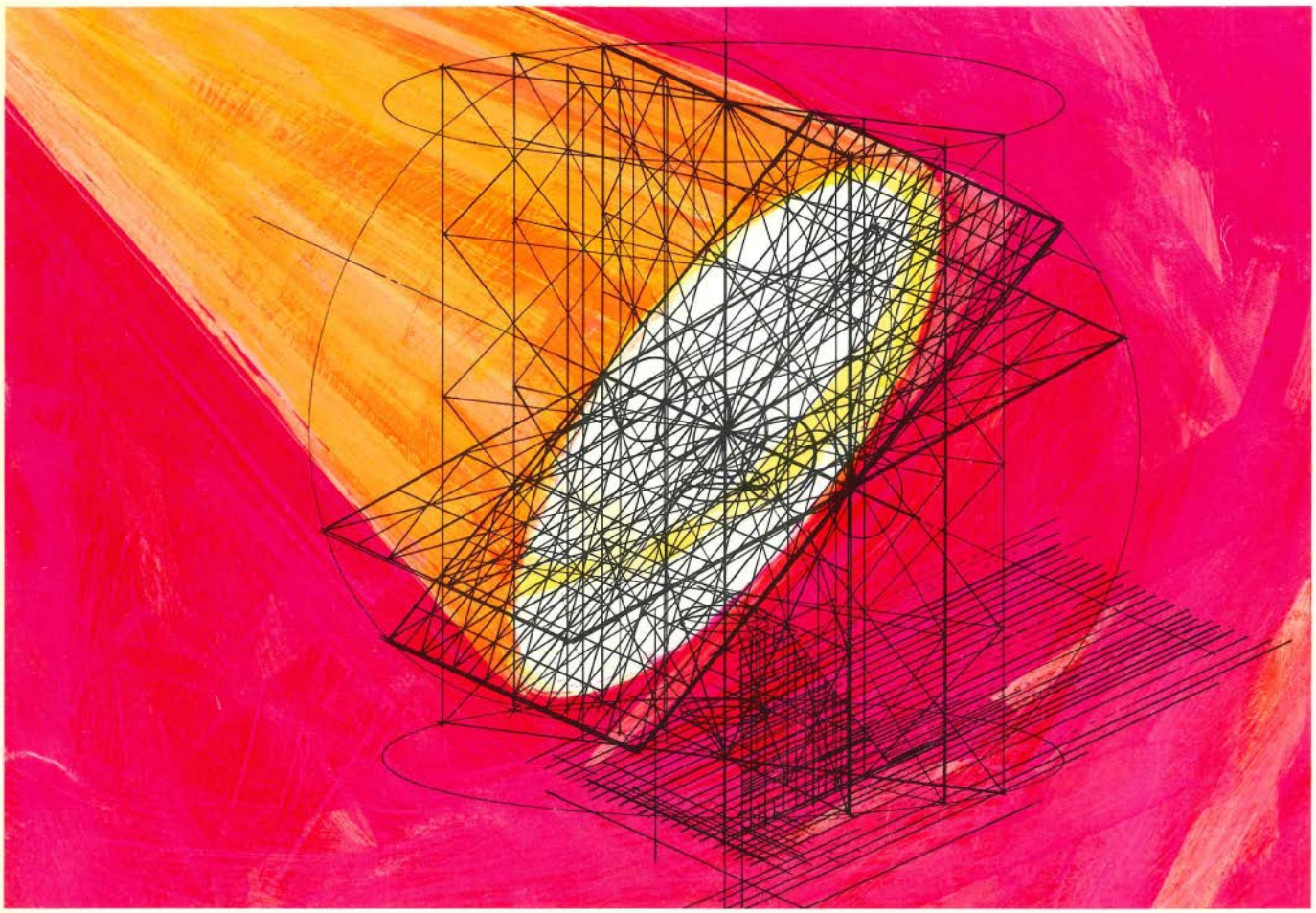
Solar Realities

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

NUMBER ONE

FEBRUARY 1976



EPRI JOURNAL is published by the
Electric Power Research Institute.

The Electric Power Research Institute
was founded in 1973 by the nation's
utilities to develop and carry out
a broad, coordinated technology program
for improving electric power production,
transmission, distribution, and utilization
in an environmentally acceptable manner.

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Cover: Artist's study of sun-tracking heliostat in
solar-thermal central receiver system

EPRI JOURNAL

Volume 1. Number 1 February 1976

This is the first issue of the EPRI JOURNAL. It has four major objectives: (1) to report on the results of EPRI research; (2) to present, through feature articles, useful state-of-the-art information and technical material for utility engineer consumption; (3) to present a coordinated, monthly update on technical division research activities; and (4) to provide a current and accurate report of developments within the Institute, such as program planning, budgeting, and relationships with government agencies.

In the short span of a few years, EPRI staff focus has shifted from organizing and planning to the management of a major research and development program tuned to the pressing technological requirements of the electric utility industry.

As our technical program gathered momentum, communications needs developed accordingly:

- Program planning, budget decisions, project starts, and, most important, project results became of immediate interest to EPRI's supporting utilities.

- EPRI was asked to play a public education role in matters of electric energy technology, using the communications channels of the utilities.

- The media found EPRI to be a comprehensive and credible source of basic energy technology information.

- EPRI was asked to respond to technical information needs of the policymakers in government.

In the past we have met these diverse communications needs in several ways. Technical reports are the foundation of the program. This year, we expect to be publishing an average of one report every working day.

To keep the industry abreast of EPRI's program planning, budget, and personnel activities, the *EPRI News* was inaugurated early in the life of the organization and was published bimonthly through late 1975.

As the broad EPRI program developed, it became evident that there was a need to disseminate detailed information on the R&D programs of the individual technical divisions. A series of *Research Progress Reports* resulted, with the four divisions publishing these monthly on a rotating basis.

Although this publication program was comprehensive and served the needs of a new and expanding organization, it became obvious that a more cohesive communications program was needed. The result is the EPRI JOURNAL, a monthly publication that replaces the *EPRI News* and the technical division progress reports.

In coming months, we hope to expand JOURNAL readership, to increase its usefulness, and to broaden its influence. Toward this end, we welcome your comments and suggestions.

Chauncey Starr, President
Electric Power Research Institute

Technical division contributions to the EPRI JOURNAL consist of program progress reports (beginning on page 30 of this issue) and three types of feature articles: state-of-the-art reports, EPRI program descriptions, and technical articles.

□ The state-of-the-art feature provides a broad, relatively nontechnical update on the status of a high-interest energy technology. In addition to informing utility industry readers, the state-of-the-art report will often have follow-on value as a public education tool.

Solar energy was an obvious selection for the first of these reports. In "Solar Realities" (page 6), Piet Bos discusses the contributions solar energy can make in heating, cooling, and electricity generation and comments on the technical and economic impediments to significant solar applications in the near future.

Bos is manager of the Solar Energy Program in the Advanced Systems Department of EPRI's Fossil Fuel and Advanced Systems Division. Before joining EPRI in early 1975, he served 14 years as associate director of solar projects for the Aerospace Corporation in El Segundo, California. Previously he was a lead development engineer in advanced weapons at Ling-Temco-Vought, Inc.

Bos completed 2 years of aeronautical engineering at the Institute of Technology in Delft, The Netherlands, prior to coming to the United States. He earned an MBA at the University of California at Los Angeles after graduating from the Massachusetts Institute of Technology with a BS in aeronautical engineering.

□ The program description feature discusses a major EPRI program in terms of industry need, potential payoff, and specific approaches to key technical problems.

The first in this series of articles comes from EPRI's Transmission and Distribution Division. "Fault Current Limiters: Problems and Prospects" (page 14) was written by Richard Kennon, project manager in the AC Overhead Transmission Program.

Prior to joining EPRI in early 1975, Kennon was the manager of capacitor equipment engineering for Westinghouse Electric Corporation in Bloomington, Indiana. Earlier positions held at Westinghouse were those of supervising engineer, senior engineer, and sales engineer.

A graduate of the California Institute of Technology with a BS in electrical engineering, Kennon received an MBA from Indiana University. He holds 5 U.S. patents and was a U.S. representative to the 1972 International Electrotechnical Commission Meeting.

□ The technical article, "Nondestructive Pressure Vessel Testing by Acoustic Emission" (page 20), is written for JOURNAL readers whose work is in this field. The authors' approach assumes reader familiarity with the subject, emphasizes technical aspects, and discusses EPRI research.

Dr. Karl Stahlkopf of EPRI and Allen Green, general manager of Acoustic Emission Technology Corporation, coauthored the article on acoustic emission. Stahlkopf joined EPRI in 1973. As program manager, his area of responsibility is pressure vessel technology and includes work in fracture mechanics, stress analysis, and nondestructive testing.

Following 7 years in the U.S. Navy in a variety of assignments related to nuclear submarine propulsion, Stahlkopf studied at the University of California at Berkeley, receiving a PhD in nuclear engineering in 1973.

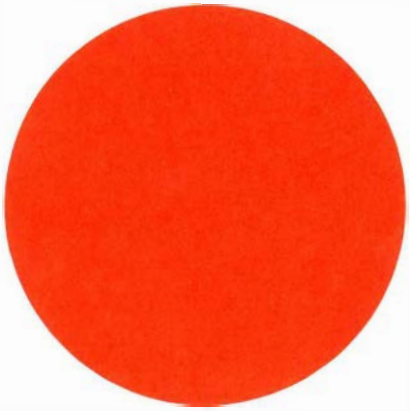
Coauthor Green, whose firm is performing acoustic emission testing studies under contract to EPRI, has worked in that technology since 1961. He has served as chairman of the Acoustic Emission Working Group and of the Western Regional Strain Gage Committee.

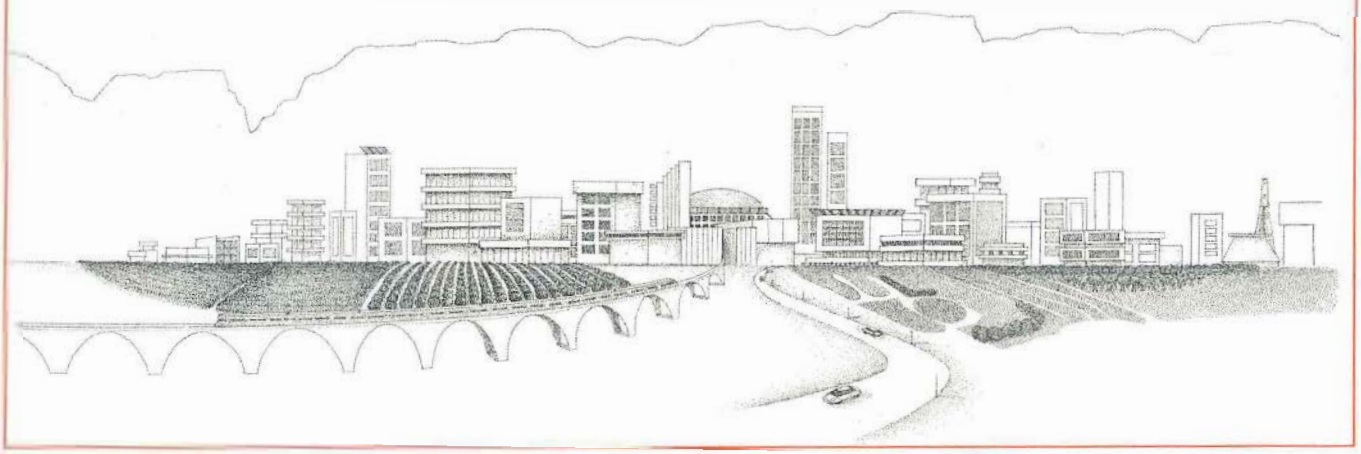
Bos

Kennon

Stahlkopf

Sunlight is a free and abundant resource, and the technology for using it is available to us. However, the high cost of solar energy systems and the availability of low-cost fuels have discouraged widespread introduction of solar energy. Now, with increasing fossil fuel costs and the renewed interest in solar energy, certain solar heating and cooling applications may soon be economically and technically feasible. At some time in the future, solar electricity generation as a complement to conventional power plants should begin to make an impact on utility systems.





Solar Realities

Piet B. Bos

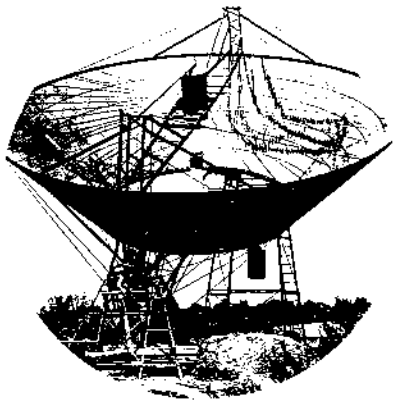
Late in the twenty-first century, our civilization may be powered directly and totally by the energy of the sun. Sprawling solar installations in the Southwest might convert sunlight into the clean fuel and electricity our nation needs. Solar collectors on rooftops could heat water and keep buildings comfortable winter and summer. Fast-growing plants might be harvested on "solar plantations" for conversion into valuable chemicals that now are made from coal, oil, and natural gas. And because nothing would be mined and no fuels burned, there would be relatively little impact on the environment.

This vision of a solar-powered utopia is often proposed as a logical projection of established technology. But because of the enormous economic and logistic problems that stem from the intermittent and diffuse nature of solar energy, it is unlikely that anyone reading this will live in such a totally solar society.

Solar energy, of course, is nothing new. Civilization has run on sun power since the first apple was eaten and the first log was burned. It is said that in 212 B.C. Archimedes reflected the sun's rays from a thousand shields to burn the sails of enemy ships invading his homeland. For centuries, windmills in Holland have pumped the sea back beyond dikes. Farmers in Arizona and California harnessed the sun to pump irrigation water with a solar-powered steam engine at the turn of the century. And in 1913, a steam engine in Egypt was powered by a solar-heated boiler.

However, U.S. farmers soon abandoned their solar-driven pumps. They discovered that pumps run by gasoline engines were not only easier and cheaper to use but also were more reliable than the sun. (Of course, like other fossil fuels, gasoline is a form of stored solar energy.) By abandoning the direct use of the sun as a primary form of energy and using gasoline-driven pumps, the farmers found they could grow more crops at lower prices.

In the same way, the industrialized nations dramatically improved living standards only after they gave up relying on the solar energy transmitted by windmills, waterwheels, skylights, and firewood and turned instead to coal and oil. A persuasive argument can be made that the Industrial Revolution and the resultant affluence we now enjoy were made possible by the availability of plentiful, low-cost energy. Without cheap energy, few could afford to travel extensively, to use household appliances, and to buy energy-intensive clothes and goods.



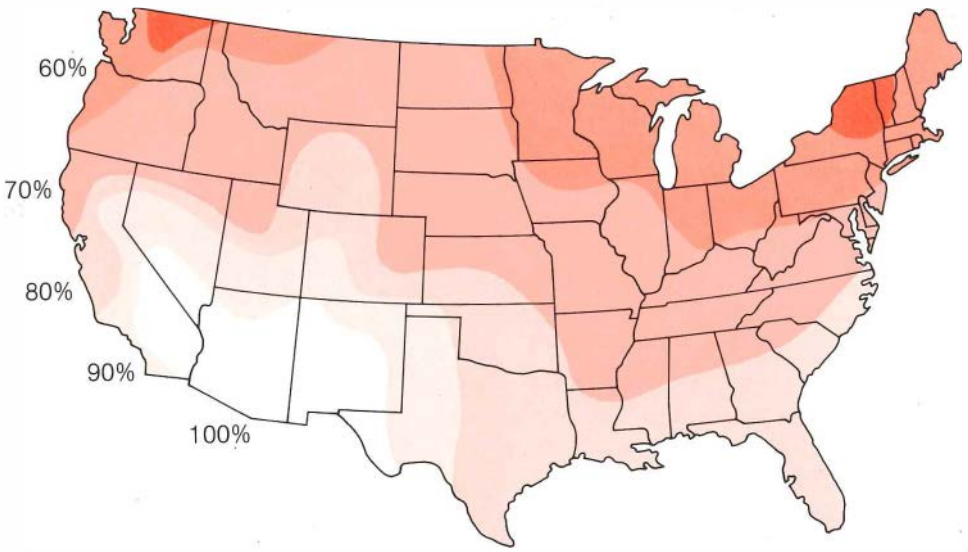
Irrigation pumps were run by a solar-powered steam engine in Arizona in the early 1900s. The system consisted of an inverted cone that focused sunrays on a boiler.

A part-time performer

Modern industries, commercial centers, and homes depend on the availability of electricity twenty-four hours a day. The sun no longer plays a major role in providing power because solar energy is a part-time performer in a full-time world. The sun's energy is available only half the day, and it is so diffuse that (with present methods of collection, storage, and distribution) electricity produced by the sun is more expensive than electricity generated from fossil or nuclear fuels. Thus, until the very closely related problems of high cost and reliability are solved, any crash effort to return to the sun as our primary source of energy could be accomplished only through a sharp reduction in our standard of living.

Piet B. Bos is manager of the Solar Energy Program, Fossil Fuel and Advanced Systems Division, EPRI.

Map shows the relative insolation (amount of solar energy striking the earth) in various regions of the United States. The section of the Southwest that has the highest insolation is designated as 100%; in the other regions, insolation is indicated as a percentage of that figure. New England, for instance, receives 60% of the annual solar energy that the Southwest section receives.



Yet, everyone has become aware that oil and natural gas will be virtually exhausted in half a century and that coal and uranium are becoming more expensive. Fusion power is still an unproved scientific concept; lack of public acceptance may delay the application of breeder reactors, and geothermal sources appear to have limited potential. As for hydroelectricity, almost all the possible sites in the United States have been developed. So, over the long run, the sun will emerge as an increasingly attractive energy source. To make it usable, we must solve the tightly intertwined technological and economic problems that have dimmed the otherwise bright prospects for solar energy.

Current research

A worldwide effort to develop better methods of tapping the sun's energy is underway. In the United States, the Energy Research and Development Administration (ERDA) plans to spend about $90 million on solar research this year. EPRI has programmed a minimum of $20 million over the next five years on solar research and development. And a number of utilities with independent solar programs will invest more millions in solar projects related to the specific needs and potential of the regions they serve.

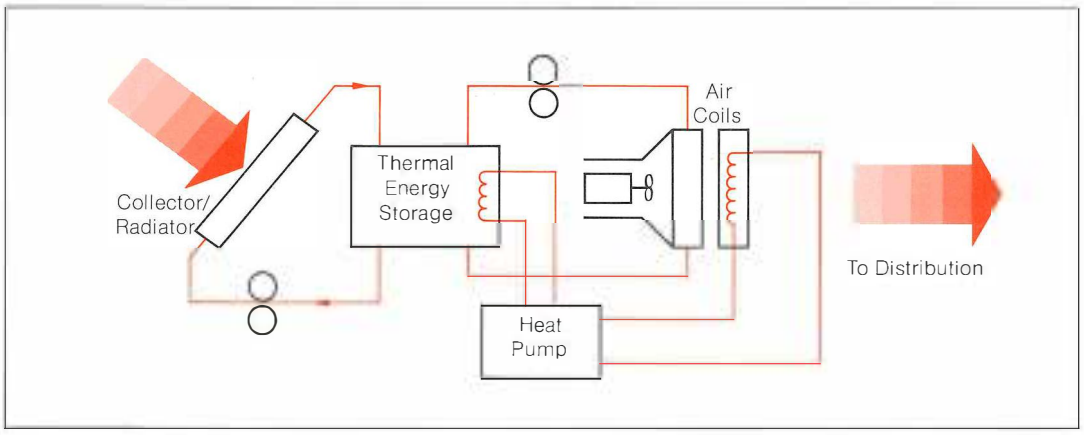
The ERDA projects are aimed primarily at lowering costs so that solar power can replace the energy that now comes from scarce fossil fuels. The complementary programs supported by EPRI are aimed at finding ways to integrate the new solar technology into the electric utility systems. For example, EPRI is supporting research on the environmental impact of solar plants, the integration of solar power reliably and economically into the general utility system, and the methods of raising the tremendous amounts of capital that will be required to build solar plants. For if solar energy is to contribute to the nation's economic and environmental health, we need to know what kinds of plants to build, how fast to build them, where to locate them, how to integrate them into the utility grid, and how to pay for their construction and operation.

