side and condensing steam from the main turbine exhaust on the shell side. Since condensing steam pressures are below cooling-water pressures, a leak in any of the several thousand tubes in a steam plant condenser will introduce contaminants into the steam cycle.

Leakage resulting from condenser tube failures is a major plant reliability problem confronting the electric utility industry because of the corrosive and fouling effects the leakage has on other steam cycle components, such as steam generators and turbines.

To define the extent of information and experience on condenser operation and design, EPRI is conducting a broad study that encompasses all the factors that could have an effect upon the deterioration and subsequent leakage of condenser tubes. The study is providing detailed tube failure-rate data as a function of tube material, cooling-water environment, and location in the condenser. This failure-rate information will enable the utilities to more accurately predict the expected service life of various tubing materials in the plant environment. The selection of tubing materials can then be based on a comparison of the cost of initial tubing with the cost of retubing the condenser during the plant lifetime. The study will also present the best methods being used to detect and locate condenser leakage and to deter condenser leakage through design, operation, and maintenance.

HTGR assessment

With the withdrawal of the vendor from the commercial offering of the HTGR for reasons not necessarily based on the technical or economic merits of that reactor type, EPRI is taking part in an assessment of the HTGR's present commercial feasibility. ERDA has initiated a program to identify which companies might form a pool to offer HTGRs using the steam cycle, and EPRI is addressing the question of technology readiness.

The essential objectives of the EPRI study are to provide a recommendation for a future EPRI-supported program should such an HTGR again be offered commercially and to provide a status assessment of the technical and economic areas that need to be resolved during or prior to utility construction of such plants. The planning for this new project has been completed, and the EPRI technology assessment is scheduled for completion in October 1977.

ATWS probabilistics

Anticipated transient without scram is NRC jargon for a hypothetical case in which two very unlikely things happen at the same instant. *Anticipated transient* refers to various deviations from normal operating conditions that might occur during the life of a reactor, most of them trivial in nature, but calling for an automatic scram or emergency injection of the reactor shutdown control rods. *Without scram* refers to the assumption that the reactor protection system, which is set on an electronic hair-trigger to shut down the reactor on receipt of any predetermined fault signal, fails to operate when called on to do so.

Since 1973, when the AEC regulatory staff issued a statistical analysis on the subject (WASH-1270), there has been contention over whether the possibility of ATWS is real enough to require regulation. Industry has felt that the analysis was faulty in its logic and mathematics and that the conclusion was erroneous.

In October 1975, EPRI undertook the task of reappraising the entire rationale for making ATWS important enough to require rule making and as of December 1976, concluded in the negative. The first two parts of the study have been published. Two other parts are in preparation. Much more extensive and thoroughly documented than WASH-1270, the study shows that societal benefit does not justify general rule making on ATWS.

Early Hardware Payoff From Systematic Approach to

Monitoring the technical content of each project is only one dimension of research management in the Electrical Systems or any other EPRI division. Another is how well various projects complement and support one another's purposes. This is what increasingly draws the attention of John Dougherty, director of the Electrical Systems Division.

It is less than a year and a half since Dougherty came to EPRI from 24 years with Philadelphia Electric Co. He brought along insights from two years of advisory service on EPRI's Electrical Systems Division Committee, where he still recalls the "hectic pressure to get research launched."

Dougherty says the pressure on the division now is to organize and plan the program well, and there has been progress during the past year.

"Perhaps the major accomplishment has been to gather together a helter-skelter collection of 160 projects and cluster them into 10 or 12 systems programs—so that now we're attacking comprehensive problem areas, rather than just the specific problems of individual pieces of equipment.

"We have a switchgear program, for example, that coordinates a dozen or so projects on circuit breakers and fault current limiters. If the fault current limiter program is very successful, the emphasis on getting circuit breakers with much larger current ratings could be decreased. Maybe a little improvement in both would be the best final solution—we don't know for sure—but certainly the best approach is to coordinate these interrelated projects.

"In the same vein, we're putting together projects on different aspects of transformer research, different aspects of transmission line research, and the same with underground transmission. It doesn't do any good to develop the world's greatest cable if you don't develop the cable accessories along with it. If the joints don't work, the cable is a failure. And the cable termination is just as important.

"This systematic approach has been in the division's plan since the beginning of EPRI, but it's only within the last year that it's been possible to stand back and look at our mix and fit the pieces together."

Electric utilities in the United States spend about $7 billion per year to upgrade and expand the systems that transport power to the points of consumption. Each system extends from the generator terminal to the customer's meter, and it encompasses all the equipment and lines used for bulk transmission and ultimate distribution of power.

The generation of power is of very little use without its delivery, and the more expeditious the delivery, the higher the overall efficiency. Every effort to improve the reliability and efficiency of the electric system is thus an effort to reduce the amount of generation required for proper service. And that effort must produce results despite an onrush of new problems stemming from larger generators, larger transformers, higher transmission voltages, and a proliferation of interconnections.

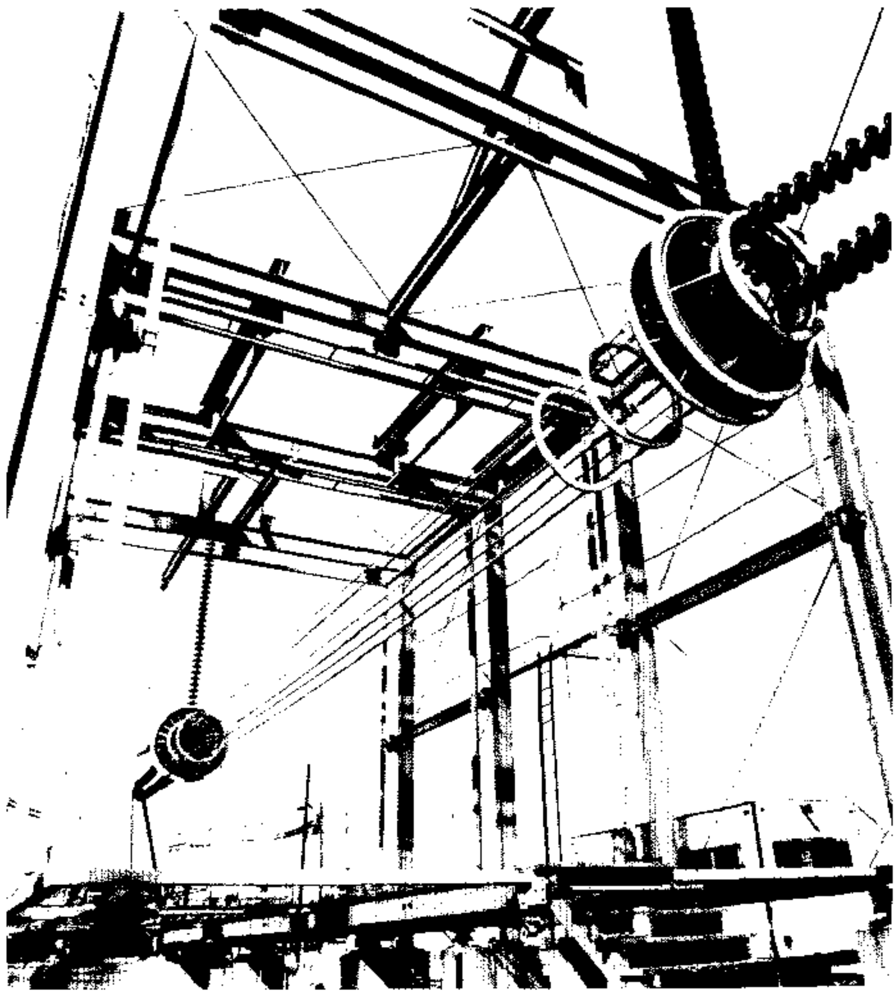
Research in the Electrical Systems Division, therefore, responds to technical, economic, social, environmental, and esthetic forces. All these represent targets toward which long-term development programs are directed. The division supports two major testing facilities for long-term research, as well as over 150 hardware-oriented projects. Of the latter, 30–50% should result in successful innovations that will have immediate applicability and quick payback to the utility industry.

T&D Problems

UHV moves toward practicality

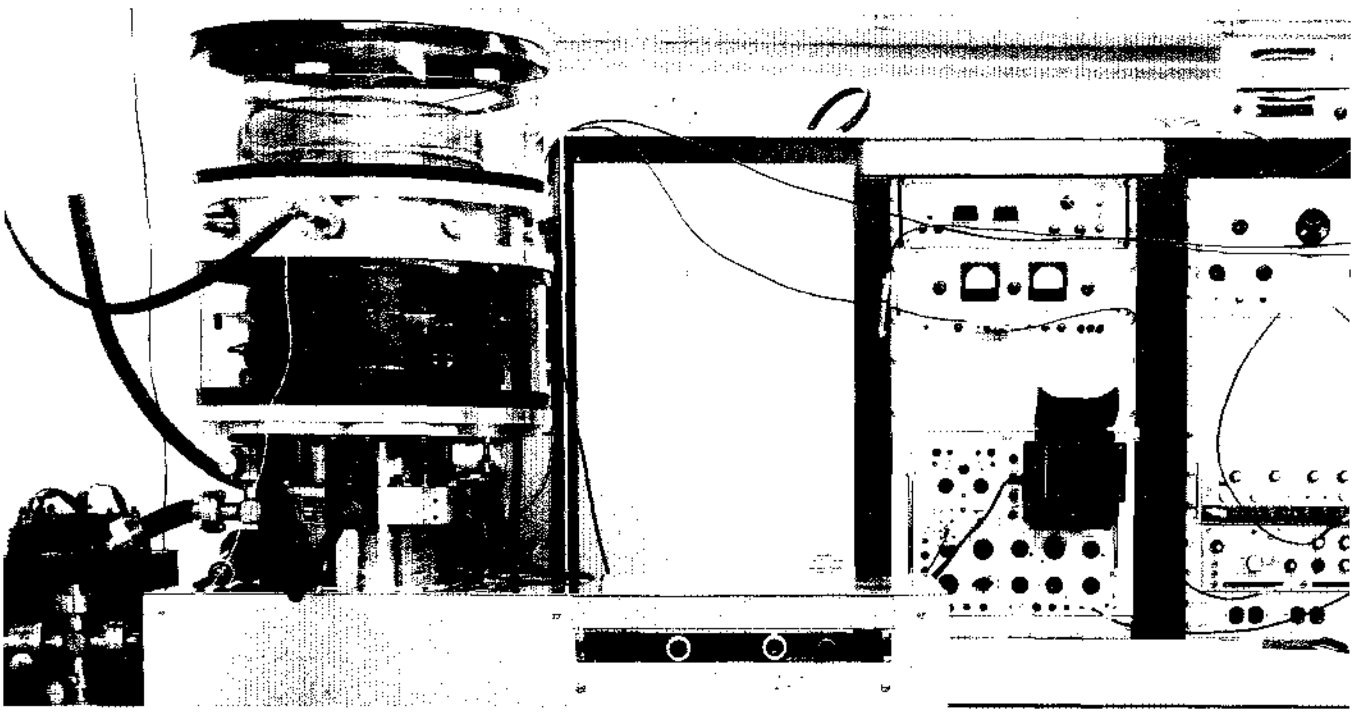
Overhead transmission remains the most economical and efficient means of moving large blocks of power to concentrated population centers. However, this places utilities in the unfortunate position of competing for land with the populations they serve (15–20 acres are required per mile of transmission line). The result has been an effort on the part of the utilities to pack the power corridors by increasing the line loading while decreasing the corridor cross section. Over the years, because of diminishing availability of rights-of-way and improved transmission efficiencies, utilities have been moving toward higher voltage transmission. In the 1960s, lines rated at 345 kV and 500 kV were introduced, and today a few lines rated at 765 kV are in operation. Through Project UHV, EPRI has been instrumental in helping to develop a number of engineering designs for these high-voltage systems and published the *Transmission Line Reference Book—345 kV and Above* in 1975.