Like other similar research, solar development can be classified in three categories: *near term*—likely to yield commercial application within ten years; *mid-term*—wide use expected within ten to twenty-five years; and *long term*—no commercial application for at least twenty-five years.

Solar heating and cooling

The project most likely to enjoy near-term success is the solar heating and cooling of buildings. Almost 25% of all energy in the United States goes into residential and commercial use, most of which is for heating and cooling, so even a small saving in the percentage of fuel used for that purpose would have a major impact.

Schematic of a solar-assisted heat pump system. The heat pump draws energy from water in the storage tank when the outside temperature is low. Since a heat pump can function with relatively low-temperature water, an inexpensive collector system suffices and the collector area on roof is minimal.



EPRI is funding six solar-assisted heating projects. One of them is a cooperative venture with building contractors and local utilities to erect five homes in the Northeast and five in the Southwest that will demonstrate solar-assisted heating and cooling under actual conditions. Similar programs involving commercial and light-industrial buildings will be started this year.

As we see it, effective use of solar energy in heating and cooling of buildings will be a three-step process, listed here in order of increasing costs.

▫ First—energy conservation with improved insulation, better design, and tighter construction, which can significantly reduce heating and cooling requirements at relatively low investment costs.

▫ Second—introduction, demonstration, and commercialization of highly efficient heat pumps. To make the heat pump most efficient and reliable, as well as independent of outdoor temperature extremes, it can be installed in conjunction with an insulated storage tank that holds heat or cold. Furthermore, heat or cold can be stored by either electricity during off-peak hours (which helps level system loads) or solar energy, when available. The economic benefits of the latter have been largely overlooked in most solar-application studies conducted to date.

▫ Third—collection of the sun's energy (the most capital-intensive step). Because a heat pump can efficiently draw heat from water that is only lukewarm, a rooftop solar-heat-collecting array need not be as large or expensive as solar systems designed to run almost totally by the sun. Yet, most of the studies conducted to date concentrate on the latter systems in order to displace as much conventional fuel as possible. With the solar-assisted heat pump system, when the sun is obscured for more than a day or the weather becomes very cold, the water in the storage tank is heated by electricity during off-peak hours. This electricity would be turned on only when the electric load is smallest, during which time the utilities can afford to charge lower rates.

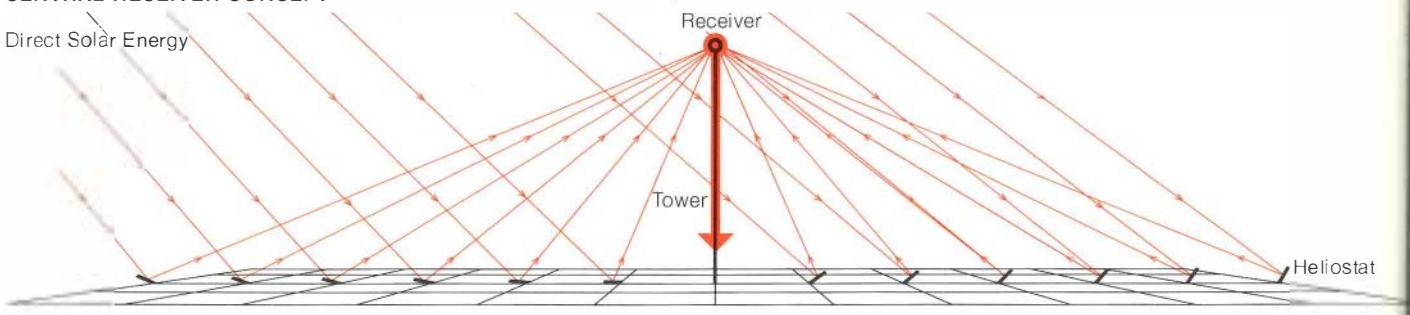
As a consequence, the solar-assisted heat pump system, in contrast with direct solar heating and cooling systems, has the inherent attributes of high reliability of operation and minimum impact on the conventional backup systems.

Furthermore, with a solar-assisted heat pump, one unit of nonscarce nuclear or coal energy burned at the electric generating plant can deliver one full unit of heat in the home. By comparison, it takes approximately three units of resource energy at the generator to make one unit of heat with electric resistance heaters and two units with conventional heat pumps. Even burning gas or fuel oil directly in space heating systems or in furnaces

Central receiver approach to solar-thermal conversion appears to be the preferred concept, though work continues on evaluating alternative systems (facing page). The receiver at the top of the tower receives concentrated radiation from the sun-tracking mirrors that surround the tower. Concentrations equal to 1000–2000 suns could produce steam temperatures up to 2000°F. A steam turbine and generator are located near the base of the tower. Plans for a 10-Mw central receiver demonstration plant are underway.

Alternative solar conversion concepts shown at right are designated "distributed" systems, with solar energy converted to thermal energy at the collector. Heat is then piped to a central power plant. The concept illustrated at top uses paraboloidal dishes that can concentrate sunlight to temperatures almost as high as those attained with central receivers. A parabolic trough (center) provides much lower concentration ratios. In the concept illustrated at bottom, flat plate collectors do not track the sun and are repositioned seasonally.

CENTRAL RECEIVER CONCEPT



requires approximately two units of *scarce* energy resources to produce one unit of heat.

Because of the present high cost of solar collectors, substantial work is needed before solar-assisted heating and cooling systems are ready for commercial application. However, the EPRI residential and commercial demonstration programs may contribute significantly by assessing technical and economic feasibility.

Less certain in terms of economic feasibility are some of the mid-term projects, such as large windmills coupled to electric generators. Several windmills are in advanced stages of development, but the capricious nature of the wind and uncertain economics make these systems questionable in terms of how much power they could contribute reliably to the nation's energy pool.

Coupled with suitable electric energy storage devices, such as batteries, wind power could begin to make an impact in remote locations where needs are small and transmission and distribution costs are relatively high. Wind energy will have a more difficult time competing in the urbanized regions of the country and will probably be less acceptable from an esthetic point of view.

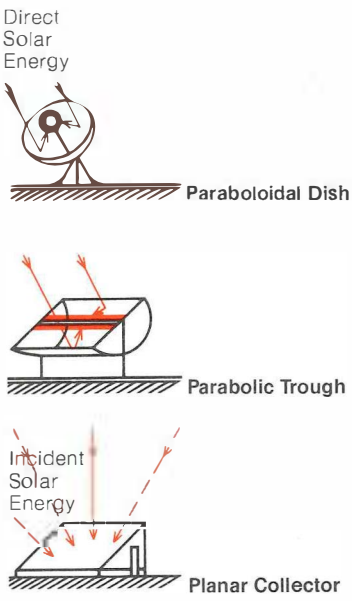
Solar-thermal generating stations

A more promising mid- to long-term possibility is a solar-thermal electricity generating station, which uses the heat of the sun to drive conventional steam or gas turbines.

Current estimates indicate that a central receiver system would cost less per kilowatt generated than other alternative solar-thermal generating plants. In the central receiver concept for a conceptual 100-Mw plant with six hours of storage, two identical reflector fields and towers would be employed. Each receiver would be perched atop an 80-story tower surrounded by a half-square-mile area covered with solar reflectors, which track the sun during the day, reflecting beams equivalent to those from 1000 or 2000 suns to the receiver. Temperatures up to 2000°F could thus be generated at the receiver, high enough to efficiently run a turbine generating plant. However, the significant materials problems encountered at these high temperatures must be resolved. The ERDA program is presently in the preliminary stages of building a 5-Mw thermal test facility and expects to be operating a 10-Mw central receiver demonstration plant that uses steam by 1980.

Since these solar-thermal conversion power plants must be sited in the arid regions of the southwestern United States, the EPRI program will be evaluating the feasibility of two alternative central tower concepts that do not need large cooling water requirements. One concept involves heating helium gas to 1500°F in the receiver before running it through a turbine and a dry cooling tower. The other would use air as the working fluid. Air pumped into the collector and heated to 2000°F could efficiently run a gas turbine

ALTERNATIVE CONCEPTS



generator. The hot air would be exhausted to the atmosphere, requiring no cooling towers.

If engineering studies continue to progress favorably, demonstration plants using either helium or air in a central receiver could be under construction in the 1980s. It's expected that one of these alternative commercial central receiver plants could be on line by 1985, with widespread construction of commercial plants possible by the year 2000, depending on achievement of long lifetimes for the materials and economic viability of the concept.

There are other possibilities for solar-thermal plants that do not depend on a central tower. In such designs, each reflector concentrates solar energy on a separate receiver, and the fluid heated in the receivers is pumped through insulated pipes to a central power plant. There it is converted into steam for driving conventional turbine generators.

According to preliminary studies, the best potential for competitive solar-electric generation is with the central receiver concept. Nevertheless, EPRI is sponsoring studies of other solar-thermal systems to ensure that no potential source is overlooked in the drive to develop viable solar power generating systems as quickly as possible. In all cases, the capital-intensive nature of solar power plants, coupled with their inherently low reliability, will present a significant obstacle to widespread market penetration.

Photovoltaic conversion

Generating electric power directly by the *light* of the sun rather than by the *heat* of the sun is attractive but seems much further away from large-scale commercial development than other solar possibilities. This concept involves photovoltaic conversion whereby solar cells radiated by the sun deliver electric current. These devices have been used with great success to provide energy for spacecraft and for some terrestrial applications, such as remote beacons or floating buoys. But the cost is so high that large-scale commercial generating station applications are presently out of the question. Based on prices reflecting present technology, using solar cells to generate electricity is still approximately 100 to 200 times more expensive than using conventional plants.

Nevertheless, the idea of solar cells remains alluring because the power is generated without boilers, turbines, generators, piping, or cooling towers. And once installed, these devices may need little maintenance. Another advantage of solar cells is that they can use diffuse radiation, in contrast with concepts using solar concentration, and thereby have wider geographic applicability. For a central power plant, the cells would be installed in large arrays with connecting wires and equipment to condition and transform direct current into a form suitable for transmission and use. Currently, the major effort is to reduce costs by improving manufacturing techniques. Alternatively, solar concentration can be utilized to reduce cell area requirements; however, in this case, geographic applicability would be limited to the southwestern United States.

Manufacturers predict that over the next decades the cost of silicon cells will be substantially reduced as new ways to fabricate cells with less energy and less labor are perfected.

Another approach is to develop thin-film cells made of cadmium sulfide or other photosensitive materials. The idea is to mass-produce cells to reduce the cost of such devices. If that kind of cheap, easily produced photovoltaic system can be developed with greatly improved conversion efficiencies and satisfactory lifetimes, the prospects for using photovoltaic energy will be increased tremendously. But it will take a technological breakthrough before cheap, efficient photovoltaic devices are perfected. And there's no way to forecast a timetable for breakthroughs.

The investment required to use photovoltaic solar cells should not be measured merely in dollars. There may also be a tremendous drain on resources, a possibility that has often been overlooked. The amount of energy that goes into producing a single-crystal silicon cell—melting the quartz, refining it, growing crystals, cutting and polishing—is so great that it takes more than two years of the cell's continuous output of electricity to pay back the energy input.

Solar long shots

Unfavorable economics, coupled with major technical problems, makes ocean-thermal-gradient generation systems relatively unattractive and limited to only a few U.S. locations for electric power production. This concept involves using the temperature differences between deep ocean waters and the relatively warm sun-heated surface of the sea. The main appeal of this process is that the temperature difference on which the system is based is

available twenty-four hours a day, every day. The idea is to boil a low-temperature fluid, such as ammonia or propane, with the warm surface waters, drive a turbine with the gas produced, then condense the gas back into liquid in the cold, deep ocean currents. Because the difference in temperatures is so small, the system is physically very large and inherently very inefficient. Thus, a tremendously large system consisting of pumps, heat exchangers, and other expensive equipment would be required to generate a relatively small amount of power. Because of the hostile and corrosive environment, significant problems of materials, operation, and lifetimes are encountered, and the large quantities of ammonia used present a potentially adverse environmental hazard. Another problem is to economically transport the power generated to the land-based load centers.

Another long-term possibility for generating electricity with solar energy is the so-called biomass, or photosynthesis, method. This is the age-old process of using the energy captured by plants from the sun—for example, by burning logs in a fireplace. One modern biomass concept envisions a facility for making electricity or clean fuel that would be located in the middle of a large plantation whose harvests would go directly into the plant. The harvested wood or grain could be burned directly or could be distilled into alcohol or methane to be used elsewhere as fuel. Presumably, the ash from the burning or the waste from the distillation could be returned to the ground and used as fertilizer. Studies are underway at EPRI to check the environmental and economic impact of growing trees or sorghum in such solar plantations. The major problems are availability of water, the energy input needed to make fertilizers, and most important, the fact that the currently projected costs of fuel production are much higher than those for alternative methods.

Storage the key

Estimating the cost of solar energy would be much easier if the sun were available twenty-four hours a day. Utility systems must be geared to provide electricity reliably at any time and in any season, according to the needs of the customers. So if these utilities are to include intermittent solar power among their sources of energy, some way has to be found to integrate that capricious solar source into a distribution grid that provides reliable service. One answer is to find ways of storing the sun's energy for use during the night and during cloudy days. Going back to the solar-thermal central-receiver generating station, the energy could be stored in the form of heat before it is turned into steam. Or, if generated by photovoltaic cells, the energy could be stored in batteries. But those methods are relatively expensive. Another potential energy storage method under study is the pumping of compressed air into huge underground caverns for later conversion to electricity. However, this method is limited to specific sites. Still other possibilities are chemical storage and the manufacture of clean fuels, such as hydrogen and methanol, by solar energy and the storage of those fuels until needed.

In the central-receiver solar-thermal system, we estimate it would cost about two to three times the cost of conventional fossil fuel plants to build a plant that could run an average of twelve hours a day. However, the absence of solar plant fuel costs could lead to lower operating costs. To guarantee twelve-hour operation requires insulated storage tanks capable of holding hot fluids, liquid metals, or molten salts that can hold enough energy to keep the plant going for an additional six hours. To add enough heat storage for the plant to operate twenty-four hours a day would add approximately 50% to plant costs. And this estimate applies to solar-thermal plants that have potential economic feasibility. With photovoltaic solar cells, even when costs are reduced enough to make them competitive, there will still be a substantial storage problem. The energy will have to be stored in batteries or by some similar method.

Some progress is now being made in developing efficient batteries that can store large amounts of energy at lower costs than the present lead-acid units.

The high cost of storage has led EPRI to actively consider another option: to assist the solar-thermal generating station by tying together the advantages of cheap solar heat with the reliability of fossil fuels. EPRI is considering a hybrid system that uses sun power when possible; but when the sun sets or is obscured, oil or gas burners would fire a conventional boiler or burner. Thus, the problem of reliability could be overcome at a reasonable capital cost, with the additional operating expense of fossil fuels used during nonsunshine hours.

Obstacle: capacity displacement

Of course, the problem of reliability involves another fundamental issue that has not received sufficient consideration: capacity displacement. Capacity displacement is the joker in the solar deck. The solar advocates argue that, once developed, energy from the sun could easily provide a major part of the energy the nation needs and eventually could do it at a price as low as any other fuel system. But what happens if the sun doesn't shine for a week? The answer is that we must then fall back on conventional energy sources until that cheap solar source is again available.

People who are building wind-powered home generators want to pump their surplus electricity back into the energy grid when the breezes are brisk so their meters will run backward. They argue that they would be merely paying back in kind rather

than paying in cash for what they buy. Of course, when the wind doesn't blow, they expect to buy electricity from the utility so the utility must keep enough capacity on standby for those times. And that again brings up the twin problems of cost and reliability. Unless our society changes drastically, we will continue to need a highly reliable source of energy twenty-four hours of every day. With solar power of any kind, reliability requires expensive backup by conventional plants. But while the solar plant is generating, the conventional backup plants would stand idle. Thus, all the expenses of the backup plants would have to be added to the price of energy from solar power.

The current outlook

Even if economic viability is achieved, it is the problem of capacity displacement—the need for expensive conventional plants standing by during the night and cloudy hours—that will prevent solar energy from penetrating deep into the total electricity generating capacity. In the foreseeable future, no utility, not even one in the sunny southwestern United States, will be able to commit more than 15–20% of total generating capacity to solar-powered units. Until inexpensive, long-term energy storage devices are available, committing additional solar capacity beyond the 15–20% of total electric capacity would require building an almost equal amount of conventional backup capacity to maintain the equivalent system reliability achievable with conventional plants.

Over the long run, as the problems identified are resolved, solar energy is expected to assume an increasingly important role. Keeping in mind that sun-driven generators require a heavier investment of capital and resources than most alternative systems, solar energy may nevertheless account for 1–2% of the nation's electric power capacity by the year 2000 and about 2% of total energy use. As we enter the twenty-first century, the new solar technology may have the potential to make a truly significant contribution. But even in the year 2000, solar energy's 2% input can save the nation the equivalent of two million barrels of oil per day.

Solar energy represents one element in a complex mix of energy supply options that will be available to utilities in coming years. Economics, as well as regulatory and environmental considerations, will help determine the relative importance of the various technologies. Yet, as the technological and economic problems of solar power are resolved and as alternative fuel sources become more expensive, the dream of at least a partially sun-powered society may come closer to reality.

If the growth of fault currents goes unchecked, reliable utility service will falter. Even now a bulk transformer failure can be as serious as a generator failure. This EPRI program aims to produce workable current limiter designs by 1978.

Fault Current Limiters: Problems and Prospects

Richard Kennon

Several utility systems have experienced major outages caused by through-fault failures of circuit breakers, transformers, buses, or lines. In the past, most systems have withstood extraordinary stresses because of the conservative design margins built into power equipment. At the rate that fault currents are growing, those margins may no longer be technically possible or economic to build.

Many interconnected networks now operate with the tie breaker open to keep allowable fault currents within the ratings of protective equipment. This defeats the purpose of interconnections. Further, to allow for higher load currents under emergency conditions and to avoid instability problems, transmission lines are rarely loaded beyond one-half their thermal rating. The integrity of a growing number of systems thus depends on the ingenuity of planners to avoid overloads on major power equipment, such as transformers and circuit breakers.

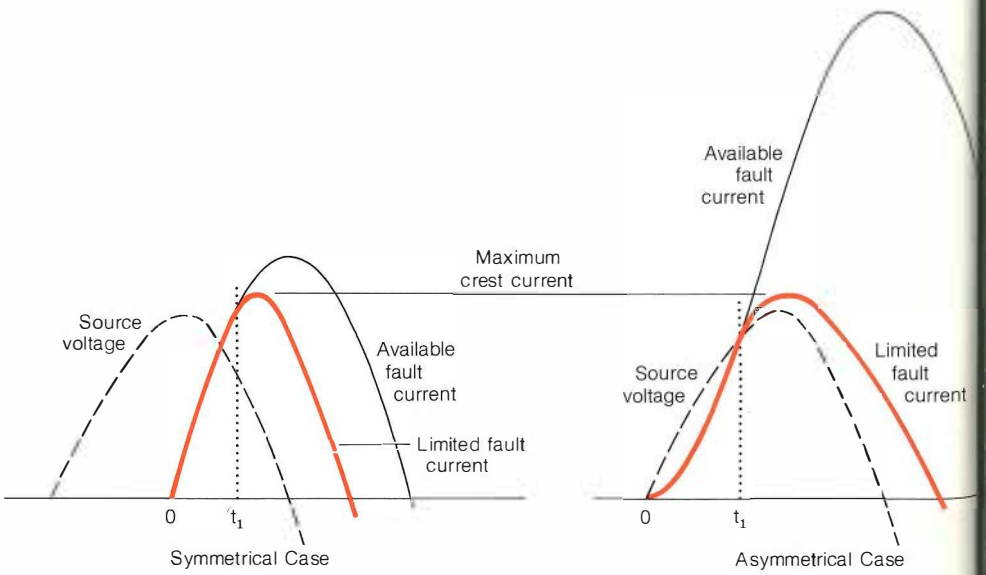
But the growth rate of loads and of generating capacity has steadily infringed on the design margin of major power equipment until it is less than some utilities require. Because of the nearly geometric growth of fault current levels, the useful application life of modern circuit breakers has been reduced from 20 years to 8 years. And the "brute force" solution of using ever-larger breakers no longer works: the largest breakers available will not meet anticipated interrupting requirements.

Against this background, the salvation offered by current-limiting devices is just now beginning to be seriously considered. Soon there will be an overwhelming interest in them, just as there was in lightning arresters years ago. EPRI is therefore sponsoring R&D that will produce one or more technically feasible designs for fault current limiters. Hopefully, development will be complete before many more utilities are forced to resort to expensive and wasteful alternatives, such as split systems or wholesale replacement of major protective equipment and bus reinforcement.

Some economic facts

One utility, Philadelphia Electric Company, already has spent over $2.5 million replacing twenty-two 230-kv breakers at two substations because it was forced to uprate them.

American Electric Power Company was faced with the prospect of replacing seventy 138-kv breakers in three of



its stations at a cost of $7 million, including bus work and switches (*1*). Even then, the available breaker rating would be adequate only for the next seven years. By contrast, fault current limiters in the EHV autotransformer secondaries or in sectionalizing positions could cost $1 million each and still be far less costly than the seventy 138-kv replacement breakers. Still more encouraging is the likelihood that the two experimental 138-kv fault current limiters AEP has contracted to purchase from Hughes Research Laboratories will cost still less.

The cost of conservative design

A fault current limiter (FCL) can be compared with a lightning arrester. A lightning arrester is parallel-connected and limits voltage; a fault current limiter is series-connected and limits current. Each accomplishes its purpose by a rapid and drastic change in impedance. In the earliest electrical systems, voltages were low and line exposure to lightning was limited. A simple spark gap was adequate for overvoltage protection. But as voltages increased and system exposure to lightning became more prominent, a valve-type lightning arrester was developed. Similarly, systems have now progressed to the point where the FCL is more than justified economically. Its technical development and application are now the industry's task.

Each new generating source contributes an equivalent short-circuit current, irrespective of where it is added on the system. The available fault current tends to accumulate on the backbone, or subtransmission system, of any utility (*2*). At the present rate of growth, this can mean a possible doubling of fault current levels approximately every 10–12 years.

Recognition of this trend is reflected in the design and economics of practically every piece of equipment in a system. A look at the design criteria for five basic circuit components emphasizes this point.

- Conductor sizes and composition for transmission and distribution lines are sometimes chosen on the basis of fault current annealing rather than power-carrying ability.
- Transformer specifications require a certain fault withstand capability, leading to costly bracing and reduced self-cooled ratings. It is estimated that use of FCLs would save 15% in transformer design costs and another 15% presently attributable to through-fault failures that occur anyway (*3*).
- Disconnect switch contacts and operating mechanisms are designed specifically to meet fault current requirements. Relaxed fault current ratings would result in obvious savings.
- Circuit breaker mechanisms and contacts must be capable of interrupting as well as closing in on fault currents.
- Insulators, although not required to carry current, are designed with extra strength to withstand the magnetic forces associated with fault currents. This need could be reduced with lower fault current ratings.

Functions of a fault current limiter

Regardless of the form a fault current limiter may take, four functional elements characterize its operation.

- A low-impedance element carries through-load current with low power loss and voltage drop.
- A high-impedance element, when switched into the circuit, limits current.
- A switching element commutates the current from low impedance to high impedance on command.
- A sensing and reset element discriminates between normal currents and fault

SENSING CHALLENGE

Perhaps the most difficult problem associated with the development of fault current limiters is in sensing the fault reliably and acting soon enough to limit the maximum crest current to an acceptable level. The allowable action time, t_1, depends on the value established as the maximum crest current. The lower the crest current, the shorter the time.

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currents, delivers an operating command to the switching element only when needed, and determines the reset logic.

In any given FCL, two or more of these elements may be combined to form a more compact or useful package. But all four must be included in an operational device.

Within this definition, two basic forms are suitable for FCL development as it is understood today: a tuned-circuit limiter and a switched-impedance device.

Important trade-offs

The ideal FCL would have zero losses at full load, anticipate faults, respond instantaneously, have resistive impedance under fault, reset automatically after the fault clears, have no effect on system relaying, be 100% available and reliable, work in all ambient conditions, create no voltage surges, require no maintenance, and have nominal installed cost.

Of course, there is no hope of meeting all these requirements. One must decide what trade-offs are acceptable. Of the many trade-offs available, how does one balance them for a particular application? The overriding conclusion we can draw at this state of the art is that no single fault limiter concept would be practical for all voltage classes or system applications.

Certain trade-offs are readily apparent. For example, the simple tuned-circuit limiter is more appropriate for moderate reductions of fault current. On the other hand, the switched-impedance device may be smaller because it absorbs less energy if the limitation is more severe.

And while the tuned-circuit limiter is inherently reliable and predictable, the switched-impedance device is less so because it contains moving parts. The tuned-circuit limiter is also faster acting, while the switched-impedance device involves a time delay in order for the switch to operate.

On the other hand, the tuned-circuit limiter may be inordinately large and costly because of the capacitor and reactor sizes, and it may have appreciable load current losses compared with the closed contact of a mechanical switch.

Because each device has its appropriate use, an assessment of the functional components is in order.

EPRI's near-term program

EPRI is sponsoring a number of projects to evaluate FCL concepts and their components in depth. For example, I-T-E Imperial has investigated the two types described above (EPRI RP281). I-T-E had earlier performed an in-depth analysis of the simple series-tuned L-C concept, which has been used in some foreign applications (4). Parameters for the capacitors, reactors, and the means of bypassing the capacitor have been determined for various FCL applications. For economic reasons, the use of this type of limiter will probably be confined to a moderate limitation of current. In addition, the losses in the reactor and capacitor portion are critical in its evaluation. If the capacitor bypass consists of a gap with a consistent sparkover characteristic, then the system would be self-sensing.

I-T-E has also evaluated the switched-impedance FCL. This type has a bypass switch, a current commutating means, and a limiting impedance, all in parallel. Conceptually, two or more of these functions can be confined in a single element, but a separate sensing and control element must also be used.

Several commutating means were investigated, including an axial magnetic field SF_6 switch, a sodium fuse, a water-arc device, and a silver-sand fuse. The most successful of these was the silver-sand fuse. After completion of high-power laboratory tests, a series of field tests was conducted at the Laguna Bell Substation on the Southern California Edison Company system. These were single-phase, line-to-ground tests at 69 kv.

Valuable data were obtained concerning fuse arc voltages and fuse energy absorption capability. The tests confirmed laboratory data. Sufficient data are now on hand to design a prototype FCL employing the silver-sand commutating device.

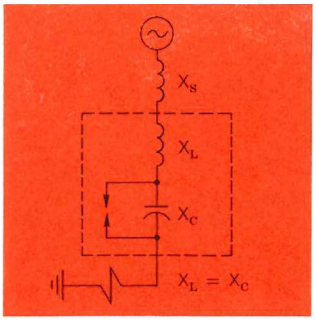
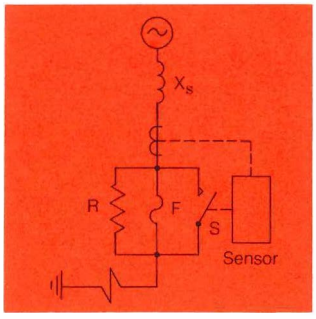
Four other approaches

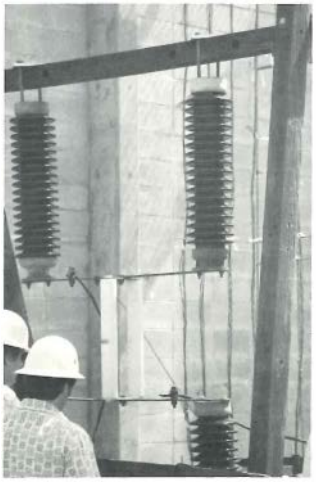
I-T-E also investigated a cryogenic device that employs the characteristics of superconductors. However, the costs of refrigeration suggest practical application only at 500 kv and above. Further work on this concept will have to come at a later date when the need at this voltage level is more urgent.

A novel commutating means is being investigated by Westinghouse Electric Corporation (EPRI RP564). This concept combines the bypass switch and commutation in one vacuum switch. The voltage necessary to force commutation is generated within the vacuum chamber by the arc instability created by a magnetic field. Preliminary test results are encouraging, although the project is barely underway.

A somewhat similar device has been proposed by the State University of New York at Buffalo (SUNYAB) (EPRI RP476). It also employs a vacuum device in which high arc voltage is generated by magnetic fields. The geometry and the operative physics are different from the Westinghouse device, however. The SUNYAB device can perform either the

TWO BASIC SCHEMES FOR FAULT CURRENT LIMITING

Operation	*Single Line*	*Advantages*	*Disadvantages*
Tuned Circuit With $X_L = X_C$ at the power frequency, the FCL has essentially zero impedance to load flow. When a fault of sufficient magnitude occurs, the capacitor is bypassed. X_L then adds to the source impedance, X_S, to limit current.		▫ Predictability, simplicity, and reliability of current sensing and switching ▫ Immediate restoration of low impedance without reset element ▫ Transients cause only momentary insertion of limiter ▫ Static components, long-lived with little maintenance	▫ Large in size ▫ High installed cost because of size ▫ Only moderate current limiting practicable because of size ▫ Relatively high losses
Switched Impedance Switch, S, is normally closed to provide a path for load current. When a fault is sensed, the switch is opened to transfer current into the commutating element, which may be a fuse, F. The commutating element then transfers current to the resistor, R, which limits current and absorbs energy.		▫ May aid transient recovery voltage at breaker ▫ Adaptable to a wide variety of applications and packaging modules ▫ Capable of severe current limiting ▫ May improve system transient stability	▫ Energy absorbed as heat may require forced cooling ▫ Reliability reduced because of moving parts ▫ Action slowed because of time necessary for sensing and switch operation



Suspended among insulators, two silver-sand fuses are the commutating elements in a switched-impedance fault current limiter tested by I-T-E Imperial at Southern California Edison's Laguna Bell substation. Melting fuses force fault current through the stainless steel resistive impedance array in background.

commutating function or, by proper adjustment of parameters, that of the limiting impedance. Although vacuum devices are generally thought to be useful at distribution voltages only, an attempt will be made to apply them at subtransmission voltages (69–138 kv) as well. This project is just starting, and results will not be available until mid-1976.

At transmission voltages an interesting candidate is a novel tuned circuit proposed by Westinghouse (EPRI RP654), which under normal load conditions is series-tuned to zero impedance. Under fault conditions it is switched to a lossy parallel-tuned, high-impedance circuit, which is seen as resistance by the system. The potential exists for this to be a self-sensing device with the switching performed across a gap. It is too early, however, to predict this performance characteristic. The device holds promise of providing severe current limitation since the circuit parameters can be arranged so that a high resistance is inserted. It thus appears to be applicable in tie positions where severe limitation is needed, but where load currents are low except under emergency conditions. As in other tuned circuits, losses must be evaluated.

Sensing faults

The only sensor work so far under EPRI contract is with I-T-E (EPRI RP281). Studies have been undertaken of different sensing criteria, such as magnitude of current, rate of change of current, the time integral of current squared, and combinations of these. It is likely that a combination of current magnitude and its rate of change will enable accurate fault sensing in approximately 1–2 milliseconds with low probability of false operation. Further analysis and the construction of a prototype are planned.

Finally, a contract is nearing completion with Phoenix Electric Corporation for evaluation of an FCL concept involving a U-shaped iron yoke surrounding the conductor, with a spring-loaded armature above the open end of the yoke. Excessive current pulls the armature across the gap (EPRI RP324). Essentially, this amounts to a one-turn, variable-inductance, iron-core reactor.

Two operating problems became apparent during this study. Under certain conditions of timing and saturation of the iron, the resultant fault current could be so offset that the first current zero might be delayed, thus delaying breaker interruption. Adding resistance in the limiting circuit was the obvious solution.

The second problem was size. Design projections show that, as originally conceived, the device would be inordinately long and heavy. Again, the solution was to add resistance. The improved devices now under test are a combination of inductance and resistance, and they are self-sensing. In one device this resistance effect is achieved by using the eddy current losses in thick iron laminations. This concept could well be applicable to distribution voltage levels.

Other research efforts

Two significant efforts outside EPRI should be mentioned. For some time Hughes Research Laboratories has been developing an FCL for American Electric Power Company (5). The heart of this device is a crossed-field switch tube, which can rapidly commutate current into a limiting resistor. This tube is a low-pressure device that will conduct in a glow mode in the presence of a magnetic field but will not conduct when the field is removed. Its sensing scheme is unique in that it generates an internal "fault" with which it compares the external fault. After 300–500 microseconds, enough information is gained to make a decision. Hughes Research Laboratories is also developing a high-speed bypass switch to complete the package.

The Calor-Emag Division of Brown Boveri Corporation offers a type of current limiter comprising a sensor, an explosive one-shot bypass "switch," and a current-limiting fuse. Used in parallel with a limiting impedance, it functions as a switched-impedance FCL. Used alone, it functions as a current-limiting fuse with the advantage of a high continuous current rating.

EPRI expects that both self-sensing tuned limiters and switched-impedance devices will be developed to a commercially acceptable stage. In addition, sensing devices will be developed and proved for switched-impedance devices.

Conclusion

Brute force is no longer feasible for interrupting fault currents. And the extra cost of series-connected electrical equipment is prohibitive if designed for the higher fault levels anticipated. A reliable FCL must be developed before utilities can be expected to specify transformers, switchgear, switches, cable, and supporting hardware that are not fully rated to withstand high fault current stresses.

Reliability, of course, must be the major factor considered in the widespread use of limiters. Even so, the industry will need to look toward redundancy in applications and fail-safe equipment designs.

ONE UTILITY'S VIEW

Philadelphia Electric Company first used current limiting in the form of lumped inductance on 4-kv and 13-kv distribution systems more than 50 years ago. In the near future, expansion of its 34-kv distribution system will necessitate the use of a specific device to limit fault currents. Hopefully, this will be an essentially zero-impedance, loss-free device under normal conditions, in contrast to the high-loss, lumped inductance used today.

Beginning in 1970, Philadelphia Electric discussed the need for a 230-kv current-limiting device with one manufacturer. If R&D could have been initiated at that time, the recent replacement of twenty-two 230-kv circuit breakers at two major transmission substations—at a net cost of approximately $2.5 million—could have been avoided.

By January 1974 the company foresaw the need to uprate circuit breakers at several other transmission substations. For example, at one major 500-kv substation, the 1974 duty was 24 Gva. By 1981, it will increase to 40 Gva, and by 1986 it will be 46 Gva. Yet, the circuit breakers now installed are rated only for 32 Gva. Elsewhere on the system, at 230 kv a new substation with a 1978 service date already has projected duties of 32 Gva by 1986. It is therefore important that a full-scale R&D program be pursued.

Development of FCLs should also include an in-depth study of their effects on the protective relay schemes used by utilities. A cursory look at the Philadelphia Electric system indicates that only minimal problems would be encountered at the transmission level. But the use of FCLs in 13-kv distribution substations might necessitate drastic changes in relaying practices.

P. Luther Kolarik, Philadelphia Electric Company

References

1. C. A. Falcone, J. E. Beehler, W. E. Mixolites, and J. Grzan, *Current Limiting Device—A Utility's Need.* C73-470-2, IEEE Power Engineering Society, Summer 1973 (upgraded to T73-470-2, Winter 1974).

2. C. A. Falcone, *Current Limiting Devices—Need and Application.* 75 CH 01037-1-PWR, Symposium on Current Limiting Devices, IEEE Power Engineering Society, Summer 1974.

3. L. D. McConnell, W. A. Donaldson, and E. R. Perry, *Fault Current Limiters for Electric Power Systems.* C74-177-2, IEEE Power Engineering Society, Winter 1974.

4. R. Banks and H. L. Thanawala, *Short Circuit Limiting Coupling as AC System Interconnector.* IEE Conference Publication No. 107, November 1973.

5. W. Knauer, *Resistor Switching Current Limiting Device with Millisecond Response Time.* 75 CH 01037-1 PWR, Symposium on Current Limiting Devices, IEEE Power Engineering Society, Summer 1974.

Acoustic emission may augment ultrasonics in assuring the integrity of nuclear reactor pressure vessels. Current research seeks to correlate the two test techniques and to define acoustic emission reliability.
An EPRI technical article.

Nondestructive Pressure Vessel Testing by Acoustic Emission

Karl Stahlkopf and Allen Green

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Acoustic emissions are analogous to pressure waves released during an earthquake in that they are waves created by deformation, or dynamic movement, within a structure. These waves travel through the structure and are detected by sensors attached to its surface. Just as in geophysical studies, the amplitude and time of arrival of acoustic emission signals are used to estimate the magnitude and location of the deformation. In this respect acoustic emission techniques have been aptly termed "structural seismology."

Acoustic emission (AE) promises to become a valuable nondestructive testing technique for evaluating the structural integrity of pressure vessels as well as of other pressure retaining components (*1, 2, 3*). Successful development of AE methods would provide a powerful tool for the location and monitoring of defects in engineering structures. However, there are still many limitations to the use of the current technology (*4*). Its acceptance as an engineering tool will depend on the confidence that can be placed in its results. This article describes a research program to evaluate the use of acoustic emission by correlating AE sources with potential defect sites found by ultrasonic inspection. The critical objective is to attain the capability of distinguishing between significant and nonsignificant signals.

AE criteria

Successful use of AE involves three distinct components: detection, location, and quantification. While the information gained from any one of these may be useful in itself, the success of AE as a positive contribution to assurance of pressure vessel integrity depends on integration of all three. The first two, detection and location, have been demonstrated with some success (*5, 6, 7*). However, much work remains to be done to establish confidence in a method of signal quantification (*4*).