In the future, the transmission of bulk power may require the use of ultrahigh voltages (UHV). This will enable the growth in transmission capacity to keep pace with the growth in generating capacity. Much of the development work in UHV is being carried out under EPRI sponsorship at the General Electric Co.



Six-conductor bundle in a test "cage" at Project UHV in Pittsfield, Mass., is one of a series undergoing research on noise and other corona-related phenomena as data are gathered on conductor performance up to 1500 kV. Accelerated tests in this cage—even including artificial rain—enable selection of configurations to be strung on test spans for long-term evaluation.

Vacuum of 10^{-7} torr (18 × 24-in chamber at left) is required by fault current limiter being developed by the State University of New York at Buffalo. Design of commercial prototype, to begin this year, will employ a permanent hermetically sealed ceramic bottle.



Advisory Council Continues Active Role

The EPRI Advisory Council continued its role last year as a group outside the realm of the electric utility industry, but very much inside the realms of business, government, and the public.

From meetings of the four Council committees on national issues, environment and ecology, communications, and power sources and uses, to a major energy seminar at the Aspen Institute for Humanistic Studies, EPRI executives listened and reflected on how the Institute's research programs are perceived by both the nontechnical and the technical communities.

Basic issues relating to U.S. and international energy problems were explored at a week-long seminar, "Perspectives on Energy and Society," in August in Aspen, Colorado. In an effort to develop a broader understanding of economic, cultural, and political issues often overlooked in day-to-day dealings with the energy situation, discussion topics ranged from changing population patterns to institutional obstacles to the development of coal resources.

The selection of the participants, including Council members, members of the EPRI Board of Directors, and a variety of energy industry specialists, ensured that the discussions would be lively and meaningful. No one questioned the difficulties that developing nations face in combating the parallel problems of population growth and diminishing world energy resources, and there were no arguments about the historical relationship between energy and economic growth, although the extension of this relationship into the future was a subject of spirited debate.

Last November, the Council met for the first time with the EPRI Board of Directors and presented short summaries of its activities.

In May of 1976, new Advisory Council officers were elected. Ruth M. Davis, director of the Institute for Computer Sciences and Technology of the National Bureau of Standards, was selected by the Council as the new chairman and Bruce C. Netschert, vice president of National Economic Research Associates, Inc., was elected vice chairman.

Three new Council members appointed last year will continue to serve in 1977: Robert K. Bloom, a member of the Pennsylvania Public Utility Commission; and Marvin S. Lieberman, chairman of the Illinois Commerce Commission. As of December 1976, there were 24 representatives from government, labor, education, science, environmental agencies, and business who are now serving on the Council.

facility in Pittsfield, Massachusetts. Entitled Project UHV, it is one focal point of research on voltages up to 1500 kV. Long-term research is under way in conductor selection, insulator performance, and environmental effects. UHV feasibility at 1200 kV has been demonstrated.

The Bonneville Power Administration (BPA) also has built a 1200-kV line. It will conduct tests and evaluations to ensure that designs are suitable for the system. The pioneering work on the measurement of electric fields at Project UHV has been of use to utilities throughout the country in regulatory hearings.

The environmental issues surrounding UHV, including audible noise, interference with radio and television, and effects of electric fields on biological systems, are the major stumbling blocks to UHV installation. Results from Project UHV have shown that corona phenomena can be controlled through design variations, such as the use of multiple-conductor bundles for each phase (up to 16 subconductors for 1500-kV lines) and phase spacing. New ways of defining and measuring electric fields have also been successfully developed, as have analytic techniques for predicting the field strengths of various line configurations. These will allow engineers to design future UHV systems with the confidence that design criteria can be obtained in practice. Audible noise remains an unsolved problem, although its source has been identified: the myriad tiny arcs drawn by drops of moisture as they fall from lines in damp or rainy weather.

Wake-induced oscillations on high-voltage lines are caused principally by wind and require some means of physical damping. Spacers at irregular intervals are effective, and general rules of placement have been developed recently. A computer program that examines span length and conductor type and then provides a spacing profile is now available for utility application.

Saving space and money

For the past two years EPRI has been investigating 3-foot phase spacing on a 138-kV transmission line in Saratoga, New York. A 2-mile test section was operated without flashover under adverse weather conditions, and the results have already led several utilities to incorporate the data into their own designs. Savings of 5–20% over conventional designs are indicated by the tests, and the concepts developed offer encouragement for compacting lines rated up to 345 kV. The project was completed in 1976 and a design reference book is due shortly for publication.

The results of the project will have direct application for high-voltage lines installed in the narrow rights-of-way within metropolitan areas. Data obtained at Saratoga indicate that new high-strength insulators will allow the placement of an entire circuit where only a single phase is now hung, permitting an uprating to higher-capacity lines. This could offer savings in the land as well as in the material required for conventional designs.

Another spinoff from the work in Saratoga is a better understanding of the motion of conductors in the wind. It has led EPRI to question the fundamental design of transmission lines, especially the relationship of tower strength and wind velocity. Projects under consideration would gather data from two sites, including one in Alaska where winds reach 200 miles per hour. If preliminary interpretations are borne out by the data collected, it would indicate the need for fewer towers and for less steel per tower.

Better substation protection

Expansion of the U.S. power system, along with needed interconnections, has resulted in a continuing growth in the magnitude of fault currents and transient overvoltages. Conventional switchgear has been unable to maintain an adequate level of protection for substation equipment. For example, the flow of fault currents through transformers, permitted by today's circuit breakers, are the principal cause of transformer failure. EPRI has responded with a vigorous R&D program to develop suitable fault current limiters, improved circuit breakers, and surge arresters.

Fault current limiters (FCLs) are being developed with millisecond response to control even the first half-cycle of fault current. The objective is to have reliable FCLs available for widespread commercial installation by 1981. A first-generation FCL has been designed and its technical feasibility proved with field testing. A commercial prototype is expected to be installed in 1978 by Southern California Edison Co. Plasma-controlled vacuum devices are also being developed for use in FCLs.

Research on FCLs has been of the highest priority, and its success will be one of the most notable achievements of the Electrical Systems Division. FCLs will have ramifications throughout the entire electric system: a likely favorable impact on system stability, improvements in the feasibility of compact spacing, reductions in the size of distribution conductors, direct design implications for circuit breakers, reductions in the failure of large power transformers, and overall extensions to substation equipment life.

Despite the timely development of the FCL, there will be a systems requirement for circuit breakers with higher interrupting capabilities and faster response. EPRI is exploring gas, vacuum, and hybrid concepts for improvements in interruption. Developments to date include SF_6 gas devices to interrupt currents over 100,000 A, nearly double the performance of existing circuit breakers. A vacuum device that is under development recently interrupted a current of 180,000 A.

EPRI is also pursuing a promising concept for cutting off voltage excursions above a certain maximum. This is basically a takeoff from the electronics industry and involves the use of metal oxide nonlinear blocks as surge arresters. To date, considerable basic work on material formulation, mix, and processing has been completed, and efforts are being directed toward fabricating blocks of adequate size and uniform quality. These should be available by the end of 1977. Enough progress has been made to confidently predict significant improvements over the present gapped arresters. The devices should allow considerable savings in insulation for transformers and switchgear over the long term.

Cutting substation size and cost

In addition to the development efforts in protective equipment, EPRI has a number of long-term programs for improving substation equipment. SF_6 gas-insulated substations require less than one-tenth the area of air-insulated substations and are less costly to install at 345 kV and above. In order to increase their acceptance, EPRI has focused its efforts on developing equipment that will improve their reliability. Gapped lightning arresters cannot be effectively used in an SF_6 environment, and the use of the metal oxide nonlinear blocks will afford a major advance in substation reliability. An EPRI-funded project has developed a three-phase gas bus that will allow cost reductions for lower-voltage SF_6 substations, and solid epoxy bushings with heat pipes have been developed to eliminate the gas-pressurized bushing.

EPRI has been investigating potential improvements in the insulating performance of the SF_6 gas that is currently used in gas-insulated substations, as well as exploring the use of other gases with superior dielectric characteristics. Analytic studies of the movement of contaminating particles in the gas have permitted the design and development of improved particle traps. This has led to an increase of about 20% in the dielectric stress level so far, and further improvements are anticipated. If all particles could be effectively eliminated, doubling the dielectric stress would permit a 50% reduction in the size of SF_6-insulated equipment.

In a related project, a low-cost, accurate system has been built to monitor sealed compartments for gas leaks. It provides a real-time readout of gas density, leak rate, and moisture content, as well as an alarm system for quick corrective response. Three prototype units of the monitoring system will soon be field-tested, including one for an HVDC gas bus. Knowledge of the leak rate will allow operators to take either routine maintenance action for slow leaks or emergency action for fast leaks.

Transformer advances

Transformers are generally considered to be a mature technology with little room for improvement. Nevertheless, EPRI has pursued a number of innovations that promise significant improvements in transformer life, performance, and reliability.

Internal corona in a transformer tends to damage its insulation, which in turn leads to transformer failure. EPRI has recently developed a very sensitive acoustic instrument to detect corona and provide indications of other transformer problems. The acoustic device now being tested can be used for diagnostics or maintenance; or in a simplified form, it can be easily retrofitted to the transformer as an alarm relay.

EPRI is also developing a hot spot detector to monitor temperature in the hottest areas of a transformer. These hot spots are unique for each transformer design and may correlate with transformer life. Selective monitoring may allow transformers to be safely overloaded under emergency conditions.

Transformer performance is adversely affected by dissolved gases in the insulating oil. EPRI has developed a laboratory prototype system that uses a permeable membrane and a unique gas-analyzing device to detect the presence of H_2 and/or CO_2 while the transformer is energized. The unit has been successfully tested, and a commercial unit suitable for retrofitting to existing transformers is expected by 1978.

A low-cost method of reducing transformer noise has been successfully demonstrated. It involves the use of an enclosure that is tuned for maximum damping. Tests at a Wisconsin Electric Power Co. substation have been conducted to obtain field performance data and to evaluate "tuned shell" installation methods. The cost of this shell design will be only about one-half that of alternative techniques, and most important, it is suitable for retrofitting transformers in service.

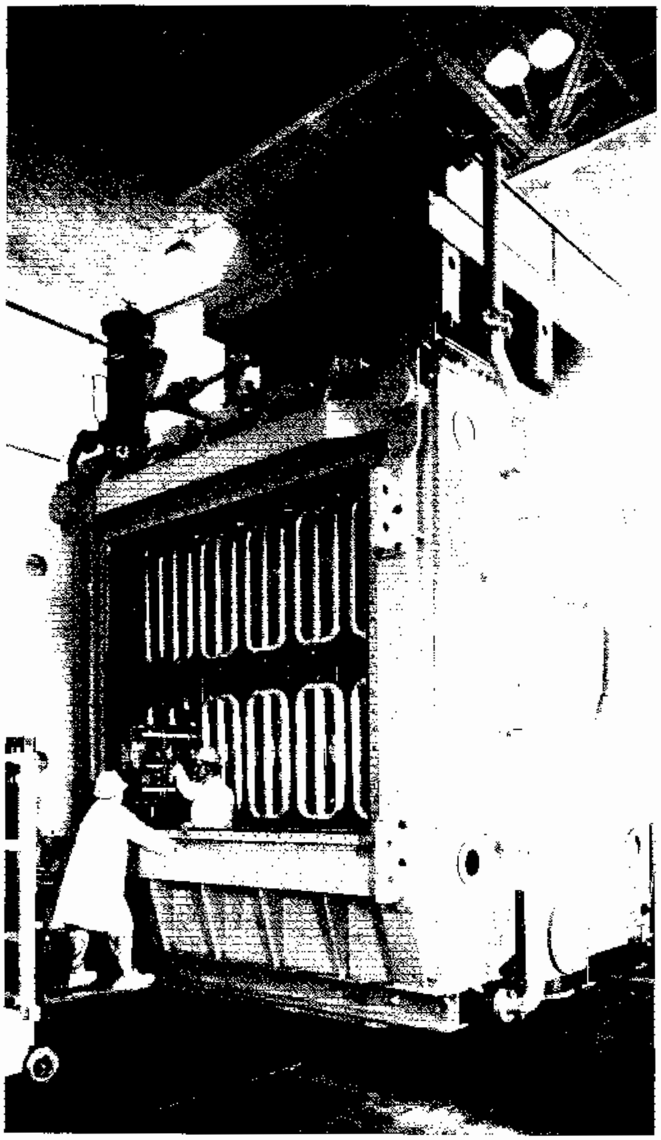
EPRI has recently begun to explore major innovations in transformer design. Feasibility work has begun on replacing the traditional oil insulants with vaporizable media. Vapor-cooled transformers offer the possibility of fireproof, nontoxic units with weight reductions of up to 30%. This would provide some relief to the problem of shipping large and bulky transformers. Basic research has also been initiated into amorphous metal alloys that will reduce core losses and allow compaction due to more efficient use of the magnetic flux field. This portends significant reductions in transformer core loss and manufacturing costs.