Methods for ranking the seriousness of sources by empirically grading their acoustic activity have been suggested by several authors (*8*). These methods have resulted in a *proposed* ASME Boiler and Pressure Vessel Code guideline for the practice of acoustic emission monitoring of pressure vessels (*9*). This approach, which is also empirical, has achieved some success. However, no direct correlation has yet been established between the size of a defect and its AE signal recorded in actual vessel tests.

Description of program

To assess the applicability of any new technique it is necessary to compare the proposed technique with an accepted standard. In this case, the results of AE examination were compared with those of ultrasonic examination conducted according to existing standards established by Section XI of the ASME Boiler and Pressure Vessel Code. The reactor pressure vessel for the LaSalle II boiling water reactor was monitored by acoustic emission during its first hydrostatic test to 1563 psig. (Normal operating pressure for the vessel is 1250 psig.) The first hydrostatic test was chosen because the "Kaiser effect" tends to suppress AE activity on subsequent stress cycles (*10*).

False signal sources

Based on previous experience with reactor pressure vessel steels, the structure was instrumented with 18 AE sensors placed approximately 17 feet apart. Unfortunately, because of fabrication shop error, most of the sensors were positioned incorrectly, causing a skew of all real-time source location with respect to actual position. However, this skew was found and corrected in post-test analysis. Figure 1 shows the actual sensor locations.

Three straps used to secure scaffolding were tightened around the circumference of the reactor pressure vessel and left in place during the pressure test. Relative motion between the straps and the vessel wall created a number of artificial signals. As shown in Figure 1, one strap was almost directly over a girth weld and, as a consequence, data originating from this weld seam region were questionable.

Figure 1 Developed surface of LaSalle II BWR vessel (cylindrical portion) shows positions of 18 sensors used to receive AE signals and triangulate their origins. Sensors on the pressure vessel domes and near the fold line of this projection are repeated for clarity. Triangular areas within which AE phenomena were recorded are outlined in red. Note concentrations of AE sites along weld seams (solid lines) and under scaffolding straps (shaded bands). Red cross-hatched areas are loci of multiple AE signals rather than discrete sites. Shaded and cross-hatched areas denote heavy concentrations of such multiple AE signals.

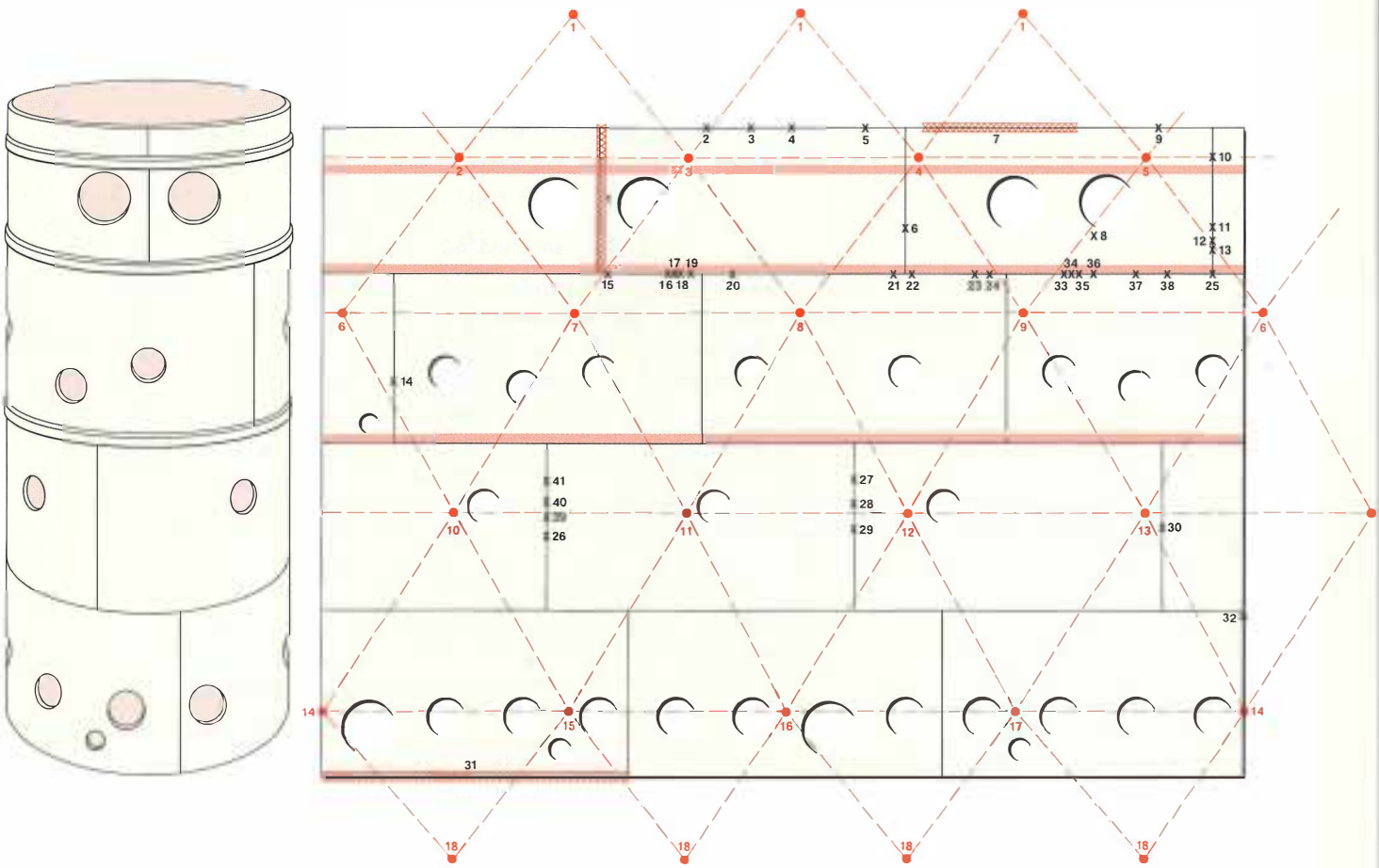


Table 1

ACOUSTIC EMISSION SITES AND RANKING*

AE Site	Rank by Number of Events	Rank by Amplitude Summation	Rank by Individual Amplitude
1	2	3	4
2			
3			
4			
5			
6			
7			
8			
9			
10	8	8	5
11			
12			
13	3	4	3
14	12	10	10
15			19
16	19	16	14
17	15	14	12
18	17	15	20
19	18	18	15
20			18
21	22	20	16
22	23	21	17
23	20		23
24	16	19	24
25			
26			
27			
28			
29	24	23	
30	5	2	2
31	1	1	1
32	6	7	8
33	10	22	22
34	14	13	13
35	7	9	9
36	4	5	7
37	13	12	11
38	9	17	21
39	21	11	6
40	11	6	
41		24	

*Blanks indicate sites for which analysis is not complete

Table 2

ULTRASONIC EXAMINATION RANKING

(45° Beam Angle)

AE Site	*Amplitude (% DAC)*	*Rank*
1	18	1
4	5	11
6	5	11
10	10	2
11	12.5	3
12	8	8
18	2.5	16
21	5	11
23	5	11
24	11	4
25	7.5	9
28	5	11
30	10	5
32	7	10
38	10	5
40	10	5
All others	2 or less	

Table 3

ULTRASONIC EXAMINATION RANKING

(60° Beam Angle)

AE Site	*Amplitude (% DAC)*	*Rank*
1	11	3
3	6	8
6	6	8
11	12.5	2
13	15	1
14	6	8
23	8	6
24	10	4
28	7.5	7
32	9	5
All others	2 or less	

Another problem that arose was the artifact noise generated by the sliding seals used to close off the nozzles during the hydrostatic test. These seals moved as pressure was increased and were the most active source of acoustic noise encountered during the test. Even so, postprocessor techniques enabled AE sites to be located between and immediately adjacent to the nozzles. Postprocessor techniques involve the use of spatial discrimination (in conjunction with amplitude levels, test time, and parametric levels) to limit the influence of nearby noise sources. Postprocessing cannot, of course, extract significant data from an excessive volume of false signals. The welds beneath the scaffolding strap and the safe end welds in the nozzle region, therefore, could not be evaluated.

Data analysis

The AE data identified 41 sites, 3 of which were along lengths of weld seams rather than at discrete locations. Table 1 lists the sites (which are also shown in Figure 1) and provides three methods of comparative ranking. The importance of each site was ranked by the number of events, the summation of the amplitudes of all events, and the largest individual event amplitude.

Tables 2 and 3 list the ultrasonic examination results with the sites ranked in terms of percent of distance-amplitude correction (DAC) for 45° and 60° beam angles, respectively. The gain for this examination was increased 10 times (20dB) over that required by Section XI of the ASME Boiler and Pressure Vessel Code.

Comparison of Tables 1, 2, and 3 provides some assessment of the sensitivity of acoustic emission monitoring. Of the 41 sites identified by AE, 20 gave no discrete indication greater than 2% DAC at either ultrasonic testing angle. Ultrasonic examination ranked sites 1, 10, 11, 13, 24, 30, 38, and 40 as the largest ultrasonic reflectors with 10% or greater DAC. These sites also ranked high in acoustic emission activity. A brief comparison is shown in Table 4.

Conclusions

Although there was not a one-to-one correlation between ultrasonic and AE ranking of sites, those that were ranked high by ultrasonics tended to be sites of high AE activity.

Acoustic emission appeared to be more sensitive than ultrasonic testing in locating very small discontinuities, i.e., the 20 sites located by AE that showed less than 2% DAC when examined ultrasonically. However, the presence of these small signals cannot be uniquely interpreted from AE data alone and should be confirmed by other methods to ensure reliability of the AE siting.

AE site detection and location are possible in generally high-external-noise environments, such as those encountered in a fabrication shop, but detection is limited where interference signals are generated by nozzle plugs and vessel straps.

Further work is needed to establish a sound foundation for ranking the importance of AE sites. The present empirical approaches, while providing valuable information, are clearly limited but can serve as a guide to more exhaustive examination by other methods.

Table 4
COMPARATIVE RANKING OF AE SITES

	Ultrasonic Examination		*AE Examination*		
AE Site	*45° Angle*	*60° Angle*	*Event*	*Summation*	*Amplitude*
1	1	3	2	3	4
10	2	–	8	8	5
11	3	2		Not Completed	
13	–	1	3	4	3
24	4	4	16	19	24
30	5	–	5	2	2
38	5	–	9	17	21
40	5	–	11	6	–

References

1. A. T. Green, "Detection of Incipient Failures in Pressure Vessels by Stress-Wave Emissions." *Nuclear Safety*, 1969, 10, 4.

2. P. H. Hutton and D. L. Parry, "Assessment of Structural Integrity by Acoustic Emission." *Materials Research and Standards*, 1971, 11, 25.

3. H. L. Dunegan and D. O. Harris, "Acoustic Emission—A New Nondestructive Testing Tool." *Ultrasonics*, 1969, 7, 160.

4. K. E. Stahlkopf and G. J. Dau, "Acoustic Emission, A Critical Assessment." *Nuclear Safety*, 1976, 17, 1.

5. D. Birchon, K. Dukes, and J. Taylor, "Acoustic Emission Monitoring of a Pressure Vessel." Conference on Inspection of Pressurized Components, London, June 1974.

6. D. L. Parry, "NDT—Acoustics Testing of Culcheth Pressure Vessel." Report XN-129, Exxon Nuclear Company, May 1973.

7. P. G. Bentley, E. J. Burton, D. G. Dawsen, and T. Ingham, "Acoustic Emission and Pressure Vessel Failure." Conference on Periodic Inspection of Pressurized Components, London, June 1974.

8. D. L. Parry, "Industrial Applications of Acoustic Emission Analysis Technology." ASTM Special Technical Publication 571, January 1975.

9. "Proposed Standard for Acoustic Emission Examination During Application of Pressure." ASME Publication, January 1975.

10. J. Kaiser, *Untersuchungen über das Auftreten von Geräuschen bei Zugverrauch*. PhD thesis, Technische Hochschule, Munich, 1950.

Three research premises, four technical divisions, a five-year plan, six major research areas, and twenty-four programs—these are the organizational parameters within which EPRI's planning is conducted. Each is a way to categorize the Institute's R&D efforts for 1976 and beyond. Each provides a distinct perspective for assessment of R&D effectiveness.

EPRI 76: Research Emphasis

FUNDING EMPHASIS BY TIME FRAME

45% Near Term

45% Mid-Term

10% Long Term

	Primary Energy Resource Planning	Conversion Systems	Transmission and Distribution
Near-Term Goals	□ Ensure the ability to burn high-sulfur, high-ash coal in an environmentally acceptable manner by means of advanced pre- and postcombustion processes	□ Strengthen the nuclear power option and resolve its safety issues so as to reduce the time necessary to obtain site approval and construct power plants ○ Improve the reliability and availability of electric utility equipment and systems so as to reduce capital requirements △ Help solve generic technical problems in the engineering, construction, and operation of electric utility systems	□ Improve the reliability and availability of electric utility equipment and systems so as to reduce capital requirements
Mid-Term Goals	■ Ensure the efficient use of abundant domestic coal resources ● Improve the use of available fissile and fertile materials	■ Develop reliable, high-efficiency, low-cost conversion systems for baseload, intermediate, and peaking applications ● Help develop liquid metal fast breeder reactors ▲ Ensure the availability of information and technology to meet regulatory requirements	■ Provide transmission and distribution equipment technology for efficient and highly reliable electricity transport from source to consumer
Long-Term Goals	■ Develop the technology needed to apply essentially unlimited energy resources, such as fusion systems and solar energy	■ Develop advanced high-efficiency generation and conversion equipment and technology for use with both renewable and nonrenewable resources	■ Develop cost-effective transmission systems for greater flexibility in siting power plants
Applicable Programs	□■ Gasification □■ Liquefaction □■ Direct utilization □■ Environmental control and combustion ● Fuels, waste, and environment (nuclear) ● Developing applications and technology (nuclear) ■ Fusion ■ Solar energy	□▲ Water reactor system technology □○ Reliability, availability, and economics (nuclear) □ Fuels, waste, and environment (nuclear) ○■■ Thermal-mechanical energy conversion and storage △ All hardware-oriented programs ■ Electrochemical energy conversion and storage ■ Geothermal energy ● Developing applications and technology (nuclear) ▲ Environmental assessment ▲ Environmental control and combustion	□■ AC overhead transmission □■ DC transmission □■ Underground transmission □■ Distribution □■ System planning, security, and control □■ Rotating electrical machinery ■ Underground transmission (cryoresistive and superconducting)

The Institute's 1976 guideline is the first to be developed entirely within the planning procedure established just one year ago. Prepared by the technical and planning staffs, it reflects inputs to them from division advisory committees and task forces, the Advisory Council, the Research Advisory Committee, and several cooperating federal agencies. The figures for each division and program are shown in the table on page 26.

Although the most familiar and convenient way to present planning data is by division organization, three fundamental premises establish the scope and emphasis of Institute research:

□ Electric utilities must continue to expand production capacity for many decades to match the nation's requirements.

□ Electricity generation, at least for the balance of this century, must rely heavily on both coal and nuclear fuels.

□ Efficiencies must be improved throughout the sequence of electricity generation, transmission, distribution, and use so as to conserve the industry's and the nation's natural and capital resources.

EPRI program planning follows the research premises cited above. The most crucial aspect thus becomes the thorough evaluation of many—and sometimes conflicting—technological needs and, from them, the selection of R&D programs that offer not only a high probability of technical success but also a high probability of payoff for the utility industry.

Evaluation is a continuing task in the Institute's planning. At the beginning of

Storage Systems	Environment and Conservation	Energy R&D Planning
	□ Develop technologies to conserve energy through more efficient use of electricity	□ Supply data, information, and professional analyses to aid in the design and management of hardware R&D programs
	○ Reassess the environmental and public health effects of electric utility system operations so as to encourage the design of effective environmental standards and controls	
■ Provide systems and equipment that will permit economic storage of energy	■ Continue to develop information on the environmental effects and safety of various fuel resource options	■ Analyze the relationships between technical performance objectives and the economics of electricity supply for guidance of hardware R&D programs; and provide information to ensure a balance among national economic factors, environmental effects, and technological options
	● Achieve more desirable environmental and esthetic conditions in electric power systems	
	■ Assess the environmental and public health aspects of advanced technologies	■ Continue to analyze the relationships between technical performance objectives and the economics of electricity supply for guidance of hardware R&D programs; and provide information to ensure a balance among national economic factors, environmental effects, and technological options
■ Electrochemical energy conversion and storage	□ Thermal-mechanical energy conversion and storage (heat pump)	□■■ Energy demand and conservation
■ Thermal-mechanical energy conversion and storage	□ Solar energy (heating and cooling)	□■■ Energy supply
	□ Energy demand and conservation	□■■ Energy systems modeling
	○■ AC overhead transmission	□■■ Environmental assessment
	○■ Underground transmission	
	○■ Environmental control and combustion	
	○■■ Environmental assessment	
	● Essentially all programs (40% of the Institute's effort)	

each year it is focused on an update of EPRI's five-year plan by the technical staff. The elements of this new draft are then reviewed by more than 300 experienced utility people who fill specialized roles in EPRI's advisory committee structure. These advisers help to define specific research objectives, thus ensuring that all 24 programs continue to address acknowledged industry needs.

Broad review

The entire five-year plan, including newly expanded detail for the forthcoming year, undergoes two important reviews before Board approval is sought. The Advisory Council, one of the key links in the program planning chain, is made up of leaders from public-interest groups, government, labor, education, science, and business. The Council provides liaison between the public and EPRI. Its review and subsequent recommendations for program emphasis particularly address those research concerns lying near the interface of power technology and society.

Finally, the Research Advisory Committee considers the program plan. As the senior group in EPRI's technical advisory structure, this committee of utility research and engineering executives judges all elements of the program plan for technological priority and balance.

Still another calibration is of interest: the scale of near-, mid-, and long-term time frames in which research results can be put to work on electric utility systems. For the five years of research now planned, the Institute's allocation of relative program emphasis is as follows:

Near Term (to 1985)	45%
Mid-Term (1985–2000)	45%
Long Term (beyond 2000)	10%

Final approval

As considered for approval by the Board of Directors, EPRI's latest five-year plan —and the 1976 effort toward its achievement—thus acknowledges the three time frames, the six research areas, and the

1976 Program Guidelines

Fossil Fuel and Advanced Systems Division	
Fossil Fuel Department	
Gasification	$10,200,000
Liquefaction	9,200,000
Direct Utilization	3,500,000
Environmental Control and Combustion	10,400,000
Supporting Research	1,500,000
Subtotal	$34,800,000
Advanced Systems Department	
Electrochemical Energy Conversion and Storage	$ 7,900,000
Thermal-Mechanical Energy Conversion and Storage	7,700,000
Fusion	3,500,000
Solar Energy	2,900,000
Geothermal Energy	1,800,000
Subtotal	$23,800,000
Total	$58,600,000
Nuclear Power Division	
Water Reactor System Technology	$11,295,000
Reliability, Availability, and Economics	8,680,000
Fuels, Waste, and Environment	8,010,000
Developing Applications and Technology	6,315,000
Total	$34,300,000
Transmission and Distribution Division	
AC Overhead Transmission	$ 7,000,000
Underground Transmission	6,400,000
DC Transmission	6,800,000
System Planning, Security, and Control	900,000
Distribution	3,000,000
Rotating Electrical Machinery	800,000
Total	$24,900,000
Energy Systems, Environment, and Conservation Division	
Environmental Assessment	$ 6,328,000
Energy Demand and Conservation	1,587,000
Energy Supply	2,172,000
Energy Systems Modeling	1,113,000
Total	$11,200,000
Institute Total	$129,000,000

twenty-four programs charted on pages 24–25. (Some programs are entered more than once because work within them addresses more than one research area.)