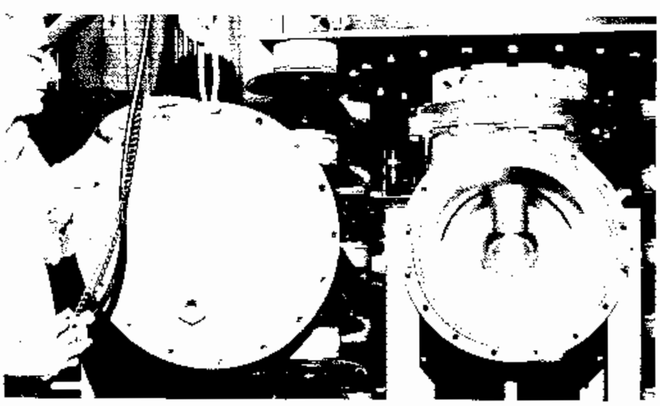
Progress toward better materials

EPRI has been instrumental in the development of new and improved materials for insulators, bushings, and poles. Cost reductions and improvements in strength and reliability will have immediate payoff for the utility industry.

Two projects presently near completion have already resulted in a doubling of the mechanical strength of both normal and high-strength porcelains without attendant increases in cost or firing temperature, and further improvements are expected. At the same time these developments were being pursued, a search was undertaken for substitute materials. (Porcelain requires large amounts of energy for firing, resulting in a high cost, with the expectation of still higher costs as energy prices escalate.) EPRI's search produced a polymer-impregnated concrete material of great versatility and low cost. The new material sets up under chemical reaction, requiring no external energy for its formulation. Its mechanical strength is equivalent to that of porcelain but it has twice the dielectric strength. It can also be used for

Two new components of a prototype compact dc terminal are opened for inspection. Pairs of liquid-cooled, gas-insulated thyristor valves (top) reveal electrostatic shielding around panels. Gas bus elbow (bottom) shows cone-shaped insulator supporting bus segment.





Flexural test (top) marks research in new electrical porcelain using less costly materials (clay, feldspar, and bauxite) in a glass-ceramic process to produce crystalline structure. Alternative approach (bottom) is a polymer-impregnated concrete that sets without firing.

configurations too complex for porcelain materials. Most significant, its cost is less than half.

In a related project, a high-power bushing was fabricated from a cast-epoxy material, using a heat-pipe design. The design allowed compaction of a 4000-A bushing to the size of a normal 800-A bushing, as well as a 50% reduction in cost. It is now expected that an additional 30% cost reduction could be realized by using the polymer concrete material.

In 1975 EPRI began a search for a substitute material for the conventional wood pole because wood shortages were apparent and pole prices had doubled in just a few years. The result was a foamed-glass material constituted from scrap glass and fly ash. The feasibility studies that were recently completed on 6-foot poles were extremely encouraging and indicate that a substantial reduction in pole costs is possible. A pilot plant for poles is now under construction and will develop the basic extrusion manufacturing technology.

Another recently completed project will extend the life of roundwood poles. The internal decay in fir poles has been significantly retarded by the use of the fumigants chloropicrin, Vapam, and Vorlex. Vapam is already available commercially.

DC developments

HVDC transmission is uniquely suited to the long-distance, point-to-point transfer of bulk power, as well as providing a stable interconnection between ac systems. Significant use began in Sweden about 20 years ago, and the first large-scale U.S. installation, the Pacific HVDC Intertie between the Columbia River hydroelectric facilities and Los Angeles, was commissioned in 1970. Projections indicate that more than 8000 miles of ac overhead line will be built by the turn of the century. Much of this will be used to supply bulk power from remote mine-mouth and nuclear power stations to urban locations. In many cases, dc cables may prove to be the most economical means of providing power to downtown load centers. As a result, high research priority has been given to the development of a compact dc converter station appropriate for metropolitan locations.

Using gas-insulated, dead-tank technology, a 90% reduction can be made in the land area required for a converter station. The goal of a major ongoing project jointly sponsored by EPRI, General Electric Co., and Consolidated Edison Co. is to make the dc compact terminal available to utilities by 1980. The R&D work is now complete, and construction of two 100-MW terminals that will prove the technology at the 400-kV level is under way. The terminals and their dc link between two buses at Con Edison's Astoria station will be ready for operational testing and evaluation in early 1978.

The full benefits of HVDC transmission cannot be realized until converters are simplified and dc circuit breakers are developed. The conceptual design of a new thyristor that allows remote firing by a light-pulsed, fiber-optic system appears promising. Working prototypes are nearing completion and are expected to significantly reduce the cost and complexity of HVDC valves. Systems studies to develop specifications for a dc circuit breaker have been completed. Development of a unique metallic-return transfer-breaker has been undertaken and a commercial prototype is due to be installed in 1977 at BPA's Celilo converter station on the Pacific Intertie.

EPRI and BPA have recently completed an analysis of the design and maintenance of dc overhead lines. The results of the investigation, undertaken at the dc test facility at The Dalles, Oregon, will be made available in a reference publication in early 1977. The book will contain all engineering design information on dc lines up to ± 600 kV.

Underground technology advances

Underground distribution cables have typically been used in residential and urban areas because of esthetic preference and congestion. Transmission cables as a rule, however, have been used only in urban areas where corridors for high-voltage transmission overhead lines are not available. But today, environmental restraints prohibit even the expansion of existing rights-of-way, yet higher power-handling capacities are required of both overhead and underground circuits. This has resulted in efforts to accelerate the technical development of cables at transmission voltages. The underground transmission test facility at Waltz Mill, Pennsylvania, operated by Westinghouse Electric Corp. and supported by EPRI, entails a long-term financial commitment to accelerated-life testing of new and improved cable systems in the 115–765-kV range. Significant over the past few years has been the successful testing of four high-

International Meetings

Two international meetings were sponsored last year by EPRI—one in September with the International Electric Research Exchange (IERE) and the other in May with 350 key energy leaders from five continents.

The members of IERE represent the electric utility industries of 14 nations. They meet annually to promote the international exchange of information on electric energy research; EPRI is the U.S. representative to IERE.

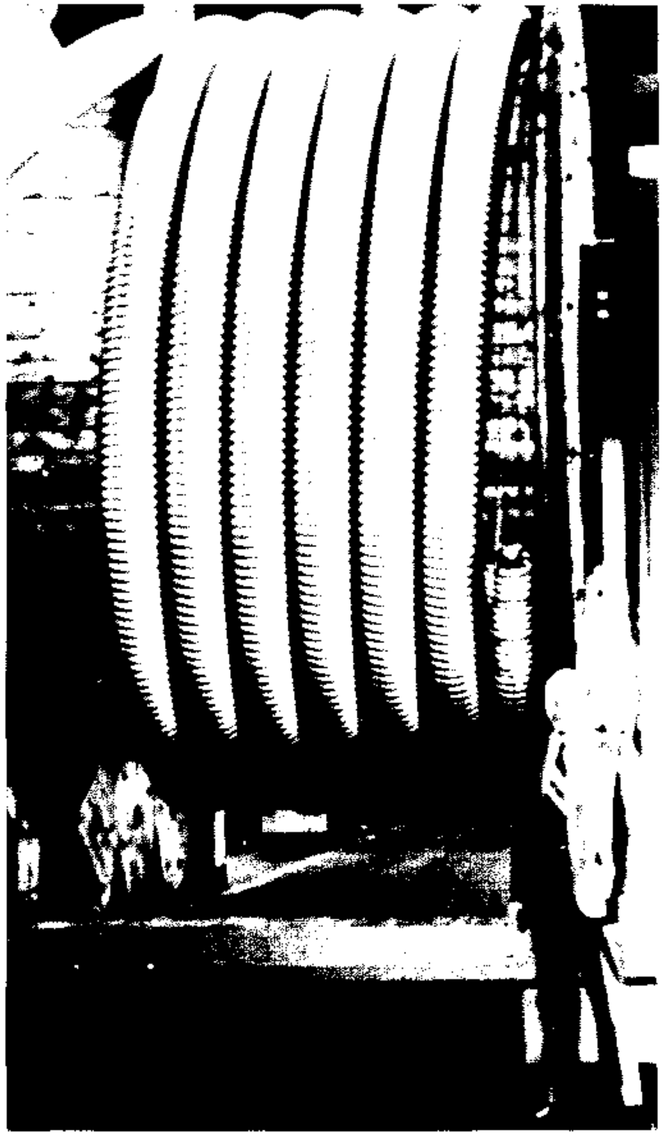
The electric utility industries in European countries are represented in IERE through the Union Internationale des Producteurs et Distributeurs de l'Energie Electrique; in Canada, through the Canadian Electrical Association; in Japan, through its IERE Council.

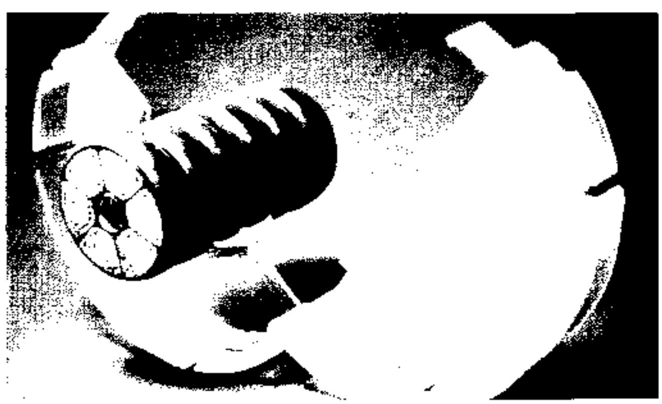
The International Symposium on Electricity Research and Development Planning was sponsored by EPRI in Washington, D.C., on May 5. It resulted in a broad survey on the research and development planning currently under way in the U.S., France, Britain, Japan, and Sweden. Dr. Robert Seamans of ERDA and Dr. Chauncey Starr of EPRI represented the U.S., and along with senior policymakers from France, Sweden, Germany, England, and Japan, summarized national energy policy issues.

Both meetings were instrumental in helping to promote the exchange of information on energy policies and the state of the art in worldwide energy R&D.