As of early December 1975, EPRI had 478 projects under contract and 125 contracts in negotiation. The total value of this work exceeds $400 million, including $120 million in cosponsoring funds from federal agencies, the contractors themselves, and other sources. In terms of EPRI division and department responsibilities, the range of this research effort is summarized in the following sections.

Fossil Fuel Department

Both natural gas and oil will decline as power-generation fuels because of limited domestic availability and national policies designed to reduce our dependence on imported energy supplies. Coal, the dominant boiler fuel in the past, remains abundant in the U.S. but it exists largely in forms not suitable for traditional use because of existing and anticipated air quality standards.

Among the methods proposed to meet environmental regulations, the most nearly available are precombustion cleaning of coal, intermittent controls with tall stacks, and postcombustion cleanup. Stack gas scrubbers and precipitators are already being used to reduce SO_x and particulate pollutant levels below regulatory standards. However, potential future standards on sulfates, NO_x, and trace organic and inorganic substances may be difficult to meet with these techniques.

Precombustion cleaning and fluidized-bed combustion with sulfur capture by the limestone bed are less fully developed approaches. Other alternatives include conversion of coal to clean gaseous or liquid fuels suitable for use in boilers, gas turbines, or fuel cells.

All these techniques are being investigated, along with basic research and related studies on fuel preparation, so that utilities can increase their reliance on coal.

Advanced Systems Department

Three major concerns define the department's work. One is to improve the efficiency and advance the art of energy conversion technologies. Interests thus range from steam plant reliability to topping and bottoming cycles. Fuel cells are also under active investigation. Many programs are closely related to those in the Fossil Fuel Department through a shared need for the clean fuels that are the products of coal gasification and liquefaction processes.

The second concern is the development of energy storage systems. In principle, storage is an alternative to fossil-fueled peak- and intermediate-load generation, enabling baseload plants to generate a greater proportion of power. Storage systems of commercial interest may result from current development of electrochemical, mechanical, and thermal concepts.

Third, the long-term sources of fusion, geothermal, and solar energy are being examined, in coordination with the national effort, to assess their likely roles in future energy supply. Each could be virtually inexhaustible, but each still has technical, economic, or environmental uncertainties that must be resolved before it can impact energy supply patterns. A controlled thermonuclear fusion reaction has yet to be scientifically demonstrated. If expectations are realized, fusion may contribute to electricity supply sometime during the first half of the next century. By contrast, the principles of wind, solar-thermal, or photovoltaic energy conversion to electricity are known, but cost reductions will have to be made before solar can compete as a power source, even in optimal regions of the country. Solar electric systems require the development of electric energy storage systems to ensure continued supply when there is no sun or wind.

Of more immediate applicability are solar-assisted methods for providing domestic hot water, space heating, and eventually air conditioning. Here the timing depends largely on the progress of engineering to reduce manufacturing costs and improve system reliability. EPRI is developing solar heating and cooling systems that optimize the utility's backup capacity requirements and its fuel savings.

Geothermal power utilization depends on resource type and location. Dry steam is being commercially exploited today, but the resource base is limited. Liquid-dominated geothermal reservoirs are more common and, as engineering problems are resolved, are expected to make significant contributions to electricity generation on a selected regional basis. Widespread use of geothermal energy requires the economic extraction of thermal energy from geopressurized sources or hot rock. Development of technology that will compete with other energy alternatives is a formidable task.

Nuclear Power Division

The major emphasis of the division's 1976 program is to improve the viability of the light water reactor as a competitive source of electric power. In support of this objective, near- and mid-term programs are directed toward increased assurance of safety, increased reliability and availability, development of new fuel systems, and technical issues of fuel performance, waste, and environmental impact. Currently there is only one major long-term program: the liquid metal fast breeder reactor.

The largest program concerns water reactor system technology. One essential effort is to strengthen both analytic and experimental understanding of system performance and safety, which is expected to validate current design margins and reduce uncertainties in expected performance. Such reduction of uncertainty is important if plants are to attain their true potential outputs. Hypothetical loss-of-coolant accidents (LOCA) and operational transients are a focus of this program. Separate studies are being performed in the blowdown, refill, and reflood phases of LOCA/ECCS (emergency core cooling system) behavior, with particular attention given to pump performance and heat transfer with two-

phase flow. The results of these studies will be combined into methods for obtaining more realistic LOCA descriptions.

In addition to core and systems projects, there are significant efforts treating tornado missile effects and studying the behavior of structural materials used for pressure vessels and piping. Important objectives of the latter work are an improved understanding of material properties and an improved ability to perform and interpret nondestructive examinations so as to distinguish between critical and benign defects.

The second major program addresses issues of reliability and availability, principally problems of steam generators, turbines, and water chemistry. Program direction and priorities are being established by analysis of plant operating data on the frequency and severity of outages. For example, an effort to establish and test the viability of a computerized lifetime prediction system may improve the availability and reliability of steam turbine rotors. Finite-element stress analysis coupled with fracture mechanics will be used for the computations, with plant operating data and field spindle-bore nondestructive examination results as input.

Considerable research is also being devoted to understanding and controlling system coolant chemistry—and to the related testing, selection, and control of materials—so as to reduce corrosion-induced failures, such as those occurring in steam generator tubes and piping. In boiling water reactors, one of the current problems is the control of leaks in the primary coolant loop. These leaks occur at cracks induced by a combination of conditions which, although rare, contribute significantly to plant outage. Individual projects are directed toward quantifying these causative conditions in operating plants and toward developing procedures to reduce the severity of each. In pressurized water reactors, the problems are on the turbine loop side of the steam generator. In some respects these problems are similar to those of the older fossil-fueled plants because the contaminants enter the loop through condenser leaks. Different kinds of cooling water alter the corrosive conditions that arise as impurities are concentrated in the boiling process. Current research is therefore comparing chemical conditions in plants cooled by brackish water, fresh river water, and recycled cooling-tower water.

The third major program deals with fuels, waste, and environment. In 1976 its emphasis is on improved fuel and core performance. The immediate objective is to begin developing a technical and statistical basis for improved fuel operations with a reduction in restrictive operating limits. A fuel rod reliability model to guide operations and safety will be developed by integrating a mechanistic fuel performance model with prototypical performance statistics. This approach requires a detailed understanding of fuel and cladding material properties, as well as comprehensive performance data.

Research in the field of plutonium recycle is stimulated by recognition that current views were developed primarily during the mid-1960s. A resolution of licensing, safeguards, and fuel performance questions must reflect present conditions. Calculational tools are being developed to aid in resolving these questions. Work leading to the eventual proof-testing of plutonium recycle fuel is also underway.

In the fourth major program, joint design studies have been initiated with ERDA on a large breeder reactor prototype. It is anticipated that this work will identify the R&D needs of commercial units and will be the basis of at least one reactor vendor proposal in 1978. Three teams of vendors and architect-engineers are now involved in the first phase of this project, and during 1976 the basis for proceeding with detailed designs will be established.

Transmission and Distribution Division

The fundamental purpose in transmission and distribution is to develop new and improved methods for transporting electric energy from source to customer at reasonable cost, with minimum impact on the environment and with sustained emphasis on reliability. The division is pursuing programs aimed at developing design data for ac and dc overhead transmission circuits at all voltages; promoting research in low-voltage (35 kv and below) distribution technology; and designing and implementing a large-scale demonstration of an automated distribution system incorporating automatic meter reading, load management, fault detection, and remote circuit switching.

In collaboration with the Energy Systems, Environment, and Conservation Division, research is underway to develop comprehensive information on the environmental effects, if any, of electric fields, corona, and audible noise in the vicinity of high-voltage transmission circuits.

Still other programs are concerned with optimizing ac and dc terminal facilities; improving system security by developing techniques for limiting and interrupting large fault currents; identifying promising underground cable technologies for bulk power transmission over distances ranging from 5 to 500 miles; devising quantitative measures for describing the security state and control objectives in large interconnected networks; and planning major laboratory facilities to support program objectives.

Energy Systems, Environment, and Conservation Division

This division's programs consist primarily of research, analytic, and modeling studies in areas representing the external constraints within which utilities must operate; for example, environmental considerations, the availability of primary energy fuels and their costs, the factors that determine the growth rate of electricity demand, and the role of conservation in altering patterns of electricity use. The results of these efforts are intended to aid in the internal planning of the Institute's R&D programs, as well as to provide valuable information to the

utility industry, government agencies, and the public.

Environmental and public health issues are major considerations in many Institute programs, such as in 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. The Environmental Assessment Department is specifically concerned with defining the environmental and health impacts resulting from energy production and utilization processes so as to guide the hardware-oriented programs in other divisions of the Institute. Research includes identification and characterization of potentially harmful constituents of emissions, effluents, or radiation associated with electricity production and use; determination of the manner in which pollutants are transported through air and water; definition of their dose-response relationships with respect to populations, ecological systems, or physical materials; and exploration of possible beneficial uses of wastes or potentially harmful by-products.

Cooperative efforts

Many EPRI programs are related to those of federal government agencies. Especially in resource development and long-range research, where federal funding is significantly higher, Institute programs are planned to complement those carried out by the government. Joint funding is another cooperative means to speed the development and use of new and improved electricity generation, transmission, and distribution systems. To facilitate such efforts, formal agreements have been executed between EPRI and the Energy Research and Development Administration, the National Aeronautics and Space Administration, the Environmental Protection Agency, and the National Bureau of Standards.

For example, a project for the near-commercial design of a liquid metal fast breeder reactor is being jointly managed by EPRI and ERDA. This $30 million, 30-month, three-phase effort combines the financial and technical resources of the utility industry with those of the government and will build on accumulated U.S. and foreign engineering and operating experience, including information obtained from the Clinch River demonstration plant.

A second example of cooperation between EPRI and ERDA is a battery energy storage test (BEST) facility. This program will provide the means to measure, characterize, and report on preprototype battery system performance before heavy financial commitment is made for technology demonstration at full prototype scale. The BEST facility will be built at a utility substation so that testing may be done in a user environment. The feasibility phase of this $10 million program has been completed, and the preliminary engineering phase is now underway.

A third cooperative program, entirely within the utility industry, involves EPRI and the Edison Electric Institute in an electric utility rate design study. Requested by the National Association of Regulatory Utility Commissioners and planned as a one-year effort, it comprises ten tasks concerned with peak-load pricing, including assessments of electricity demand elasticity, costing, ratemaking, metering, potential cost advantages, and customer acceptance. Consulting agreements have been negotiated, and initial reports are planned for release in the fall of this year.

Program details available

While underscoring the premises of EPRI's research programs and describing the planning cycle that produced its 1976 guideline, this review has only highlighted Institute tasks for the new year. A more detailed analysis, *A Summary of Program Emphasis for 1976,* is being prepared and will be available in February.

Fossil Fuel and Advanced Systems Division

Richard E. Balzhiser, Director

Fossil Fuel Department

NO_x CONTROL TECHNOLOGY

Among the major responsibilities of the Environmental Control and Combustion Program are the development of technologies to control emissions from fossil-fueled power plants and the evaluation of costs for such technologies.

The NO_x program is intended to assure that utilities can meet control standards on oxides of nitrogen with a minimum impact on the operation, construction, or economics of fossil-fueled power plants. Specific projects are directed at the operational and reliability impacts of NO_x control on fossil-fired steam generators and the economics of water injection in gas turbines and combined cycles.

Work is also directed at controlling NO_x emissions originating from nitrogen organically bound in the fuel. This is particularly relevant to coal, shale oil, and synthetic fuels derived from coal.

Because stricter NO_x regulations are likely in the future, projects to achieve higher levels of control and to evaluate the associate costs have been undertaken.

Need for an NO_x Program

The question is frequently asked: Why an NO_x program? After all, current NO_x regulations for steam generators can be met with existing technology, and considerable controversy exists within the scientific community as to the need for NO_x control except in a few metropolitan areas, such as Chicago and Los Angeles. Several recent developments, however, indicate that a substantial effort in NO_x control technology development is appropriate.

The most important development is the strong possibility that the federal government will soon impose much stricter NO_x controls on stationary sources in general and on utility boilers in particular. This action stems from the fact that the automobile industry has failed to meet the NO_x standards specified by the Clean Air Act without unacceptable fuel economy penalties.

While specific regulations have not been issued, a recent publication by the EPA indicating goals for stationary sources is probably indicative of the levels of control under consideration (Table 1). Because of renewed emphasis on coal as a utility fuel, the goals for coal-fired utility boilers are particularly relevant. An examination of Table 1 shows that NO_x emissions of 200 ppm and 100 ppm are being considered for 1980 and 1985, respectively. It should also be noted that this is well beyond state-of-the-art technology, which can meet approximately 300–350 ppm.

Accurate and thorough technical and economic assessment of advanced NO_x control technologies can be important in determining the true costs of any benefits derived from such future regulations.

The low NO_x emission requirement for gas turbines and combined cycles is the second major development. As shown in Table 2, the EPA has proposed standards of 55 ppm and 75 ppm NO_x emissions for gaseous and liquid fuels, respectively. To achieve these emission levels for conventional fuels will require significant departures from past combustor designs if expensive water injection techniques are to be avoided.

Further, if similar levels of control are required for high-nitrogen fuels (for example, residual oil, shale oil, and some synthetic fuels from coal) even more advanced techniques will be required since water injection techniques cannot meet the proposed NO_x levels. Again, the need for low-cost, reliable NO_x control technologies is apparent.

Considerable public attention has been focused on photochemical smog and other compounds (nitrates, amines, PAN) formed from nitrogen oxides in the atmosphere. The potential health effects of these chemicals are currently being investigated in various clinical and epidemiological studies, including those by EPRI's Environmental Assessment Department. NO_x has been identified as a participant in the complex atmospheric reactions that produce smog and other visibility-limiting aerosols. The effect of these chemicals on plants, animals, and even man-made objects is less certain, but the need for economic NO_x emission control technologies is indicated.

NO_x Control Research

To satisfactorily resolve the problems of NO_x control, EPRI has mounted a complete spectrum of research programs that

Table 1
EPA'S R&D GOALS FOR NO_x CONTROL
(ppm, 3% excess O_2, dry)

Source	*Existing New Source Performance Standards*	*1980 Goal*	*1985 Goal*
Utility boilers			
Gas	168	100	50
Residual oil	230	150	90
Coal	500	200	100
Industrial boilers			
Gas		80	50
Residual oil		125	90
Coal		150	100
Commercial boilers			
Gas		50	30
Distillate oil		70	50
Residual oil		150	90
Spark ignition engines			
Gas		1200	400
Compression ignition engines			
Diesel oil		1200	800

Table 2
PROPOSED EPA STANDARDS FOR GAS TURBINES
(15% O_2, dry)

Species	*Fuel*	*Limit (ppm)*
NO_x	Gaseous	55
	Liquid	75
CO	Gas and liquid	90
SO_2		0.3% S or 55*
Smoke		10% opacity

*By weight in fuel

ranges from fundamental studies on the fate of fuel nitrogen compounds to tests for evaluating the operational and reliability impact of NO_x control on a 750-Mw plant.

Since techniques for controlling NO_x depend largely on the type of power system, the fuel to be used, the duty of the system, and its application, all of these factors are covered by the EPRI program.

NO_x Control in Steam Boilers NO_x emissions from boilers burning natural gas and residual oil have been substantially controlled by minimizing the availability of oxygen with staged combustion and by lowering the flame temperature by recirculating flue gas into the combustion air. However, staged combustion in coal-fired plants raises significant questions about the operational and reliability impacts of corrosion, slagging, and fouling, as well as the impacts on both precipitator and overall boiler performance.

One project, jointly funded by EPRI and EPA, is evaluating the levels of control possible in coal-fired boilers with existing technology, principally that of staged combustion. This project also calls for assessing corrosion problems that might be encountered during staged combustion operation on high-sulfur, high-iron eastern coals. The research should be completed by June 1976 and for the first time will provide operating data for utilities that must control emissions by the staged-combustion method.

Another project is defining the operational problems of staged combustion with low-sulfur, western coals. Arizona Public Service has modified those furnace areas that might be subject to local reducing conditions so that detailed information on accelerated corrosion can be obtained. In addition, for the first time tests are being performed to evaluate precipitator behavior resulting from staged combustion.

Windbox gas recirculation is also an effective NO_x control for clean fuels. Until recently, however, the effectiveness of this technique on coal-fired units was the subject of considerable controversy based on theoretical studies or bench-scale laboratory experiments of limited value.

Since most NO_x control systems to be purchased by utilities in the near term involve gas recirculation, EPRI has funded Allegheny Power Service Corporation to examine the effect of windbox recirculation on a 550-Mw super-critical eastern coal unit. To date, preliminary results indicate no significant benefit from recirculation when used in conjunction with staged combustion in coal-fired units.

EPRI is presently evaluating the possibilities of developing a burner-boiler combination with the lowest NO_x emissions compatible with other design and operational requirements. Such a program would be very important because modification of the combustion process will probably remain the lowest-cost approach to NO_x control.

In another project, several compounds have been identified that can selectively and noncatalytically reduce NO_x at tem-

peratures and residence times characteristic of the convective heat transfer sections of a boiler. This has significant near-term importance in coal-fired boilers where the high fuel-bound nitrogen and the inherent difficulties in burning solid fuels may limit the level of control that is possible by combustion modifications. Additional research will assess the viability of these chemical additives when SO_x and particulates are present. This approach probably represents the lowest-cost, postcombustion NO_x control technology.

Other current projects will provide basic information on the fate of organic nitrogen compounds. These studies are being performed on laboratory flames where the molecular nitrogen normally present in the combustion air is easily replaced by another inert gas, such as argon. This permits a mass balance of all nitrogen compounds and allows an accurate determination of the fate of fuel-bound nitrogen.

NO_x Controls in Gas Turbines and Combined Cycles While there are no present national standards that limit NO_x emissions from gas turbines and combined cycles, EPA has proposed regulations. To meet current local NO_x emission standards operating with conventional turbine fuels, water or steam is injected into the combustion chamber to lower the flame temperature. This technique is effective, but expensive: capital costs are $2–10 per kw and heat rate penalties are about 2%.

Less capital-intensive technologies using catalytic reduction or premixed, lean, primary-zone combustion are interesting alternatives. A current research project will help determine to what extent low-cost, noncatalytic control is possible.

To date, research results suggest that a premixed system with a relatively simple variable geometry combustor can meet proposed EPA regulations. At least several years' development time, however, is required to confirm full-scale feasibility. Since variable geometry adds complexity, additional work on other, simpler NO_x control technologies is underway. Initial results are encouraging and may be particularly important for fuels containing bound nitrogen. Since many synthetic fuels, such as coal-derived liquids and shale oil, will be used in combined cycles to improve overall economics, and since these fuels are likely to be high in organic nitrogen, the results of this program are of considerable importance.

Although important steps are being taken in combustion control of NO_x in gas turbines and combined cycles, the work has not reached the point where postcombustion treatment methods can be discounted.

Unfortunately, the selective noncatalytic technique being developed for steam generators is not applicable to gas turbines or combined cycles because the required temperatures and residence times are not readily achieved. Consequently, EPRI is considering a project to assess the technical and economic aspects of scrubbing or catalytic processes for removal of NO_x in the stack.

On a near-term basis, another project has demonstrated the emissions benefits obtained by incorporating staged combustion into a supplementally fired combined cycle. Reductions of almost 60% in NO_x emissions from the gas turbine were recorded and possible reductions in CO, hydrocarbons, and carbonaceous particulate emissions were indicated. To confirm the results of this small pilot research, a full-scale demonstration is planned.

In other studies it was found that a conventional steam boiler using a gas turbine to supply vitiated air in place of the normal forced-draft system may yield up to a 10% improvement in heat rate. This could result in a reduction in the use of clean fuels, depending on how the gas turbine-boiler combination is operated and on the needs of the generation system.

Summary

A major shift in NO_x control strategy at the federal level, proposed regulations significantly affecting the operation, cost, and reliability of gas turbines and combined cycles, and potential future standards on nitrogen-contained species derived from atmospheric reaction of NO_x with other compounds prompted EPRI to embark on a substantial program to develop NO_x control technologies and evaluate the associate costs.

Projects are designed to meet the requirements unique to each type of power-generation device and application, with emphasis on coal-fired boilers and on gas turbines and combined cycles. Controls for combined cycles are particularly important because overall economics strongly indicate that synthetic fuels, many of which are inherently high in fuel nitrogen, will be used in combined cycles.

Advanced Systems Department

BATTERY STORAGE

A basic problem of a typical utility is that the demand for electric power shows marked daily and weekly variations. To satisfy all its customers, the system must have a generating capacity equal to the highest daily demand, plus a reserve capacity to ensure reliability of service. As a result, much of a utility's generating capacity is used only part of the time.

If energy storage were available, efficient and economical baseload power generation could be increased, and the excess over demand during off-peak periods could charge the energy storage system. Discharge of the stored energy during periods of peak power demand could then be used to reduce or replace gas turbine generating capacity.

Outlook and Requirements for Battery Energy Storage

The utility industry has been interested in the prospects for battery energy storage since 1970. A recent EEI/EPRI survey by the EEI System Planning Committee revealed that battery energy storage deserves a high R&D priority (Table 1). The tabulation is based on 34 responses from utilities having over 40% of the nation's total generating capacity. The major reason for this priority is probably because dispersed energy storage in batteries appears to offer a combination of operational, economic, and environmental benefits that cannot be matched by most other storage technologies. These benefits include the following.

- Flexible application with minimum environmental impact
- Short lead time for construction
- Distributed power "generation," allowing for transmission credits
- System stabilization with the ability to absorb current and voltage surges
- System regulation with the ability to meet minute-to-minute demand fluctuations
- Modular construction, allowing initial sizing and additions on an as-needed basis
- Potential for increasing overall system reliability
- Partial reserve "generation" capacity

Although the potential benefits from storing energy on electric utility systems are highly significant, battery energy storage will not become a reality unless its economics are competitive with other methods of generating peak and intermediate power. Based on economic comparisons with gas turbines, battery systems must achieve certain technoeconomic characteristics to be cost competitive. Assuming an off-peak energy cost of 12 mills/kwh and credits (e.g., transmission, distribution, spinning reserve) of $60/kw,

Cost	$80/kw plus $20/kwh
Life	10–20 years (250 cycles/yr)
Efficiency	70–75%
Operation / Maintenance	1.0 mills/kwh

Using these assumptions and objectives, battery energy storage promises to become more economical than gas turbines and combined cycle machines for the generation of peak and intermediate power up to approximately 2500 hours of annual operation. Assuming a capital cost of $20/kwh, a growth rate of utility generation of 7%/yr, and a 10% saturation of battery energy storage in the generating mix, the utilities could spend about one billion dollars a year on energy storage technology. Ultimate penetration of this market depends, of course, on the technoeconomic competitiveness of batteries with other storage and peaking technologies.

Table 1
SURVEY OF ENERGY STORAGE PRIORITIES

	Number of Utilities Responding			
Technology	*Favorable*	*Marginal*	*Poor*	*Total**
Batteries	19	9	3	16
Compressed Air	12	13	4	8.5
Thermal (after meter)	15	5	9	6.4
Underground Pumped Hydro	10	10	9	1.1
Flywheels	6	10	13	– 7.5
Thermal (before meter)	4	10	13	–10
SMES	1	5	15	–21

*Total is computed by allowing one point for favorable rating, zero for marginal, and minus one for poor, and then adding. The answer is normalized to the base number of responses (34).

Battery Program—Organization and Projects

The objective of the program is to develop economically, technically, and environmentally suitable battery systems for utility application. To accomplish this objective, EPRI has initiated a coordinated series of R&D projects to evaluate potential battery systems for utility application and then develop the most promising of the candidates. EPRI's activities related to these systems are shown in Table 2.

The scope of the program will narrow as the projects enter the engineering development stage and the development costs increase. As more information becomes available, decisions will be made to discontinue EPRI involvement in many of the less promising battery systems. By 1979, it is likely

that the Battery Program will encompass only about three of the systems identified in Table 2, despite the fact that the funding for development is expected to triple by that year. The six major areas of program activity are described below. The relationships of these activities are shown in Figure 1.

▫ *Technology Development* Assisting private industry to develop battery systems for utility application is the focus of the program. This area now involves five projects, which are cost-shared with private industry. The average support for each of these projects is $740,000 with about $330,000 from EPRI. The systems being developed are sodium-sulfur (General Electric Company and TRW Systems Group); sodium-antimony-chloride (ESB, Inc.); lithium metal sulfide (Atomics International), cost-shared with ERDA; and zinc-chlorine (Energy Development Associates), a joint venture of Gulf & Western and Occidental Petroleum.

▫ *Supporting Activities* Limiting problems in the development of advanced battery systems are being addressed by private industry and universities in three EPRI-funded projects.

▫ *New Concepts* Exploration and evaluation of potentially viable technologies for utility applications, such as zinc-bromine and redox batteries, are included in two projects.

▫ *Power Conditioning and Control* Assessment, evaluation, and development of ac/dc conversion equipment for batteries and other advanced systems are being examined in two projects.

▫ *Technoeconomic Studies* Cost and design studies of lead-acid batteries, alternative chlorine storage concepts for the zinc-chlorine battery, and various energy storage technologies are presently being addressed in three projects. Two of the projects are cost-shared with ERDA.

Table 2

POTENTIAL SYSTEMS FOR BATTERY ENERGY STORAGE

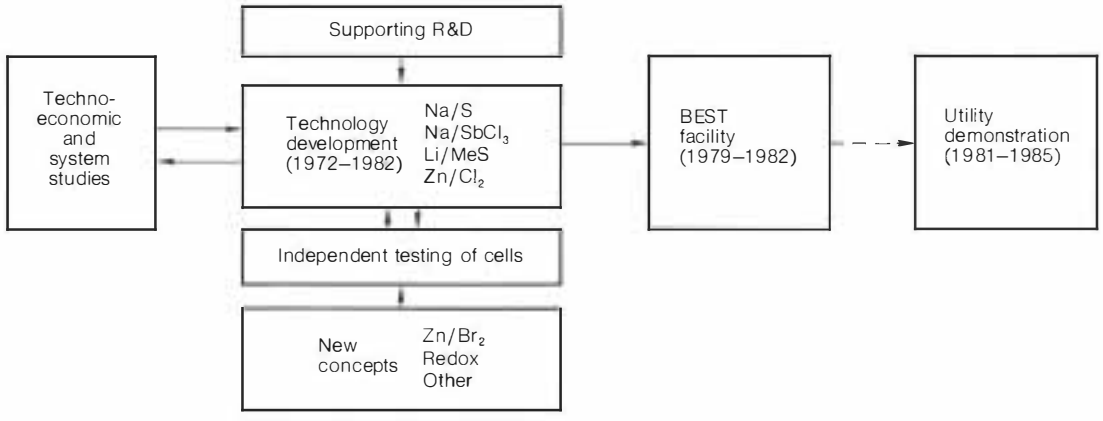
System	*BEST Facility Installation Goal*	*Possible Commercial Availability*	*Current Status*
Pb/PbO_2 (Present technology)	1979	1979–80	Cost and design studies; discussions with utility planners
Zn/Cl_2	1979	1982–86	Development
Zn/Br_2 and Redox	—	1983–88	Exploration
Na/S and $Na/SbCl_3$	1981–82	1985–90	Development
Li/MeS	1981	1985–90	Development

▫ *Testing* Small-scale cell testing at independent laboratories, as well as large-scale battery testing in a national testing facility, constitutes a continuing evaluation of alternative battery technologies. Two small-scale testing contracts and the Battery Energy Storage Test (BEST) Facility are involved in this area of activity. ERDA is cofunding the BEST Facility.

Summary

The development and introduction of new technology for utility application require evaluation and selection of alternatives, research on key limiting problems, engineering development of promising technologies, and development and demonstration of complete subsystems in coordinated programs that have long-range direction and goals. The 18 projects within the Battery Program constitute a coordinated and focused effort to advance the development of battery systems for utility application.

Figure 1



EPRI–USSR FUSION POWER EXCHANGE

The ultimate goal of fusion research and the principal emphasis in both the EPRI and ERDA programs is economic electric power generation based on pure fusion reactions. Nevertheless, the neutrons produced by the deuterium-tritium (D-T) fusion reaction may have important alternative uses, many of which do not require plasma conditions as stringent as those in pure fusion and hence may be applied earlier. Three of these—the transmutation of radioactive wastes, especially the actinides; the breeding of fissile materials; and the hybrid fusion-fission power reactor—have been the subjects of studies sponsored by EPRI. These studies, like others carried out elsewhere, have indicated that such applications have promise as well as problems. A recent development for prospective international cooperation in fusion has highlighted the EPRI efforts in alternative fusion applications.

Proposed Joint Program

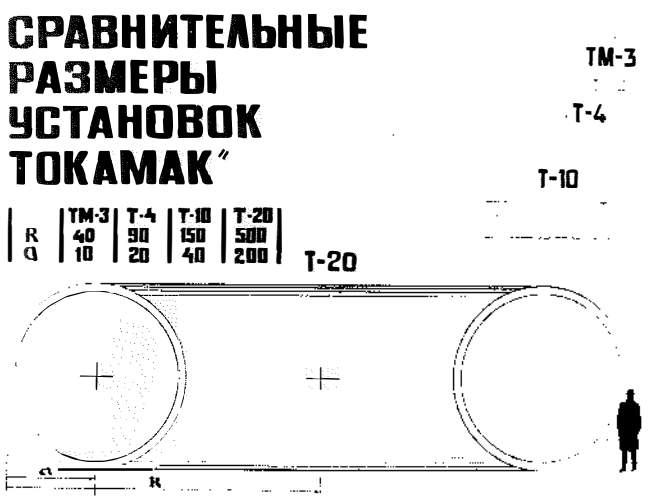
In May 1975 a Soviet delegation visited EPRI for discussions on the Institute's fusion power program. At that time the Soviets stated that their program's highest near-term priority was the development of a hybrid fusion-fission reactor based on a Tokamak. In addition, their efforts on pure fusion reactors will continue, with emphasis on pulsed systems.

A joint EPRI–USSR program involving the testing of blanket module elements on the Soviet T-20 Tokamak was subsequently proposed. The facility, which will be in full operation in 1983, will be uniquely suited for such experiments. No other machine with comparable size and neutron fluences is presently scheduled for operation in the U.S. or elsewhere in the same time period. Last September an EPRI delegation met in Moscow with officials from the Kurchatov Institute, the Efremov Institute, and the USSR State Committee for Atomic Energy. As an outgrowth of this meeting, a step-by-step approach to such a joint project was formulated and a preliminary protocol was signed by the participants. Last December, the president of EPRI and the chairman of the USSR State Committee for the Utilization of Atomic Energy met at EPRI and further detailed this proposed agreement, reaching a general accord.

Module Testing on T-20 Tokamak

Although no specific joint program has been decided, one possibility is the testing of modules for fission fuel production and actinide burning in T-20. The modules would be designed and built in the U.S., installed and tested by a joint team at the Kurchatov Institute in Moscow, and returned to the U.S. for destructive testing. To give an idea of the scaling of the T-20, Figure 2 shows the size of its vacuum envelope, which surrounds the fusion fuel, compared with that of the T-10, a smaller operating Tokamak. Exterior to this, eight moderating modules would be placed to slow down the 14-Mev fusion neutrons. Some of these modules will be used by the Soviets for studying the breeding of tritium and fissile material and for obtaining the engineering know-how for prototype applications. The tentative proposal for a joint venture will give the U.S. access to two of these eight modules.

Figure 2



The overall size and operating characteristics of the T-20 plasma will be comparable to that of a fusion-fission prototype power reactor. The T-20 will not be expected to provide all the necessary information for a demonstration fusion-fission fuel and electric power production reactor. However, if it reaches its fusion design goals, the Soviets would then feel confident to build a prototype experimental power reactor. The anticipated design goals for T-20 are $n\tau_E = 10^{14}$ sec cm^{-3}; $T_i > 7$ kev; confinement time, 2 sec; major torus radius, 5 m; minor plasma radius, 2 m; central toroidal field, 3.5 Tesla; and axial current, 6×10^6 amperes sustained for 5–20 sec.

Assessment of Proposed Project

The implications of the Soviet plans for a hybrid fusion-fission reactor have not yet been fully evaluated in the U.S. If successful, the nuclear energy field will be impacted by an option for a second breeding system in the early 1990s, well before pure fusion reactors are expected to enter the energy-producing arena. EPRI believes it is important that the U.S. utility industry understand the potentials and limitations of the fusion-fission option. Therefore, EPRI is seriously examining this offer from the Soviets for a joint project.

Nuclear Power Division

Milton Levenson, Director

WATER REACTOR SYSTEM TECHNOLOGY PROGRAM

The Nuclear Power Division has four major program areas: (1) Water Reactor System Technology, (2) Reliability, Availability, and Economics, (3) Fuels, Wastes, and Environment, and (4) Developing Applications and Technology. Each program consists of several subprograms. In this issue, major emphasis is on the LOCA-ECCS subprogram of Water Reactor System Technology. Other subprograms and the other major programs will be covered in future issues.

Zircaloy-Steam Oxidation Kinetics

Under RP249, Worcester Polytechnic Institute (WPI) will provide isothermal and transient Zircaloy-steam oxidation data in the 1600–2700°F range under various steam flow conditions from tubing sections of reactor grade Zircaloy-4 cladding. Careful attention will be paid to monitoring and measuring the specimen temperature. The isothermal oxidation data obtained to date at WPI and those from other studies, including preliminary data from a program sponsored by the Nuclear Regulatory Commission (NRC) at Holifield National Laboratory, confirm the conservative nature of the analytic procedures imposed by current NRC licensing criteria to describe Zircaloy oxidation.

A complementary project funded jointly by EPRI and the Metal Properties Council at Battelle, Pacific Northwest Laboratories (RP251) will provide additional information about the mechanical and oxidation behavior of Zircaloy. These data and subsequent analyses will be used to provide a realistic assessment of cladding oxidation under postulated loss-of-coolant accident (LOCA) conditions.

On this project (RP249), oxidation studies under isothermal conditions and unlimited steam flow conditions, and the associate metallurgical analyses, have been completed. Temperature was monitored by a thermocouple welded to the specimen and was controlled by a high-speed time-temperature controller. Use of a thermocouple in a dynamic environment requires that careful attention be given to measurement errors resulting from heat transfer losses. The indicated sample temperature was correlated with the actual sample temperature by obtaining a calibration curve against materials with known melting points. The measured discrepancy in this calibration procedure corresponded closely to results predicted by an analytic heat balance model that was used to estimate the thermocouple error.

Knowledge of the specimen temperature is required since the rate of oxidation is an exponential function of temperature. It is also necessary to know the difference between the specified value of the temperature and the temperature measured by the thermocouple because this temperature difference controls the energy input used to heat the sample. The temperature measured by the thermocouple differs from the temperature of the specimen, thereby making an analysis of the thermocouple error mandatory.

Following oxidation of samples under isothermal conditions, the thickness of the oxide layer, the stabilized alpha layer, and the transformed beta layer were measured on mounted and polished metallographic sections. The total amount of oxygen absorbed was calculated from the measured thickness data and phase equilibria information. Results were obtained under unlimited steam conditions. Data have been obtained where steam flow of 40 lb/hr was split equally between inside and outside flow and where steam flow of 20 lb/hr was restricted to the inside of the Zircaloy tubing and then discharged to oxidize the outside under essentially stagnant conditions. It was found that as long as unlimited steam is present, there is no difference in oxidation rate for these different flow conditions.

The isothermal data indicate that oxide thickness varies linearly with the square root of time and exponentially with temperature. Best-estimate fits were obtained for all the oxidation data between 1800°F and 2700°F for the inside and outside oxide thickness and for the inside and outside ξ thickness (oxide thickness and stabilized alpha thickness). Data obtained at 1600°F and at 1700°F (below the beta tranus temperature) followed the same form of the oxidation kinetics expression but with different constants.

The calculation of the oxygen absorption served as the basis for comparing this data to existing models of Zircaloy oxidation. The parabolic rate constant K_p (in units of $[mg/cm^2]^2/sec$) for the total reacted zirconium was calculated from the oxygen absorption and these values were compared to those reported by Klepfer and Baker and Just:

Klepfer	$K_p = 2.96 \times 10^5 \exp(-33{,}200/RT)$
WPI	$K_p = 3.58 \times 10^5 \exp(-33{,}500/RT)$
Baker and Just	$K_p = 3.36 \times 10^5 \exp(-45{,}500/RT)$

Here, R is the Boltzmann constant and T is the absolute temperature (K). The above expressions indicate that the Klepfer and Baker and Just results are more conservative than the WPI results. The Klepfer analysis is about 5% more conservative over the entire temperature range. The Baker and Just analysis, which is currently required in licensing calculations, is increasingly conservative with increasing temperature, the percentage difference varying linearly from ~10% at 2000°F to ~72% at 2600°F. Preliminary data from the Zircaloy oxidation study sponsored by NRC at Holifield National Laboratory appear to be in excellent agreement with data obtained by WPI.

Specimen weight-gain measurements of oxidation appeared to be a less reliable indicator of oxidation behavior than the metallographic measurements due to acceptable variations in clad thickness in the as-received tubing. The hydrogen content was measured on a large number of samples to determine the extent of hydrogen contamination during oxidation. Most values appear to be in the 20–30 ppm range, compared with the original concentration of ~15 ppm. There appears to be no correlation of hydrogen absorption with experimental variables, such as time at temperature.

Linear heating and cooling ramp transient oxidation experiments in an unlimited steam environment have been initiated. Ramp rates that bound those calculated for hypothesized LOCA situations are being simulated. Computational procedures for predicting oxidation under transient conditions based on the isothermal oxidation data are being developed, as is a procedure for calculating oxygen diffusivity in Zircaloy.