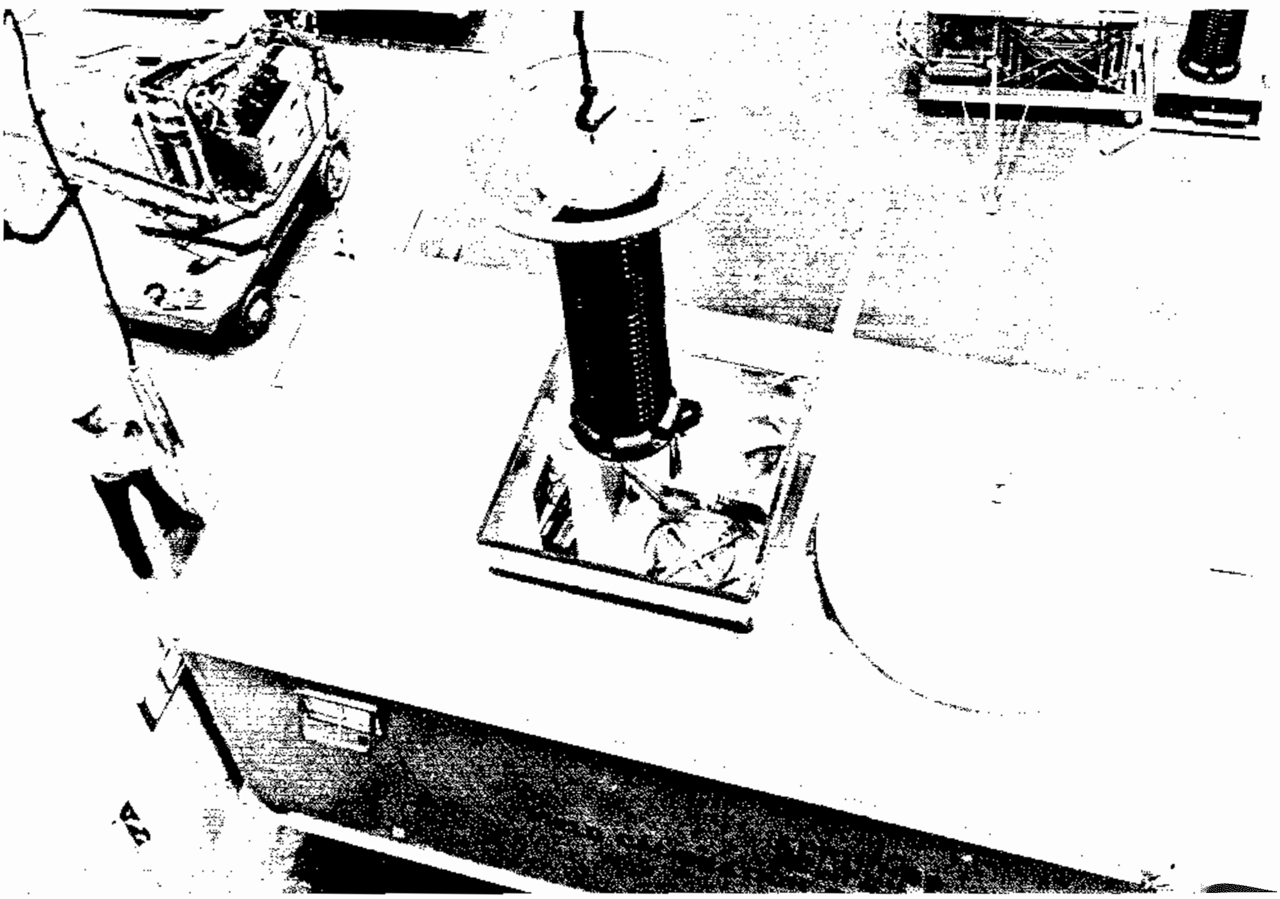
Tuned panels provide a field fix for transformer noise at about half the cost of other noise suppression schemes. Panels bolt into place without disturbing radiator. EPRI research established criteria for panel dimensions needed to cancel resonant frequencies.

Shipping reel (top) holds 100-m continuous length of fully assembled 345-kV gas-insulated cable. Conductor (bottom) has aluminum wires stranded and grouped to cut "skin effect" and uses low-dielectric-constant spacer halves that snap together during continuous assembly.





Ten loops of underground transmission cable are the feature of test facilities operated for EPRI at Waltz Mill, Penn. Six HV bays are in the foreground and four EHV bays flank the instrumentation building where computer programs monitor all tests.



Voltage divider is lowered into truck being outfitted for field calibration of coupling capacitor voltage transformers used for revenue metering at EHV system interconnections. Gradually accumulated CCVT errors of 2–3% can be cut back to the ANSI limit of 0.3%.

pressure oil-filled cable prototypes for 500-kV systems and the identification of fundamental design weaknesses in 138-kV extruded cables.

The transmission capacity of classic paper-oil (taped) cable is basically temperature limited. Higher voltages impose undue electrical stress that can result in higher temperatures and the possibility of thermal runaway. One of the basic thrusts at solving this problem is the development of semisynthetic tapes, and two projects are under way to develop cable systems for both 500- and 765-kV nominal operating voltages. Both systems, of course, would receive their final testing at Waltz Mill after successful factory or laboratory testing.

Another major effort that would counteract the temperature limitation is the study of forced cooling, a process that carries off the heat with a flow of low-viscosity oil. Forced cooling can also be used to uprate existing pipe-type cable systems and to increase the current density in new systems in a congested underground environment.

Extruded polyethylene cables have been in service for years at distribution voltages and at lower operating stresses. However, even at these lower stresses, serious problems have been encountered recently with electrochemical treeing. At transmission level voltages, which require higher operating stresses, the insulation is subject to even more severe treeing problems. Fundamental research into the formation and propagation of these trees is now under way. Parallel investigations to mitigate or eliminate the consequences of treeing include improved manufacturing techniques, improved design, and the use of chemical additives.

Extruded cables hold great promise for both economy and reliability if these problems can be resolved. One of the objectives of the EPRI program is to have a 345-kV cable suitable for commercial use within five years. Over the past year, EPRI has funded the development of a new solid dielectric extruded cable that requires only one-half the insulating material of conventional cables. This project will include the manufacture of prototype cables for testing at Waltz Mill at voltage levels of 138 kV, 230 kV, and 345 kV. Proof-testing on the 138-kV prototype is expected to begin at Waltz Mill in 1977. Also, two utilities have found the concept so promising that they are planning prototype testing on short cable samples at their own facilities.

EPRI has recently completed a design guide for gas-insulated transmission systems. All existing data have been integrated into composite unified designs appropriate for a wide variety of applications. The guide also incorporates optimized parameters developed in the research study.

In general, gas-insulated systems have been economical only for very short lengths, higher power-handling capacities, and higher voltages. However, a new development is likely to extend the competitive range of gas cables, vis-à-vis other cable technologies. New, flexible cable for 345-kV systems and the automated production technique required for it are expected to result in at least a 25% savings on installation and operating costs.

Distribution refinements

EPRI is involved in several projects to develop better load-forecasting tools for the distribution planner. Over the long term, these should help to minimize operating expenses and unnecessary capital investment, as well as promote better reliability in the distribution system. To date, the concentration has been on the acquisition of a reliable data base and the construction of preliminary models. Several computer programs have been completed this year for forecasting loads in small areas. These are now being evaluated by several utilities.

With the growing need for end-use conservation and the advent of peak load pricing, the development of automated systems has been accelerated. In the past, these concepts have been frustrated by the lack of an economical and reliable two-way communication system. R&D efforts to explore the various communication options have now assumed a high priority. EPRI has recently completed a comprehensive state-of-the-art survey of available communications systems. Also, EPRI and ERDA have begun field installations with host utilities of six prototype communications systems: a radio system, a telephone system, and four power-line-carrier (PLC) systems. These demonstration systems will be functional by the summer of 1977. Each will be run for a one-year trial period and will concentrate on the potential for load control, remote meter reading, and system monitoring and control.

Better T&D planning

The electric power system is both a resource and one of the world's most capital-intensive industries. Advanced planning methods and operational procedures are required for its reliable and efficient utilization. EPRI has undertaken a major program to develop analytic tools and modeling techniques for planning and control strategies. The major effort to date has been focused on computer simulations of the bulk power system. In one simulation, large power systems are being studied for their stability when sudden, severe disturbances are introduced. Such disturbances could conceivably lead to a breakup of the power system, causing widespread blackouts and brownouts.

In another project, simulation is being used to study spontaneous, oscillatory behavior that sometimes occurs without a known disturbance in a large power pool.

New studies are also being launched that will improve the minute-by-minute operation of power systems for improved economy in generation, while carefully controlling environmental impact. The techniques being developed are aimed at securing better control of generation costs in the face of rising fuel prices. These and other analytic techniques are presently being validated and will be introduced into the utility operational planning program in 1977.

Building the Fact Bases and Methods for Sound Energy

It has been more than four years since the energy dependence of the U.S. was given sharp focus by the oil embargo, and over seven years since national concern for protecting our environment effected passage of the National Environmental Protection Act. Unfortunately, there is still no adequate fact base for determining how to provide for our future energy needs while protecting human health and the environment.

The efforts of EPRI's Energy Analysis and Environment Division are directed toward developing such fact bases. As René Malès, the division's director, sees it:

"In the long run, environmental issues will not be driven solely by the ambitious goals of zero discharge. Rather, society will have to decide on the levels of environmental effects on human health and the ecology that are low enough to be acceptable in trade for the benefit from the energy sources that cause the effects."

Malès, who is on loan from Commonwealth Edison Co., where he served for 20 years and was general service manager, points out that "a continuing task of EPRI's Environmental Assessment Department is to develop sound methods for examining and evaluating the trade-offs between energy needs and environmental effects." During the past year, Malès notes, the department made progress in developing fact bases with state-of-the-art studies, design of experiments to fill gaps in knowledge, and initial implementation of these experimental designs.

Similarly, the division's other programs continued efforts during the past year to generate knowledge needed for decisions on the U.S. energy future.

Malès notes, "The Demand and Conservation and the Supply programs will produce at the end of each year an updated set of three-dimensional projections of time, quantity, and price for demand and supply of electric energy and other fuel sources. While these will be developed in the traditional form of the quantity demanded or supplied related to price, their purpose will be to make explicit the factors affecting supply and demand curves over time. Emphasis will be given to the role of technology in changing the shape of these curves. The areas of greatest uncertainty in the supply and demand projections will be identified. These analyses in turn will be used to plot the direction of further research, with priority being given to the areas of uncertainty that would have major effect in the ranking of EPRI's R&D priorities.

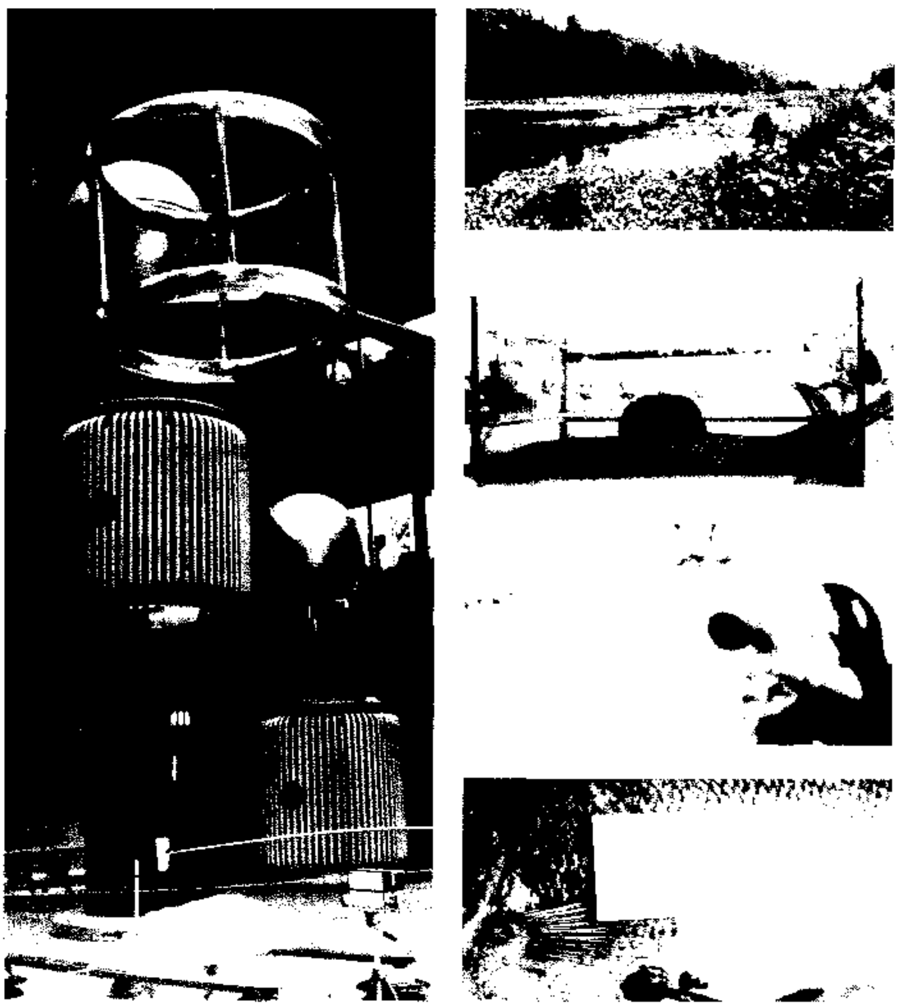
"About the middle of each year, the Systems Program will complete the annual cycle by integrating the demand and supply projections into a consistent economic and environmental framework, thereby identifying the major assumptions affecting the future outcome of the energy-economic system.