Gamma Energy Deposition

In power reactor safety analysis, the energy associated with the decay of radioactive fission products is a persisting source of sensible heat in the core and a source of potential radiolytic effects. The maximum temperature in the fuel cladding resulting from gamma heating during a postulated loss-of-coolant accident (LOCA) is important in licensing and in setting the operating rated power of nuclear plants. The absorption of radiation energy by the aqueous solutions used in the emergency core cooling system may result in some radiolytic decomposition of water. Measurement of the decay heat emission rate after shutdown is being made under contracts RP230 and RP392.

Mathematical Applications Group, Inc., (MAGI) is the prime contractor for RP492 and with S. M. Stoller Company will perform calculations of gamma-ray energy deposition in typical light water reactors (LWR) during postulated LOCA conditions. The project will provide data in such a form that absolute gamma heating and hydrogen radiolysis correlations can be made. The calculational scheme involves the use of transport kernels computed by Monte Carlo methods to obtain the position-dependent gamma-ray heat deposition in the coolant and in various components of typical LWR cores. Gamma-ray absorptions in the control rods, fuel, cladding, and assembly walls will be determined, along with redistribution factors for gamma rays from a hot pin or assembly into the surrounding lattice. The calculations will be done for a series of time intervals from several seconds to several months after shutdown.

The University of Virginia will perform a series of experimental measurements on suitable models of reactor cores to provide an experimental benchmark of the gamma heating in a core lattice and to validate the calculations of gamma heating done at MAGI. The experiments will employ a series of small monoenergetic gamma sources embedded in a clad fuel-pin-like rod. The rod will be placed in various regular arrays of similar rods, simulating core regions. Adjacent rods and coolant will be appropriately instrumented with thermoluminescent dosimeters to record the energy deposition. Experimental information thus obtained will be used to verify the accuracy of the results obtained through the Monte Carlo computations.

Pump Model Testing

The applicability of steady state pump performance curves under two-phase flow conditions to predict transient two-phase pump performance will be assessed by Babcock & Wilcox Company under RP598. Development of a two-phase homologous curve performance model based on air-water test results on a $\frac{1}{3}$-scale reactor coolant recirculating pump will be performed. This model will subsequently be included in an appropriate loss-of-coolant accident (LOCA) analysis code to determine realistic peak clad temperatures and pump overspeed under LOCA conditions.

Performance air-water tests with the $\frac{1}{3}$-scale reactor coolant recirculating model pump will be fully documented, including a detailed analysis of the test data. These air-water data, together with data taken in steam-water pump tests (RP301 and RP347), will help in assessing the influence of a noncondensable versus a condensable gas in the pump fluid.

Two-Phase Pump Performance Modeling

Analytic modeling of nuclear reactor coolant circulating pumps under two-phase flow conditions will be performed by Massachusetts Institute of Technology (MIT) under RP493. This analytic development work will interphase with experimental pump tests performed at Combustion Engineering, Inc., (RP301) and at Creare, Inc., (RP347). The test results from the latter programs will be used in the modeling work performed by MIT.

Initially, MIT will perform a state-of-the-art study and evaluation of current two-phase pump performance modeling. Based on existing data, MIT will attempt to further develop models for different assumed flow regimes. As test results become available from other projects, these results will be used to verify and/or improve the models, thus incorporating greater sophistication and detail. The pump models thus developed will cover pump performance in all four quadrants.

Analytic Evaluation of LWR Integral Tests

The performance of light water reactor (LWR) systems under hypothetical loss-of-coolant accident (LOCA) conditions is currently predicted through conservative LOCA analysis tools based on separate effects and system-effects tests of various kinds. The largest-scale integral tests for LWR performance under the loss-of-fluid test (LOFT) program and the performance of LOFT and its interpretation could have a definite impact on the utility and nuclear industry.

Intermountain Technologies, Inc., is the contractor for a project whose purpose is to provide expeditious and proper interpretation of experimental results from integral LWR safety and performance tests (RP496). Particular emphasis will be focused on closely following the LOFT program and determining its implications on LWR behavior under hypothetical accident and off-normal conditions. During the initial phase of the project, a computational model of the LOFT system will be developed, using publicly available system analysis codes. Selected sensitivity analyses will be performed with this model to assess the significant differences between the characteristics of LOFT and full-scale LWR systems. Pre-test predictions for selected LOFT experiments will be performed with this analytic model. When completed, post-test evaluations will be made and the model updated, if necessary. Similar comprehensive follow-up of other system-effects tests will also be undertaken.

Analysis of NRC Standard Problem #5

Standard Problem #5 in the Comparative Analysis of Standard Problems (CASP) program sponsored by the Nuclear Regulatory Commission (NRC) will be an analysis by Energy Incorporated (RP445) of a large-break blowdown experiment to be performed with the new semiscale MOD-1 system. This problem represents a new and significant analysis effort to provide insight into the capabilities of computer programs to predict the unique thermal-hydraulic phenomena. To date very little effort to analytically or experimentally examine accident behavior has been expended in the public sector.

The purpose of the standard problem activity is to provide a testing ground for the adequacy of reactor licensing codes. Participation by EPRI in the CASP program is of importance in order to follow and support the development, application, and evaluation of LOCA/ECCS computer codes. Standard Problem #5 is a large break in the semiscale MOD-1 test rig. The analysis of this test will complement the efforts under the loss-of-fluid test (LOFT) program. It is believed that this participation will enable the utility industry and EPRI to better interface with the semiscale and LOFT programs. The national program also envisions future tests at the semiscale facility to investigate alternative ECCS concepts for LWRs. EPRI modeling of the semiscale facility, initiated under this project, may then be used to closely follow these development efforts at the facility.

Separated Flow Model of Two-Phase Flow

Improving the basic understanding of two-phase fluid flow is the objective of experimental and analytic investigations by Dartmouth College (RP443). This two-year project is expected to provide a verified model that could be used to predict certain types of separated two-phase flows that are relevant to light water reactor performance and safety.

The experimental portion of the project will focus on a well-defined flow regime (e.g., bubbly, slug, annular, or mist) and such pertinent parameters as flow rates, bubble size, void fraction, and flow orientation with respect to the gravitational field. There may be a limited amount of measurement technique development to accurately determine the parameters needed to support the analysis. The analytic efforts will be based on the detailed multiphase constitutive equations to provide a validated "influence coefficient" model for the specific two-phase flow regime selected for study.

This work will further the development of techniques for predicting the performance of various engineering systems, such as water-cooled reactors. In particular, better estimates of loss-of-coolant accident (LOCA) consequences may eventually be possible by using codes that allow nonequilibrium or slip between the phases.

Previous attempts to develop such improved methods have been thwarted by a lack of understanding of the underlying phenomena and by insufficient experimental data input to the computational methods. Because the need to understand complex reactor system performance under hypothetical

accident conditions is well recognized nationally and internationally, this type of project is necessary for the advancement of two-phase flow studies.

Multifluid Flow Analyses Related to Reactor Safety

Jaycor, Inc., is the contractor on a project to further the development, application, and verification against data of a general two-dimensional transient multifluid flow code that properly accounts for interphase mass, momentum, and energy transfer effects in transient two-phase flows (RP599). The contractor will reexamine, document, and improve, as necessary, the physical formulation and numerical solution of the transient two-phase equations contained in the MUFF (Multifluid Flow) code. The code will then be applied to selected transient two-phase flow problems with special emphasis on applying it to test configurations on which data have been gathered.

A transient two-phase flow code that accounts for nonequilibrium phenomena (neglected in current codes such as COBRA and RELAP) is needed by the industry for the realistic evaluation of certain phenomena related to reactor safety. These phenomena include various aspects of reactor primary system and reactor containment performance during postulated accident conditions, such as steam-water interaction processes.

This project is expected to provide an assessment of generalized two-phase flow formulation and numerical solution techniques, an improved version of the MUFF code with selective verification, and identification of areas that will require further research.

Methodology for Plastic Fracture

The last decade has witnessed giant strides in the capabilities of applied mechanics to predict the behavior of flawed structures. The widespread use of linear elastic fracture mechanics —more recently of methods permitting a certain degree of plasticity, such as J-integral or crack opening displacement— has served well to describe the initiation behavior of flawed structures for near-elastic boundary conditions.

At operating temperatures, the steels used to fabricate nuclear pressure vessels will deform significantly prior to the unstable extension of defects. This fact has been demonstrated many times for both large and small test vessels in the NRC-sponsored Heavy Section Steel Technology program. Consequently, fracture mechanics predictive methods directly applicable to operating nuclear pressure vessels must be capable of accounting for plastic behavior. Because the application of current fracture methodology to fully plastic structures is questionable, a new methodology is required—a methodology that not only predicts accurately the behavior of flawed plastic structures but also leads to a more realistic perspective on design assumptions.

The General Electric Company and Battelle-Columbus Laboratories have been contracted to jointly conduct a creative three-year program focused on providing the greatly needed plastic fracture methodology (RP601). This program will embrace a comprehensive development of appropriate methodology needed to make sound engineering predictions of structural behavior, including fully plastic conditions. Under this project, the contractors will

- develop the theoretical methodology necessary to describe the fully plastic behavior of flawed structures;
- develop the capability of applying the methodology to the analysis of engineering structures;
- generate appropriate material properties to support and successfully apply the above analysis;
- design and conduct definitive engineering tests to benchmark the developed procedures and to ensure the applicability of such procedures;
- apply the developed methodology to two hypothetical accident conditions for nuclear reactor vessels.

The successful completion of this program will thus provide the needed fracture technology and the means with which to apply this technology to operating nuclear components.

Tornado Missile Risk Analysis

A contract with North Carolina Power & Light Company (RP616–1) concerns the development of risk methodology for the evaluation of the effects of tornado-propelled missiles on nuclear power plants. The scope of the work includes the development of a tornado missile risk analysis model and the evaluation of risks for typical nuclear power plants. Currently acceptable objective and subjective data bases will be incorporated in both the formulation and the application of the risk model development. The results of the work will include identification of various missile types, statistical distributions for such parameters as tornado intensity and missile velocity, and risk assessments for a typical plant layout.

Transmission and Distribution Division

John J. Dougherty, Director

The T&D Division's research program is focused on prudent application of capital, conservation of land, fuel savings (through reduced losses), and increased reliability. In brief, it offers technical options that are cost-effective and reliable.

In order to be cost-effective, all elements of the T&D research program are addressed as an integral, contiguous system. The vast network of T&D lines, transformers, switches, and protective equipment now extending from generating source to customer load are links in a chain valued at nearly $60 billion. Power supply to a customer, no matter how efficient the source, is affected by the weakest link in this chain. The T&D research program now underway is a balanced program, addressing the most critical needs throughout this complex chain. At the same time, all new and improved methods of transporting electric energy from source to consumer must be implemented at a reasonable cost to the consumer and with a minimal impact on the environment.

The T&D Division's program has been and will continue to be closely coordinated with programs of the Energy Research and Development Administration. This liaison is sufficiently established to accommodate continuous evaluation of funding schedules on a project basis.

All the objectives mentioned above are included in the division's five program areas: AC Overhead Transmission, DC Transmission, Underground Transmission, Distribution, and System Planning, Security, and Control. In addition, a small effort has been initiated in Rotating Electrical Machinery. The rationale for each major program is included in the overviews that follow. Future issues of the JOURNAL will discuss one or two program areas in greater detail.

AC OVERHEAD TRANSMISSION PROGRAM

This program is divided into overhead line research and substation research, to help classify emerging technologies according to need.

Overhead Line Research

Because a transmission line is essentially a "product" designed by a utility engineer, research programs must not only provide new and improved components (insulators, conductors, and towers) but must also provide specific design data. These data help determine conductor selection, insulation coordination, right-of-way requirements, and safety and mechanical parameters. Research on environmental effects is an integral part of the programs. Research on construction methods and technology completes the scope of work.

In the months to come, the JOURNAL will present details of Project UHV, insulator research, electric and magnetic fields, and mechanical design research. These programs are expanding to provide for utility needs.

One line research project underway is RP260, a study being conducted to improve right-of-way utilization by Power Technologies, Inc., of Schenectady, New York. The major objective is to demonstrate the practicality of reduced spacing for 138-kv transmission lines. Testing has been conducted at the Saratoga test site on a line operating at 138 kv with 3-foot phase spacing.

Conductor motions caused by ice, fault currents, and wind action are being investigated, along with such factors as radio and TV influence. It is hoped that the results of these studies will demonstrate the practicality of these reduced spacings for transmission lines.

The experimental phase of the project has been essentially completed. Remaining work includes the correlation of empirical data with analytic results. PTI reports that conductor motion from ice dropping causes only vertical movement and thus does not increase the probability of line flashover. Wind motion studies verify that transmission line conductors behave in a manner similar to distribution line conductors, where no differential motion occurs and where no wake-induced oscillations are excited. No radio noise problems occur, but careful attention must be given to hardware problems.

The final results of this project will be presented in a design manual containing the engineering information necessary to design and construct 138-kv lines with reduced spacing.

Substation Research

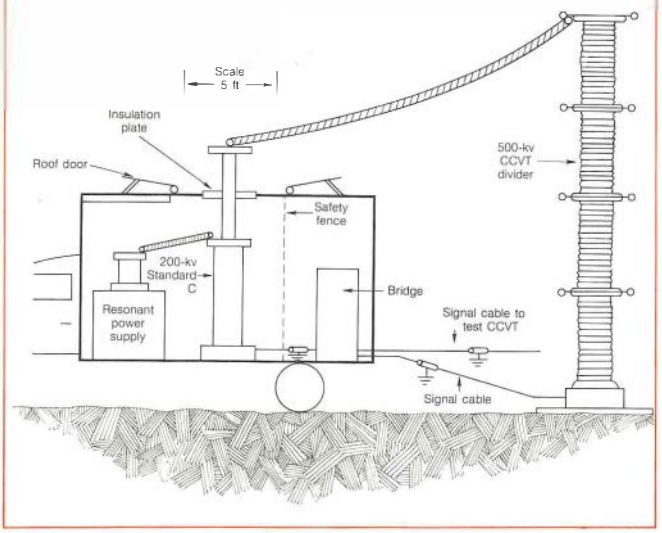
Research in this area is concentrated on equipment development to provide the increased ratings required, improve

reliability, reduce sizes and costs, and increase efficiencies. Early research has been concentrated on switchgear, especially fault current limiters, as the need in this area appears imminent. As the program develops, projects are being added to make possible greater utilization and increased efficiency of power transformers. New and improved surge arresters should provide added protection for, and thus reduce the cost of all large power equipment. Other areas to be addressed include VAR supply, substation insulation, and gas-insulated substations. Subsequent JOURNAL articles will review these programs in detail.

One of the earliest substation projects to be funded was RP134, which is now nearing completion. The goal of this project is to develop a low-cost portable calibration system for on-site verification of the voltage ratio and phase angle in CCVTs used for metering on EHV and UHV systems. After researching utility needs and available test methods, the contractor developed a system that uses a modular CCVT divider, a resonant power supply, and a current comparator bridge, all mounted on a truck bed (Figure 1). Its performance has been verified in tests of a full-wound 500-kv potential transformer at a manufacturer's facility. The completed prototype is being field-tested at a 500-kv substation of the Baltimore Gas and Electric Company.

This project was carried out under the guidance of a steering committee appointed by the EEI Meter and Service Committee. Mr. R. M. Reesey of Pennsylvania Electric Company has been the chairman of the steering committee for three years. The project will be completed during the first half of 1976.

Figure 1 Prototype mobile unit for field calibration of EHV metering coupling capacitor potential transformers.



DC TRANSMISSION PROGRAM

A multifaceted R&D program is conducted in the dc transmission field for maximum exploitation of the technology leading to cost-effective, compact, reliable dc transmission systems. The largest ongoing project is the 100-Mw compact HVDC terminals built by General Electric for Consolidated Edison of New York. A tremendous reduction of the real estate needed for dc terminals is made possible through the use of gas-insulated buses and valves. Other projects will develop light-triggered thyristors for simpler converter valves, determine dc circuit breaker duties through comprehensive system studies, develop a metallic return transfer breaker for bipolar dc systems, determine dc line design parameters, and develop electronic current transducers for measurement of direct current at high potential. Two projects nearing completion are described briefly below.

HVDC Transmission (±600 kv)

RP104, managed by N. G. Hingorani of EPRI, was started in 1974. Jointly funded by EPRI and Bonneville Power Administration (BPA), work has now been completed on the design studies of ±600-kv dc transmission lines. The investigation was carried out at The Dalles Test Facility, with Harold Hill of BPA as the project manager. The final report, in the form of a design reference book, is expected to be completed by April 1976. The study covers all aspects of electrical design, including corona, RI, audible noise, insulation requirements, insulator flashover studies, current flow, and charge voltage on bodies near the ground.

The project has demonstrated dc barehand maintenance. Where state and local safety regulations permit, this method is widely used on ac transmission lines. The feasibility of the barehand method for dc had been previously demonstrated by the LADW&P and A. B. Chance Company on the ±400-kv Pacific Northwest–Southwest Intertie. The latest exercise at BPA takes this demonstration to ±600 kv.

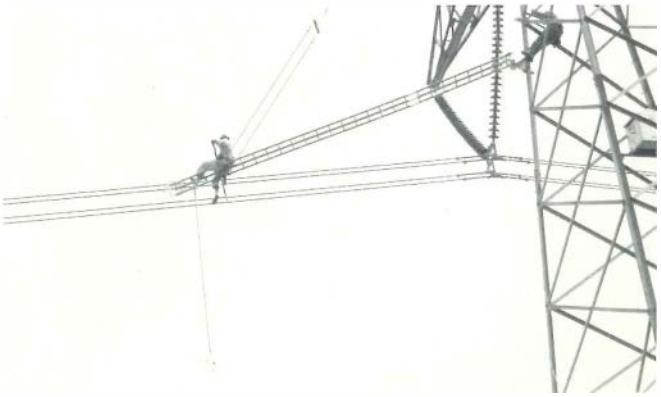


Figure 2 Workmen performing barehand maintenance on a ±600-kv transmission line. The man on the tower is monitoring the leakage current on the access ladder.

Access to line by the workmen is accomplished via insulated ladders. Shielding of the workmen from electric field effects is provided by conductive clothing—gloves and socks that contain a fine mesh of conductive threads.

DC Circuit Breaker Specification

RP326, managed by S. L. Nilsson of EPRI, will define the duty of dc circuit breakers for HVDC applications. The availability of circuit breakers will make multiterminal dc system operation feasible. System studies conducted by the Hydro-Quebec Institute of Research will provide specifications of breaker duties for different system configurations. The project will give the system requirements for application of dc breakers of current design as well as "ideal" breakers. The applications under study include breakers with diode rectifiers in parallel line operation, in tapped systems, and in other multiterminal radial or circular dc networks. A less demanding application would be the use of a breaker for load transfer, which would change a bipolar system operating with ground return to one operating with metallic return, or vice versa.

The study uses the IREQ simulators for the dc systems with associated ac generators and networks. Models of conceptual dc breakers will be integrated into the simulator for verification of postulated duties. The first phase of the study has centered around the use of dc breakers in conjunction with diode rectifiers directly connected to large generator facilities. The duty of a metallic return transfer breaker is also given high priority in the study because it has the potential for immediate use.

The preliminary system studies for these applications are completed. The simulator is now equipped with a specific breaker model for continuation of the studies. Other breaker models are being built for use later in the program. Completion of the study is scheduled for 1976.