"It is intended that the results of the division's research will serve as a sound technical base for decisions by EPRI in its R&D planning, by utilities in dealing effectively with their long-range planning, and by all other sectors of our society in confronting the crucial issue of energy—the need for it, its sources, its effects on the environment."

Energy is an essential driving force in our economy. Nearly 30% of the primary energy in the United States takes the form of electricity. It is predicted that by the year 2000 electricity will account for as much as one-half of that primary energy. So it is crucial that the electric utility industry—responsible for generating and delivering this energy and for the consequent effects on the environment—base its actions on the most complete and accurate knowledge obtainable. The search for and evaluation of that knowledge are basic objectives of EPRI's Energy Analysis and Environment Division.

The work of this division, with its professional staff of economists and environmental specialists, consists largely of research, analytic, and modeling studies in areas representing the external constraints that affect the operation of electric utilities. Among these constraints are environmental considerations, the availability and cost of primary energy fuels, the factors that determine growth and rate of electricity demand, the role of conservation in changing patterns of electricity use, and the interrelationships among these concerns and their feedback effects on the economy and the environment. The results of the studies are intended to aid the internal planning of EPRI's R&D programs and to provide information to the utility industry,

Decisions



Hanford miniature swine are being exposed to high-voltage electric fields comparable to those produced by transmission lines to determine possible biological effects. Vegetation and small animals are being studied for ecological effects of high-voltage electric fields. Impacts on aquatic life of cooling-water discharge are also under study.

government agencies, and the public that will assist their decision making with regard to the energy future.

Following is a review of highlights in the division's four major program areas during 1976.

Assessing environmental effects

Environmental and public health issues are major considerations in EPRI's overall R&D program. Priority is given to such matters as developing clean forms of fossil fuels, managing waste heat rejection, assuring the safety of nuclear systems, and improving the environmental compatibility of transmission and distribution networks. About half EPRI's total R&D effort is related directly or indirectly to environmental effects. More than half of the Energy Analysis and Environment Division's budget supports work on environmental assessment.

Under the direction of Cyril L. Comar, the division's environmental research is specifically concerned with defining the environmental and health impacts resulting from energy production, transport, and use so as to provide a reliable data base for industry and regulatory agencies, as well as guide the hardware-oriented programs of EPRI's other technical divisions. Research includes: identification, characterization, and monitoring of potentially harmful constituents of emissions and effluents resulting from electricity production, transmission, and use; determination of the manner in which pollutants are transported through air and water; determination of their actual effects on populations, ecological systems, and physical materials; development of methods for cost-benefit and cost-effectiveness analyses; and exploration of possible beneficial uses of wastes or potentially harmful by-products.

EPRI has launched a set of major, long-range projects aimed at identifying, characterizing, and monitoring the emissions of fossil-fueled electric power plants and determining the health effects of such emissions. Official air quality standards in the U.S. were established in 1971, based largely on inadequate data from episodic events dating back 20 years—the 1952 London "killer fog," for example. There is a critical need to improve the understanding of air pollutant effects under present conditions so that a rational and cost-effective control strategy can be developed.

Analysis of power plant emissions

An EPRI survey of the extent of available information on the health effects of sulfur oxides in the ambient air was completed in 1976. The survey indicated that although current knowledge of the emission sources and the network of monitoring stations are relatively adequate for sulfur dioxide (SO_2) and SO_2 plus particulates, data are still inadequate for sources, for chemical and physical characterization, and for formation of the other sulfur oxides, such as sulfuric acid, metallic and acidic sulfates, and sulfites. The survey also noted that information on SO_2 health effects is reasonably adequate and indicates that currently accepted safe levels are defensible, but only in the sense that SO_2 is regarded as an indicator of the harmful substances. Some critical data on sources, transformation, and fate of SO_2 are missing, and EPRI is taking steps to fill these gaps (see comments on the SURE program below).

Also completed during the past year was the first phase of an EPRI analysis of the controversial results of the Environmental Protection Agency's large-scale CHESS (Community Health Evaluation Surveillance System) studies of air pollutants conducted in the early 1970s. The CHESS data are being evaluated with the intention of establishing a firmer base for future investigations of the health effects of air pollutants.

EPRI joined with the National Institute of Environmental Health Sciences last year in support of the largest ongoing air pollution–epidemiological study in the U.S. Known as the Six Cities Study, this nine-year effort by the Harvard School of Public Health will investigate six communities with varying degrees of existing ambient air quality. In each city large samples of adults and children will be given questionnaires and lung function tests. Air pollution data will be collected at three levels of monitoring: fixed location, indoor-outdoor, and personal. The resulting data will be analyzed to provide estimates of the relationship between air pollution and health effects.

The past year saw the startup of the extensive ground-monitoring network for the EPRI-supported sulfate regional experiment (SURE) in the northeastern sector of the country. This projected three-year study is designed to provide an understanding of the transport and conversion of air pollutants under various meteorological conditions. It will supply data primarily on sulfates, as well as on particulates, nitrates, and trace elements. Specially instrumented aircraft will supplement the work of the ground-monitoring stations. The northeast was selected because it has a high concentration of electric power plants, has reported high levels of sulfate in the air, and has several monitoring stations.

Preliminary studies in the SURE project indicate tentative conclusions:

- Significant differences in sulfate behavior seem to occur in different geographic regions.
- The widespread summer maximum in sulfate concentrations observed in the northeast does not occur elsewhere.
- The highest sulfate levels are observed in the area of West Virginia and western Pennsylvania.
- Systematic correlation is found between high sulfate levels and the temperature, atmospheric water vapor content, and tropical airflow.
- The highest intensity of sulfate appears confined to regions less than a few hundred kilometers downwind from isolated sources of SO_2.

It is important to note that these studies so far show that no direct relationship exists between changes in levels of sulfur dioxide and sulfates.

These early conclusions suggest that the high sulfate levels in the northeast result from several large SO_2 sources in the path of warm air masses, as well as from slow atmospheric oxidation. Confirmation of these tentative conclusions and other findings awaits completion of the project.

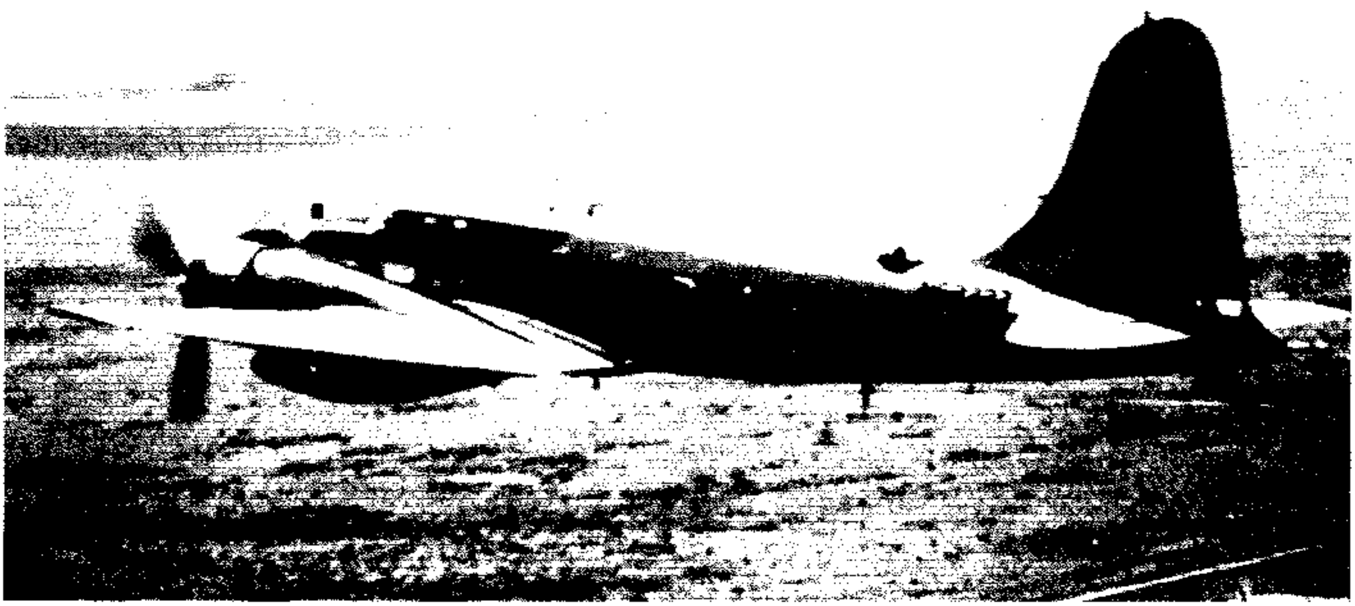
EPRI is supporting development of a high-power, tunable infrared laser as the core of a remote system for monitoring power plant stack plumes. The system, which includes a 16-in telescope specially designed for measuring air pollution, will make it possible to monitor the atmosphere around a power plant site from one location instead of requiring a network of point monitors. In the past year, construction of the optical system and computer hardware was completed and outdoor measurements were begun. Testing includes measurement of SO_2, NO, NO_2, and CO, as well as air temperature profiles, wind velocity and direction, and relative humidity at various altitudes.

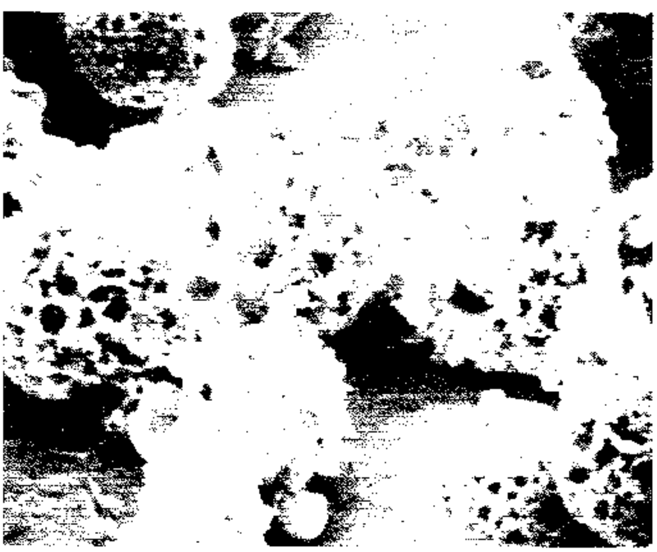
Effects of high-voltage fields

In addition to analyzing the emissions from fossil-fueled power plants, EPRI researchers also are investigating the effects that electric fields generated by high-voltage transmission lines may have on humans and plant and animal life.

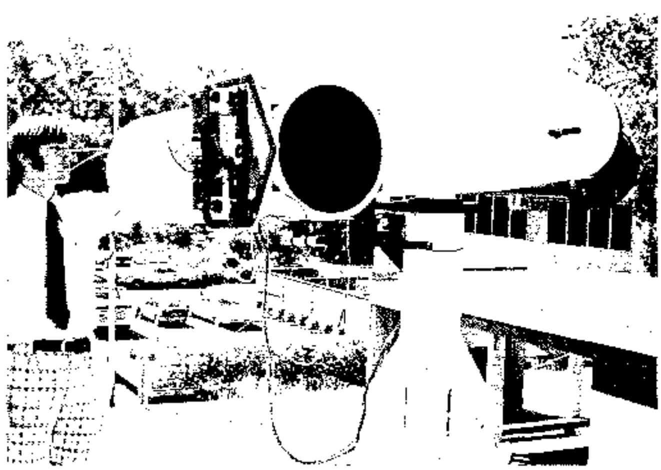
An EPRI-supported survey of previous research on effects of electric fields from high-voltage transmission lines revealed

Specially instrumented aircraft and ground stations are measuring sulfate content in the ambient air in the Northeast in extensive, three-year sulfate regional (SURE) monitoring program. Early data indicate no direct relationship between levels of sulfur dioxide and sulfates.





For a better understanding of the chemistry of power plant emissions, a molecular beam reaction system is being used to study what happens when SO_2 and oxygen contact fly ash. Spongelike fly ash from an oil-fired power plant is revealed in scanning electron micrograph.



This 16-in, f-3 telescope receiver is being developed in conjunction with a high-energy, tunable infrared laser to measure air pollution in power plant stack plumes. Laser-telescope enables ground monitoring from a single location instead of by a costly network of ground stations.

that test conditions were not closely controlled and other environmental influences existed that could have affected the results. The inconclusiveness of these previous studies called for more scientific investigation of the problem.

In September 1976, EPRI published preliminary results midway through its three-year study of the biological effects of electric fields produced by power transmission lines and substations. No significant detrimental effects were observed in the small animals and chicks tested. Investigations are continuing and will include blood chemistry and pathological tests. However, it was found that tips of plant leaves exposed to high-gradient electric fields were damaged. The physical and biological mechanisms that cause this damage are being studied. The project is being conducted for EPRI by Westinghouse Electric Corp. and Pennsylvania State University, with initial tests carried out in the environmental chambers at Penn State and subsequent testing planned at the Westinghouse Waltz Mill underground transmission test facility.

Recognizing the need for carefully controlled research to identify subtle effects on biological subjects that may be caused by electric fields, EPRI launched in mid-1976 a two-year study coordinated with a parallel study by ERDA. A major portion of the investigation involves exposing a group of Hanford miniature swine to electric fields. Another group of Hanford swine, not exposed to the electric fields, serves as a control for comparison of effects. The Hanford miniature swine are specially bred to serve as a research model for humans. Therefore, the test results collected by the team of biologists, physicists, electrical engineers, biochemists, and behavioral physiologists who are monitoring the experiment will be relevant to humans. The electric utility industry is leading in this field of research.

In the past year EPRI supported a feasibility study on conducting an epidemiological survey of high-voltage electric field effects on utility linemen and switchyard workers. This work, if carried out, is intended to cast light on the questionable findings of earlier Soviet and Spanish reports that indicated adverse effects. These previous tests were not carefully controlled and interpretation of the resulting data has been questioned. Land management practices along transmission line rights-of-way are also being studied so as to allow minimum interference with the local ecology.

Impacts on aquatic ecosystems

A comprehensive investigation of the environmental effects on aquatic ecosystems of thermal power plant cooling was undertaken by EPRI during the year. Impact on the environment is being studied from the standpoint of effects on aquatic populations and communities, chemical effects, and ecosystem management.

Among the problems under study are the impacts that discharge of heated water and chemicals have on the life forms inhabiting bodies of water surrounding power plants. Effects on communities of aquatic life from the entrainment and destruction of such forms as fish, fish eggs, and larvae are also being examined. One study is comparing a cooling lake fishery in central Illinois with a fishery in a similar lake not used for cooling. The ecology and economics of the cooling lake fisheries are being evaluated and a mathematical model developed for managing them. It is intended that the results be applied to other cooling lakes in the Midwest.

Also being studied are the effects of chlorinated effluents; various methods for controlling growth of mussels at water intakes; development of optimum chlorine dosages to control algal growth on condensers and minimize potential detrimental impact on the environment; and determination of the accuracy, sensitivity, and potential interferences of various chlorine monitoring procedures.

Using the technique of ecosystem management—an approach to environmental assessment that considers an ecosystem's capacity to support a combination of industrial, municipal, and recreational demands while preserving, and perhaps improving, environmental quality—EPRI researchers are developing over a three-year period a general methodology to assess the integrated ecological impacts of several power plants situated on a single body of water.

All these investigations are being coordinated with EPRI's Water Quality Control and Heat Rejection Program in the Fossil Fuel and Advanced Systems Division.

Sizing up energy supply

In order for EPRI and the utility industry to make informed decisions on the nature and pace of hardware R&D, the best possible estimates of the energy future are required. It is this future that will determine whether or not new technologies, if developed, can be commercially viable. The timing of technology development can be crucial. Accelerated development may produce costly but unreliable equipment—witness the case of stack gas scrubbers. Delayed development may mean that costly but inadequate technologies are used for longer than necessary.

Absolute certainty about the role of various technologies in the future could save large amounts of R&D expenditure, but such certainty will never be achieved. However, careful, informed, objective analysis can do much to delineate the bounds of the future and reduce the risk in hardware development, with attendant savings in R&D costs.

The end products of supply analysis are those items that are important in determining the nature and pace of hardware development. Fuel price and availability, construction costs, and the availability of land, labor, capital, and water are some of the more crucial items. Equally important is assessment of the role of competing technologies and of those fuels that vie with electric power in the marketplace. Also crucial to analysis of future energy supply are considerations of institutional and governmental policy factors and environmental policies and constraints. Research designed to meet EPRI's and the industry's needs for information on energy supply is the responsibility of the division's Energy Supply Program, directed by Milton F. Searl.

Estimating fuel resources

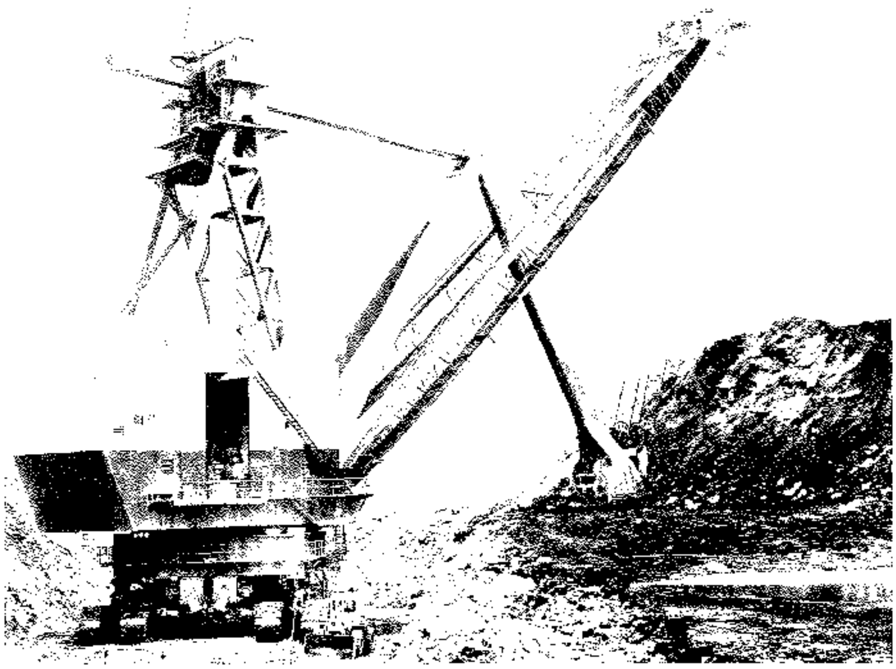
Key to the long-range viability of conversion technologies, such as those used in the production of electric power, is the long-term adequacy of its fuel supply. The adequacy of uranium resources to meet the growth of nuclear power has been a matter of growing concern. In order to determine the adequacy it is necessary to understand the nature and meaning of present uranium reserve and resource statistics. Although this is a problem common to all resources, it is particularly severe in the case of uranium, where confidentiality of government data has made independent analysis extremely difficult.

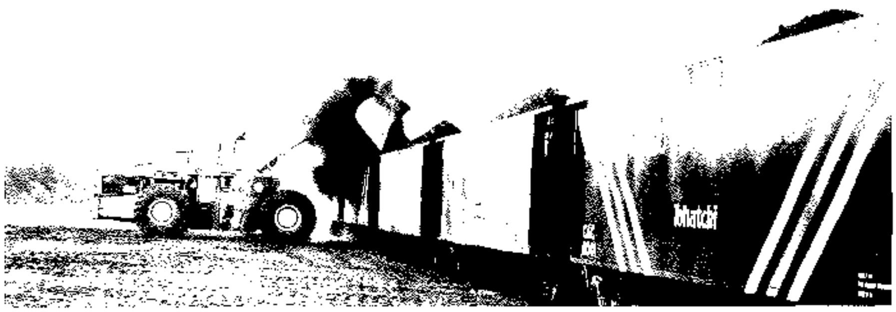
Work was completed during 1976 on two studies designed to throw light on the scope, meaning, usefulness, and limitations of published government data on uranium reserves and resources and to provide information on what might be gained by further analysis. Publication of the results is scheduled for early 1977. Follow-on work has been started on analysis of the results being produced by ERDA's five-year, $100-million National Uranium Resource Evaluation program. Without such analysis, most results of this program would not be readily available to the industry.

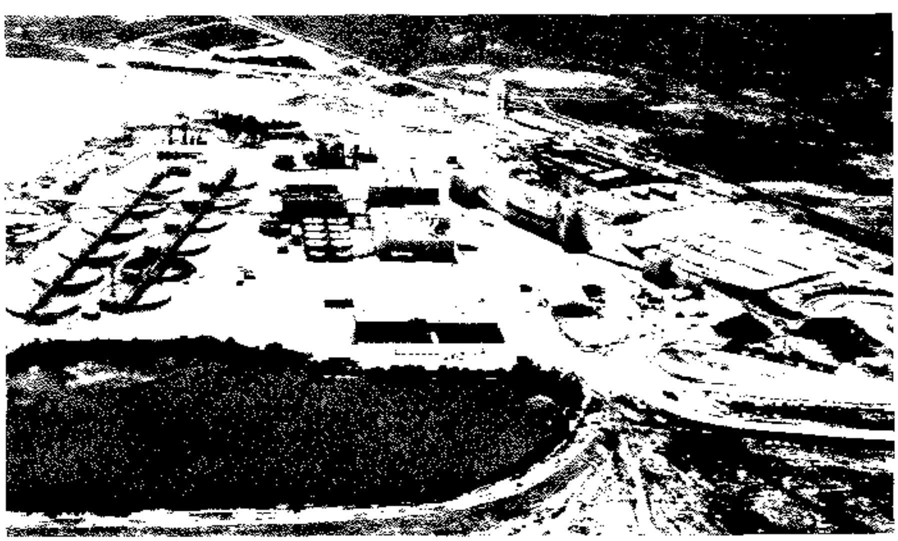
Work was begun on assessing the quality of existing coal resource information as well as on the problem of comparability between estimates of the various energy resources. In general, frequently cited estimates vary widely in their assumptions, particularly those about economics and technology, and they differ greatly in their treatment of uncertainty.

Two major studies were completed late in 1976 that will serve as a basis for projection to the year 2000 of the prices of conventional fuels (oil, natural gas,

Essential to the long-range viability of the electric power industry is the adequacy of its fuel supply. Efforts aimed at estimating and forecasting fuel resources include cost and price analyses of coal and uranium. The crucial capability of the rail and water transportation networks to haul projected quantities of coal has been assessed.







coal, and uranium). These projections will be the first such comprehensive fuel price forecasts since the 1973 Mideast oil embargo. Previous forecasts by the Federal Energy Administration in connection with Project Independence and the National Energy Outlook extend only as far as 1985–1990. Along with other research, including work on foreign oil and foreign uranium, they will form the basis for forecasts by the Supply Program staff.

A large amount of research aimed at deeper understanding of the energy supply system and preparation of more reliable forecasts by the staff were completed or nearing completion at the end of the year. Analyses of existing coal, oil, natural gas, and electricity supply models were completed and work started on the development of EPRI's own advanced systems for supply analysis. Fundamental research on cost evolution and price formation in the coal and uranium industries was nearing completion. Resource costs, such as those obtained from mining models, are frequently less important factors in the variation of mineral fuel prices. So a thorough understanding of industry economics, such as can be provided by cost evolution and price formation studies, is a prerequisite to successful long-term price and availability projections.

Resource costs, however, are the starting point for cost and price analysis. Work was completed during the year on advanced coal mining models that are believed to be superior to any such models now available. Arrangements are being made for independent tests of these models. The Illinois Geological Survey is among those currently testing them. Work has been started on uranium mining and milling models as well, including models of solution mining, a relatively new technique with considerable promise for certain regions.

Evaluating battery industry capacity

In view of a growing interest, backed by funds, in developing energy storage systems for use by electric utilities, EPRI in late 1976 launched a study of the ability of the metal and battery industries to meet the potential rapid growth in demand that may occur if battery research is successful. The study aims to identify potential material shortages and manufacturing bottlenecks and critical lead times for large-scale battery production in the 1984–2000 period. Information from this study is designed: (1) to ensure that if R&D is successful, there will be no surprises in regard to the ability of industry to supply batteries; (2) to assist battery developers in choosing among alternative technological approaches and designs; (3) to assist in predicting equipment costs and capabilities for system expansion planning by EPRI member utilities; and (4) to aid investment planning by the battery and metals industries as R&D progresses. The work is being coordinated with hardware development efforts in EPRI's Fossil Fuel and Advanced Systems Division, with engineering assistance from the Energy Management and Utilization Technology Department. The project is considered a prototype analytic framework that eventually may have application to other technologies.

If solar heating and cooling were to make a significant impact in the next few decades—and there are varying degrees of optimism about prospects for this—the capability of industry to produce, install, and maintain the necessary solar equipment would need to expand substantially. Late in the year, approval was given to a study to determine how solar heating and air conditioning growth will be affected by supply factors, for example, marketing, distribution, and installation characteristics. Installation problems arising from numerous small, often poorly financed equipment manufacturers' dealing with a fragmented, initial-cost–conscious construction industry and uninformed buyers and users may be severe and may possibly lead to government intervention. Since heating and cooling represents a substantial portion of the potential growth in utility load, it is important for EPRI and the utilities to know the extent that load could be served by solar heating and air conditioning.

Water availability

There is a great need for information on the availability of water for expansion of energy production. Although the volume of data on water is massive, it has been compiled by a host of federal and state agencies and is therefore uncoordinated and difficult for an outsider to use efficiently. EPRI is developing from these various sources a central data base of water facts that will enable its staff and the utility industry to get the combination of water information needed. This work has enabled EPRI

Technical Publications

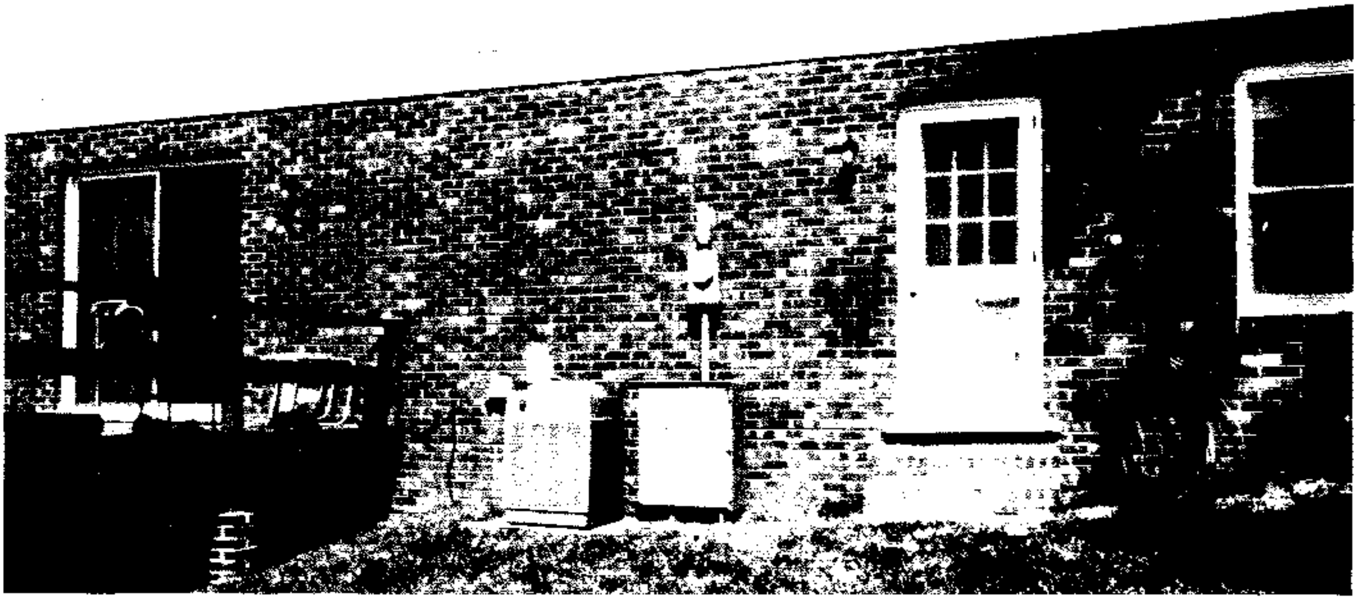
During 1976, approximately 350 reports were published by EPRI. This figure will more than double in 1977 with the publication of reports that mark either the completion of projects or their key phases.

A number of steps have been taken to make research results more easily accessible to members of the energy community—both in and out of the utility industry. One innovation has been the appointment of technical information coordinators within EPRI's supporting member utilities. These coordinators are responsible for seeing that individuals in their companies receive the EPRI publications that are of interest to them.

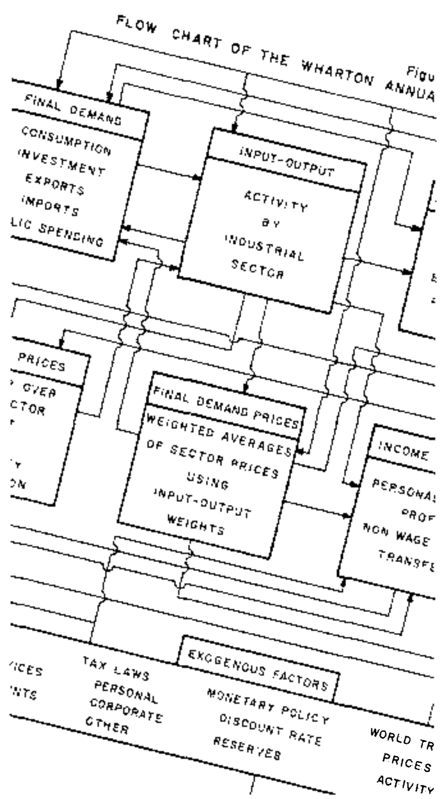
Because EPRI's technical publications program has grown significantly and will continue to do so, EPRI is presenting a broader and more flexible set of options to the coordinators. One feature of this program is the publication of summary editions of EPRI reports because the information requirements of many readers can best be met by a summary that is 5–10% the length of the complete final report.

Another useful option will be a compilation of abstracts of recently published or soon to be published reports. These abstracts (usually 200 words or less) will be sent to the information coordinators and other interested parties on a quarterly basis.

Load and use characteristics of late-model residential heat pumps in actual household operation are being studied in one of several projects to measure residential energy use. Data on heat pump performance are being collected from 120 residences.



Energy Modeling Forum brings together model developers and users to evaluate major energy-economic models. Some Forum members gathered in discussion are (*l* to *r*): George Dantzig, Stanford; Richard Richels, EPRI; William Hogan, Stanford (Forum director); Martin Greenberger, EPRI; Shail Parikh, Stanford (Forum associate director); and Alan Manne, Stanford.



Work is under way to extend the means for linking the Wharton model of the national economy with satellite models so the system can be applied to utility industry problems.

Division Changes

The titles of two EPRI divisions were changed last year to better reflect division responsibilities. The Electrical Systems Division (ES) is the new title for the Transmission and Distribution Division, and the Energy Analysis and Environment Division (EAE) is the new title for the Energy Systems, Environment, and Conservation Division.

The range of work in ES extends from the turbine-generator coupling to the customer's meter, including transformers and substations. The new name more accurately reflects that broad scope.

The title Energy Analysis and Environment describes the primarily analytic nature of this division's efforts. Work on conservation technology is the responsibility of the Fossil Fuel and Advanced Systems Division, while the impacts of conservation on future energy demand and related economic effects are the responsibility of EAE.

Another major change in EAE last year was the appointment of a new division director, René H. Malès, who is on loan from Commonwealth Edison Company of Chicago. Malès succeeded Sam H. Schurr, who returned to Resources for the Future, Inc., as a senior fellow after two years with EPRI.

A major reorganization took place in the Fossil Fuel and Advanced Systems Division (FFAS). There are now four departments in the division, one of which is responsible for a new program area.

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, from the coal pile to the electric busbar," FFAS Division Director Richard Balzhiser said shortly after the reorganization was announced. He also commented at that time that 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 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.

In the reorganization, Dwain F. Spencer (formerly technical manager, Planning) and Fritz R. Kalhammer (formerly program manager, Electrochemical Energy Conversion and Storage) were 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 are sharing responsibility for researching and developing environmentally acceptable technology for converting coal and other fossil fuels into electricity.

The Fossil Fuel Power Plants Department is focusing on improving current technology and developing new direct coal-fired systems. The Advanced Fossil Power Systems Department is concerned with systems further down the road to commercialization, including coal liquefaction and gasification integrated with combined cycles.

The third department involved with energy production, the New Energy Resources Department, is 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 is concerned with fuel cell research and reducing energy costs.

Assigned to this department is a new EPRI program, the Energy Utilization and Conservation Technology Program, which is exploring residential, commercial, industrial, and transportation applications of electricity. This new program reflects the utility industry's goal of not only producing more electricity but also using it more efficiently.

to become a member of the National Water Data Exchange (NAWDEX), the federal government's data coordination project. Participation in NAWDEX will allow EPRI efficient communication and data exchange with its members and provide access to large federal data bases, such as STORET and WATSTORE. Progress in this area continued during the year with information being compiled on water resources in the Colorado River basin.

Transportation capability

Transportation is among the essential links in supplying energy to the consumer and is a crucial factor in the economics of energy supply. Results were published late in 1976 of an EPRI study that assessed the capability of the U.S. rail and water network to haul projected quantities of coal. The study was made possible through the cooperation of the Federal Railroad Administration, which made available a complex network model of the railroad system (14,000 origin-destination links) and an analysis of waybill statistics for other commodities. A set of sources, corresponding to some 30 mining states, and hypothetical consuming centers, basically the Federal Power Commission power supply areas, served as the basis for the study. Among the study's conclusions were: a large portion of western coal production is destined for the coastal states; some parts of the rail network will be overloaded with the projected coal increases; although there are alternative rail routes, they can be used only at higher costs; and only a few waterways can handle the large additional tonnage required under increased coal use scenarios.

Forecasting energy demand

In planning its R&D program, EPRI must have a firm idea of the range over which the level of electric energy consumption may be expected to vary in the long run. Such information indicates how intensively fuel resources will be used and suggests which technologies appear promising in particular time frames. It is also important to know about the time-of-day and seasonal patterns of anticipated use so that R&D funding can take into account the expected mix between peak and baseload requirements.

The division's Energy Demand and Conservation Program, directed by Robert Crow, uses the results of its research in formulating long-run conditional forecasts. A separate but related research area involves investigation of technological change oriented to energy conservation and interfuel substitution and their impact on electric utility system loads. The program also is concerned with gathering data related to energy conservation.

The program is based on the assumption that price is the major consideration in decisions on energy use. But behind this motivation must be the technology capable of translating motives into action. Therefore, EPRI has undertaken a number of programs to assess the way in which energy is employed and the effects of various technologies on the intensity of energy use.

Early in 1976, EPRI's first set of energy demand forecasts was released. By the end of the year, work was completed on the second forecasts of energy consumption for all sectors of the economy and for conventional fuels. These later forecasts, to be published in early 1977, will produce conditional demand curves relating to energy price and growth.

Gauging residential energy use

During the year the first phase was completed of a major study of residential energy use. Data have been collected from a test sample of specially instrumented residences and apartments in Columbus, Ohio, that gave information on such factors as energy used by furnaces, heat loss through infiltration and door and window openings, and heat gains from other appliances. These data will serve as the basis for a comprehensive simulation model of fuel use in heating and cooling. In the second phase of the project, to begin this year, a generalized, simplified version of the model will be validated by information being collected from a sample of houses in six utility service areas across the country. Weather stations in each area are supplying data on temperatures and intensity of solar radiation to be used in validating the model. The final report on this project is anticipated by the end of 1977.

Progress continued during the year on projects designed to measure residential energy use. One such study, sponsored jointly by EPRI and the Association of Edison Illuminating Companies, is examining the load and use characteristics of late-model residential heat pumps in actual household operation. Information on heat pump performance is being collected from 120 residences in 12 utility service areas, providing degree-day representation for climates ranging from Florida to Minnesota. Resulting load data will be useful in further efforts to determine the impact of residential heat pumps on utility system loads. A current survey of monthly watthour consumption of major appliances, cosponsored with the Federal Energy Administration, aims at providing representative data on household appliance use and correlated socioeconomic characteristics. The results are expected to be the best source of information on this subject comparable across regions, and should be of value in conducting household-level studies of energy-using behavior.

A major study was completed to develop a forecasting model of residential electricity consumption. The effort is unique in that it takes the declining block structure of rates into account explicitly. Personal income and lags in adjusting consumer behavior to changes in prices and incomes also are considered. In addition, the study investigates the demand for energy-using residential equipment and for competing forms of energy.

Identifying commercial use

Work continued during 1976 on developing a forecasting model of energy consumption identified by region and industry for industries in the commercial sector. This project is the first attempt to identify 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 in small manufacturing industries, as well as demand by most of the commercial industries. Adding to the problem is the fact that some of the larger commercial establishments are included in the industrial service class. Some 40 utilities are being surveyed in various regions to determine industrial consumption by SIC code. If possible, corresponding data will be collected on the buildings and equipment used by these commercial industries. From these new data, a forecasting model for energy use will be constructed that accounts for both short-run use and long-run capital acquisition decisions of commercial industries. The model will be amenable to consideration of specific scenarios for the introduction of energy-conserving design and construction of new commercial buildings.

During the year work got under way on three related studies on time-of-day and seasonal residential load forecasting. The entire load curve is being studied, that is, kilowatt demand by time of day, week, and season. The long-run forecasting model that will result from these studies will be conditional on weather data; the stock of energy-using consumer durables; electricity prices (including differential time-of-day or seasonal rates, if applicable); family income, size, and characteristics; and other socioeconomic variables.

Transportation energy impact

EPRI's two transportation demand forecasting projects moved forward during the year. The models being developed are important for two major reasons. First, it is necessary to know the energy required for transportation in order to complete the forecasting efforts for national energy needs. Second, it is also 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, mass transit, and intercity rail electrification.

Technological change aimed at energy conservation in the manufacturing industries is likely to have important long-run consequences for the growth of the electric utility industry. Work was begun in 1976 to construct models to explain the role of factor prices, especially those of energy, in inducing technological change related to energy use. The most important features of this modeling effort are the investigation of a process of technological change and the characterization of dynamic adjustment processes. The models attempt to capture the response to changes in factor prices in the way existing capital stock is used—a reflection of the use of current technology—and also to model the influence of changed energy prices and other factor prices on investment in new capital stock—reflecting the application of new technology.

With recent increases in the cost of energy, one important factor influencing decisions on in-plant generation of electricity has changed. To access the implications, work was started during the year in building forecasting models of in-plant generation that take into consideration such aspects as legal and economic implications, availability and cost of fuels, regulatory and technical constraints.

Late in the year a proposal was approved to begin work on constructing a model to forecast energy consumption by regions of the country. Regional characteristics differ as to type of economic activity, fuel source, population trend, climate, and so on. There is a need to reflect divergent effects in each region of such factors as natural gas shortages, oil price changes, and regulatory limitations. This project is intended to result in thoroughly documented approaches to forecasting electricity consumption and peak load for about 20 multistate regions in the country.

U.S. energy-economy modeling

The broad objective of the division's Systems Program, under the direction of Martin Greenberger, is to improve the analytic base for planning and developing economic and socially acceptable ways to satisfy the future electric energy needs of the nation. More specifically, the aims are to integrate energy supply, demand, and environmental effects into consistent models of the energy system; to deepen understanding of the relationships between the engineering and economic aspects of the energy system; to illuminate the complex interrelationships between the general economy and the energy sector; and to probe, analyze, refine, link, and apply existing energy system models.

Work was begun during the year on four parallel studies for the synthesis of research in the division. Operating within a common framework, but differing in focus and emphasis, these studies are aimed at designing a set of strategies for integrating supply, demand, and environmental research in a way that will serve the needs of EPRI and the electric utility industry. Among the objectives of the studies are: to describe specific integrating procedures useful for directing the research and modeling work of the division to the problems of the industry; to evaluate the prospective costs and benefits of these procedures; and to make recommendations on the degree to which integration should be undertaken.

Progress was achieved during the year in expanding the input-output system of the Wharton Long-Term Model of the national economy to enable it to display in more detail important energy-producing and energy-consuming industries. Work also was directed toward extending the means for linking the Wharton model of the economy with satellite models of important industries to make the system applicable to the problems of the electric power industry.

Adapting energy models

Assessing the commercial value of alternative future energy technologies is fundamental to R&D decision making, but it involves considerable uncertainty and subjectivity. Energy models can provide a useful structure for incorporating subjectivity in a consistent way to help answer questions on the relative values of competing technological alternatives. Work continued during the year on adaption of two interrelated energy systems models for potential use by EPRI in R&D management. The models are the Brookhaven Energy Systems Optimization Model (BESOM) and DESOM, its dynamic version. BESOM is a static linear programming formulation that represents the U.S. energy system from source to use at a key year in the future. DESOM is, in effect, several BESOMs, one in each of 10 time periods, connected across all time periods. The appropriate use of either model for technology assessment is for gaining insight regarding possible implications of technology alternatives, rather than for predicting what choices will be made.

A preliminary version of the experimental PILOT model was completed in 1976. This model is designed to assess U.S. energy and economic options in terms of their effect on the standard of living as an aid in developing policies that are resilient to various contingencies. It is believed that the PILOT model can provide analysis and information and a better understanding of the interactions relating to such questions as: Are we consuming our cheap energy resources too fast? Are we making adequate investments now so that new energy technologies will come into commercial operation when needed in the future? What are the various energy options under different patterns of crude oil import price realizations? An examination of questions such as these is necessary in forming national energy policies.

Forum for energy modeling

The various models of energy-economic systems developed in recent years have the potential of providing significant insight into many complex economic and environmental interactions. They could provide better answers for decision makers on a wide range of issues bearing on energy supply, demand, and distribution. But to realize this potential requires effective interchange between decision makers and model builders.

With this objective in mind, EPRI in late 1976 awarded a contract to the Stanford Institute for Energy Studies to establish the Energy Modeling Forum. The need for and soundness of the Forum concept—modelers and users working together to understand and improve energy models through the study of particular energy issues—were confirmed in a workshop at Stanford last summer. This was followed by the first working-group meeting in October in Washington, D.C. The first phase of the project is an experimental period that began last fall and will extend to early this year, during which time the Forum will focus on the issue of feedback from the energy sector to the economy. The early months of the Forum project are providing an opportunity for demonstration of the feasibility and value of the concept and, if the idea proves worthy of further development, for the formation of a panel of experts for continuing work on future Forum studies.

Progress in rate design

A report of research progress thus far in the Electric Utility Rate Design Study was published in October of last year. The study focuses on methods of controlling the peak period uses of electricity and the feasibility of shifting loads to off-peak periods. An examination of the technology and cost of time-of-day pricing was completed during the year and preliminary findings were included in the report.

The interest in peak load pricing stems from a concern by utility ratemakers and regulators that electric rates should reflect costs, including time-varying costs, and should provide correct price signals to consumers. In addition, time-differentiated rates and other forms of load management offer the potential for efficient handling of peak demand.

Considerable support exists among most participants in the study, as well as from various regulatory commissions and the electric utility industry, for the concepts of time-differentiated pricing and load management. Given the appeal of peak load pricing, the research has stressed an analysis of the effects of implementing rate design changes.

Major issues cited

Two major issues were examined in detail and are discussed in the progress report: (1) whether and to what extent costs that vary with the level of demand at various times should be reflected in rates; and (2) whether and to what extent marginal costs, as distinguished from average costs, should be reflected in rates.

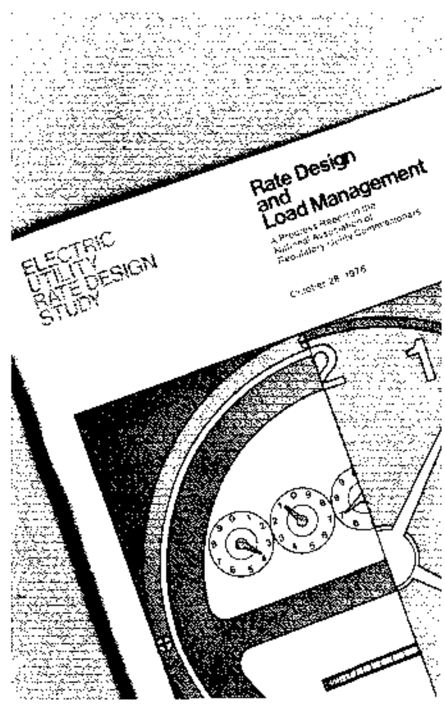
Study continues on the choice between the use of average costs or marginal costs as a basis for peak load pricing and on the question of the net benefit of time-differentiated pricing and other approaches to load management.

Three alternative forms of rate design are being studied: (1) traditional ratemaking practices, (2) time-differentiated rates, and (3) peak load pricing based on marginal costs. It is important to note that time-differentiated rates may be based on various costing methods. Each alternative rate form is being evaluated in relation to various regulatory objectives, such as the necessity of realizing adequate revenues, the importance of apportioning costs fairly among customers, and the desirability of achieving economic efficiency.

The central issue in the study is to determine whether the costs of implementing peak load pricing or installing direct load controls on a specific utility system are more than offset by the savings achieved from shifting loads and slowing peak load growth. Because the level of additional costs is unclear and the degree of consumer response uncertain, the cost-effectiveness calculations are difficult at this time.

Study extended

The Rate Design Study is being conducted on behalf of the National Association of Regulatory Utility Commissioners (NARUC) by EPRI, the Edison Electric Institute, the American Public Power Association, and the National Rural Electric Cooperative Association. The study's findings will be presented to NARUC early this year. In July of last year NARUC foresaw that work beyond that planned for completion in 1976 was warranted and requested a continuation of the study, which the EPRI Board of Directors subsequently approved. Investigations will continue this year in five areas: (1) the conduct and assessment of rate design experiments; (2) appraisal of load management hardware; (3) evaluation of user equipment under peak load pricing and load controls; (4) assessment of customer acceptance of novel rate designs; and (5) improvement of methods for analyzing the costs and benefits of time-differentiated pricing and load management.



Preliminary findings in an examination of the technology and cost of time-of-day pricing were included in a report of research progress in the Electric Utility Rate Design Study.

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