UNDERGROUND TRANSMISSION PROGRAM

The Underground Transmission Program has been developed to investigate the economic payoffs that may be obtained by the development of new systems. The program's primary objective is to reduce the per-unit cost of transmitting electric energy underground. The program has been formulated with the theme of achieving a balance between improvement of the state of the art for near-term application and the development of new, and what many consider exotic, systems for the long term.

The program will have a changing emphasis with time. Presently, considerable effort is directed to improvement of existing paper-oil cable systems and development of advanced concepts, such as gas-insulated and cryogenic cables. Extruded solid dielectric cables under development are expected to find economic application at lower transmission voltages and modest power levels. But universal acceptance of such advanced concepts as solid dielectric cables will not occur until we have a better understanding of electrical breakdown in the insulation, or "treeing."

Treeing

The electrical breakdown of the polymeric insulants commonly used in power cable has been a subject of study for many years. Although the governing mechanisms are not fully understood, there is evidence that the final disruption of some insulants is preceded by an induction period, during which microscopic globules or tubular fissures are formed in the insulation. These tubules form treelike patterns of branches emanating from a trunk.

In the view of many researchers, trees can be broadly classified as electrical or electrochemical. Electrical trees are generally characterized by ionization that occurs in the gas-filled tubules; their propagation times are measurable in minutes or hours. Electrochemical trees, in general, occur only in the presence of moisture, either with or without dissolved salts. They consist of water-filled microscopic fissures or stringlike agglomerates of globules. These trees do not normally involve ionization and are characterized by very long propagation times, typically months or years at power frequencies.

Although the inception and growth mechanisms of trees are not fully known, there is strong experimental evidence to indicate that they are more likely to occur in regions of high electrical stress. In power cable insulation such regions might occur at certain voids, contaminants, or protrusions from the shields.

EPRI has contracted with General Electric to develop experimental techniques for the initiation and observation of electrical tree growth and additives that would inhibit tree inception. The additives are to be soluble in polyethylene or other high-voltage cable insulants and should exhibit increasing degrees of dissociation with increasing voltage gradients. The high-voltage stress that would normally exist in the vicinity of a stress enhancer would then promote sufficient ionic conduction to maintain the stress in this region at a lower level, and thus decrease the probability of tree inception.

The experimental setup for tree initiation and growth observation uses a point-to-plane electrode arrangement. The point is a needle with a controlled-tip radius molded into the polymer and faces an electrode applied to a plane surface on the sample. The sample is made sufficiently thin in the direction of observation to render it essentially transparent, thus permitting microscopic observation of trees initiated at the needle tip.

Several additives have been developed that suppress tree growth to a high degree at very low frequencies (< 0.1 Hz) and to a more limited degree at power frequencies. At 60 Hz

some polyethylene samples containing these additives demonstrate inhibited tree inception. In other cases the rate of the growth decreased. However, there was little or no increase in breakdown voltage.

Toward the end of this program, some limited testing was performed on a new additive, ferrocene, with very encouraging results. This material completely suppressed tree inception and doubled the breakdown voltage. The action of this material is not yet understood; it appears that the material does not dissociate into ions in accordance with the model developed.

The experimental portion of this project has been completed, and a final report will be issued early in 1976. A contract is presently being negotiated to investigate ferrocene additives and to establish, through model cable tests, their suitability for use in high-voltage extruded dielectric cables.

Gas-Insulated Transmission Systems

Another project has been undertaken to translate the known data on gas-insulated transmission systems into a composite unified design for various applications. A completed design guide (EPRI 7825) is now available, as well as a final report under the same number. The design guide provides a basis for selecting and specifying gas-insulated systems, including approximate costs of standard designs.

The most economical gas-cable system will not always have the lowest initial cost. The cost of power losses must be considered. Even if the cost of power losses is low, a system with high losses may require wider phase spacing (larger trenches) and special backfills for heat dissipation. These installation costs may offset any lower material costs. To facilitate a proper systems approach, considering all these variables and their interdependencies, a computer program to optimize the choice has been formulated.

When considering the economics of one transmission system versus another, the three basic parameters involved are capacity (Mva), voltage (kv), and length (miles). At voltages ranging from 138–500 kv, rated 500 Mva and above, but no longer than 500 ft (urban or suburban sites), compressed-gas cables appear the most economical. Other combinations of the above parameters may work out to be equally cost-effective, of course, but selective trade-offs would have to be made. The design guide is organized to give the utility systems designer an opportunity to make this kind of evaluation, considering the parameters cited and other factors.

Superconducting Transmission

A central cryogenic research facility might be valuable to the development of all kinds of cryogenic power systems, especially superconducting transmission lines. It would avoid duplication of resources. With the present national approach to superconducting transmission line research, there are a handful of programs, the cost of which is escalating rapidly. Refrigerator capital costs of $1.0 to $1.5 million per project are prohibitively high.

A central facility would permit additional laboratories to compete and could thereby accelerate development of the technology. Some of the associated benefits would be the establishment of a common testing standard and an opportunity to test Soviet and other foreign exchange cables.

Two small research projects on the economic feasibility of such a facility have been completed by the National Bureau of Standards and the Linde Division of Union Carbide. These laboratories independently reached the same conclusion: such a refrigeration unit would be technically and economically feasible, saving considerable investment capital and operating costs. The NBS study concluded, for example, that a single versatile, high-capacity refrigerator capable of handling seven superconducting cables would cost $704,000 in 1973 dollars. Seven separate refrigerators would require roughly seven times the land area, foundations, and operating equipment.

The input power requirements are equally divergent. Separate facilities would require at least 1315 kw of input power to operate, while a single facility would require only 904 kw to simultaneously cool all seven cables. The results of the Linde study are similar.

Impressive as these findings are, no action is anticipated until the results of cryogenic research and interest in development potential provide sufficient incentive to construct such a facility. Detailed results of these two studies are available in two final reports, EPRI 282 and EPRI 7839.

DISTRIBUTION PROGRAM

Because of never-ending expansion of distribution systems in size and complexity and the steady increase in distribution feeder voltages, it is extremely important that these systems be as dependable and economical as possible.

The major objectives of EPRI's Distribution Program are to

- develop new system concepts that will efficiently match future capacity requirements to loads;
- develop systems and equipment that will reflect a reduced cost per unit of load served;
- design new system components that are environmentally and esthetically acceptable;
- develop systems with improved reliability at no increase in cost; and
- build improved safety into distribution systems of the future.

To achieve these objectives in the most efficient and timely manner, the Distribution Program will approach problems and their solutions from an overall system requirements concept,

rather than through piecemeal hardware development. The following examples will illustrate our efforts to reduce overall industry R&D costs and to avoid redundancies. The means are sophisticated planning techniques, automation of functions, and development of improved hardware.

- An analysis of distribution planning has documented existing practices and techniques in system planning, data file utilization, and system surveillance and control. The final report (EPRI 329) includes a series of research statements that outline a coordinated program of research in these areas.
- Automation offers great potential for solving many expanded distribution problems, particularly reduced system reliability, time-of-day metering, and increased operating complexity. Initial investigation will demonstrate communication system design parameters, such as speed of transmission versus accuracy, communication methods, and hybrid systems.
- Research on catastrophic distribution transformer failures is focused on fuse characteristics and pressure relief as functions of tank parameters and fault duration. The results may be used by the industry to prepare guides for re-fusing practice and for specifying pressure relief requirements on new and existing transformers.
- It appears that naphthenic-based crude insulating oils will become acutely short in about five years. Oils refined from paraffinic crudes have various disadvantages, including poor viscosity at low temperatures, low resistance to oxidation, and a tendency to form wax deposits on electrical contacts. Extensive research is underway for the development or modification of oils to ensure a continuing supply of suitable insulating media.
- Expensive tree trimming along distribution lines and transmission rights-of-way have plagued utilities for many years. Environmental factors today also call for research in chemicals and methods to control tree growth. Several EPRI projects address these problems.
- Progress has been made toward development of economical power poles manufactured from foamed glass, with fly ash as a filler; tests show that at high density, foamed-glass poles would meet wood standards for power poles.

Present distribution research also includes other projects in fault and transient management, cable loading and insulation, corrosion problems, lightning instrumentation and demonstration testing of various new concepts and systems. In addition, over fifty projects have been identified for research in various distribution subprogram areas. These will be investigated over the next four-year period.

SYSTEM PLANNING, SECURITY, AND CONTROL PROGRAM

Transient Stability Studies

In transient stability studies, a detailed mathematical model of the power system is often required in order to achieve the acceptable simulation accuracy. Because of size and complexity, these stability simulations often require large amounts of computer storage and running time. Since a large number of transient stability cases are run routinely in system planning, there is naturally great interest in finding methods to improve the efficiency of such studies. A procedure familiar to many power system engineers is to classify generators remote from the study area into coherent groups, each represented by an equivalent generator. The manual procedure used for this classification is time-consuming, and the end results are not entirely satisfactory.

A study being conducted by Systems Control, Inc., (RP904), has resulted in a computerized procedure to perform the classification and reduction. It requires as input the computed swing curves of transient stability cases. Based on the swing curves and a set of specifications (usually coherency selection criteria provided by the user) the program will automatically (1) recognize the groups of coherent generators; (2) replace the coherent generators by their dynamic equivalent; (3) reduce the network by a Ward-Hale Reduction technique; (4) print out the parameters of the reduced equivalent power system in a format compatible with the input format of transient stability programs for direct implementation.

The prototype computer program has been tested on two sample systems: 732 buses and 295 generators, and 39 buses and 10 generators, respectively. The 732-bus system has a simple generator representation, whereas the 39-bus system has detailed generator and excitation system representation. In each case, a tenfold reduction of the external system was accommodated without sacrificing the required simulation accuracy.

The RP904 project has been highly successful, and an extension has been granted to refine the techniques developed. One major drawback of the existing method is that it requires a full transient stability run as input to the Coherency-Based Reduction Program, which is expensive and impractical for many applications. The primary goal for the follow-on effort is to develop an analytic procedure using a frequency spectrum analysis to classify coherent generators. The need for running a full transient stability case is thus eliminated. The results so far are encouraging, and the final reports are expected to be issued in February 1977.

Long-Term Power System Dynamics

Following a major disturbance, a power system may experience large excursions in frequency and voltage. Heavy overloads may be imposed on transmission lines as well. These stresses on the system may last for several seconds or minutes, and in some cases, may result in a cascading failure of the system. During this period of high stress the system may separate into islands, and some loss of customer load may be experienced.

Conventional transient stability programs are designed to provide accurate system simulation up to only several seconds after a disturbance. Furthermore, program structure and component models are not suitable for analyzing the longer-term response of the power system. The goal of RP907, being conducted by General Electric Company, is to provide the necessary analytic tools to permit the study of long-term power system dynamics for periods of up to 20 minutes following a major disturbance.

The project's first task was to define the problem by conducting a survey of major disturbances related to long-term dynamics. Eighteen major disturbances, most of which occurred in the United States over the past nine years, were selected for the study. Principal findings of the survey are:

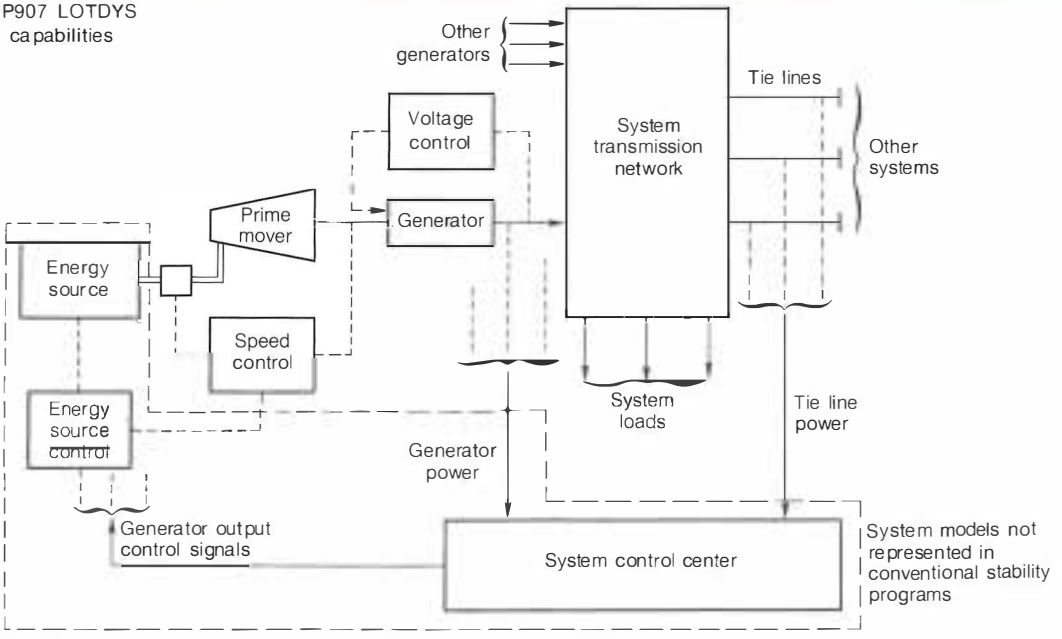
- The widespread practice of underfrequency load shedding is beneficial in limiting the ultimate consequences of a major disturbance.
- Disturbances that are initiated by the malfunction of protective equipment or human error are often more devastating than those of natural origin.
- Complex control schemes could be prone to initiating widespread failures because protection against the failures of these schemes is difficult.
- It is nearly impossible to predict in advance all the events that could trigger a disturbance.

The project's second major task was to develop a digital computer program suitable for simulating long-term dynamics. A prototype computer program for long-term dynamic simulation (LOTDYS) was written. In the program, inter-machine oscillations are ignored in the simulation because that aspect can be studied with conventional transient stability programs. The LOTDYS program represents a detailed model of the prime movers, including the steam generation process, boiler controls, and the characteristics of power plant auxiliary systems at off-nominal voltages and frequencies. It also includes a model of the automatic generation control.

The LOTDYS program was tested on a 68-bus, 16-generator sample system. The results indicated that the program is valuable in providing information about the interaction of power system components during critical periods that may lead to long-term instability. A preliminary study was conducted to evaluate the merits of several control strategies for mitigating the effects of disturbances. The LOTDYS program is a potentially valuable tool for analyzing the impact of these control strategies.

A one-year extension of RP907 has been undertaken to expand the size of the LOTDYS program to 500 lines, 300 buses, and 100 generators, and to implement other important prime mover models, particularly the boiling water reactor. The next step will be to test the program in an actual utility environment to obtain feedback and guidance to redefine the objectives of long-term dynamics research.

Figure 3 Diagram of RP907 LOTDYS program structures and capabilities



Energy Systems, Environment, and Conservation Division

René H. Malès, Director

ENVIRONMENTAL ASSESSMENT DEPARTMENT

During the short period since publication of the division's *Research Progress Report ES-2,* work on three projects has progressed to a point where summary review may be helpful. In months to come, current activities of the department will be discussed according to subprogram organization. Such an approach will enable individual projects to be related in terms of their shared purposes and goals.

SO_2 Reactions on Fly Ash

The kinetics of reactions occurring on solid surfaces are difficult to study, yet they may have a strong influence on the overall chemistry of power plant emissions. Research now nearing completion at the State University of New York (Albany) and at Rensselaer Polytechnic Institute has been designed to shed light on this phenomenon. A molecular beam reaction system is being used to study what happens when SO_2 and oxygen impinge on such surfaces as fly ash particles.

Fly ash itself is a complex mixture whose exact properties depend on fuel characteristics and combustion conditions. Particles from oil-fired boilers, for example, are often porous or irregular in shape, providing a large surface area for reaction (Figure 1). Coal fly ash can be distinctly different (Figure 2). X-ray dispersive chemical analysis indicates the presence of elements, such as copper, iron, vanadium, and manganese, which are capable of acting as catalysts for SO_2 reactions.

Using the molecular beam system, the probability of single-collision reactions of SO_2 molecules on a particle surface can be determined. Understanding this basic reaction parameter will lead to a better assessment of the importance of such reactions and may influence the design of systems for emission control.

Design of a Sulfate Regional Experiment

The impact of gas and particulate emissions from power plants on regional air quality must be assessed because of the apparent correlation of these pollutants with observed health and ecological effects. Also at issue are "second-generation" pollutants, such as sulfates, nitrates, and acid precipitation. To better understand the transport and conversion of such agents under various meteorological conditions, EPRI is planning a major regional air quality monitoring program in the eastern states.

To provide supporting information for this effort, the experimental design contractor, Environmental Research & Technology, Inc., has prepared and examined a new annual set of simultaneous SO_2 and water-soluble sulfate air quality data collected in the Ohio Valley during 1974 and 1975. To minimize the influence of local SO_2 sources, samples were selected from utility monitoring stations upwind of power plants in rural areas. Comparison of upwind and downwind data at two sites confirmed that local interferences were not significantly biasing the results. These data have been analyzed in terms of other aerometric variables, including weather, humidity, and temperature. Results have been compared with recent data from U.S. government archives. Several tentative conclusions emerge.

- 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 annual sulfate levels are observed in the region of West Virginia and western Pennsylvania.
- A systematic correlation is observed between high sulfate levels and the temperature, the atmospheric water vapor content, and the tropical airflow.
- The highest intensity of sulfate appears to be confined to regions less than a few hundred kilometers downwind from isolated sources of SO_2.

These conclusions suggest that the high sulfate levels experienced in the northeast result from many large SO_2 sources being in the path of warm air masses, as well as from slow atmospheric oxidation processes.

We are preparing a request for proposals to implement the regional monitoring network. Funding authorization will be sought in the spring of 1976.

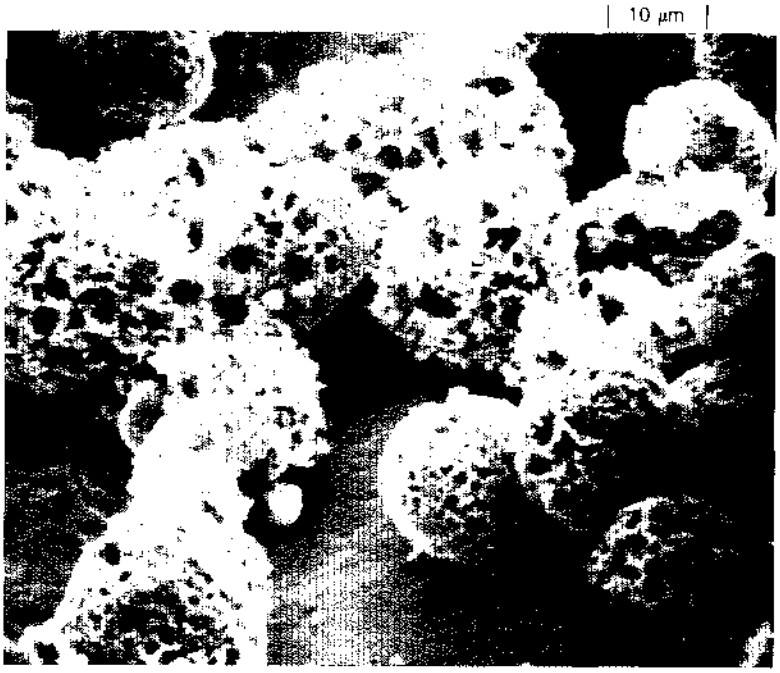
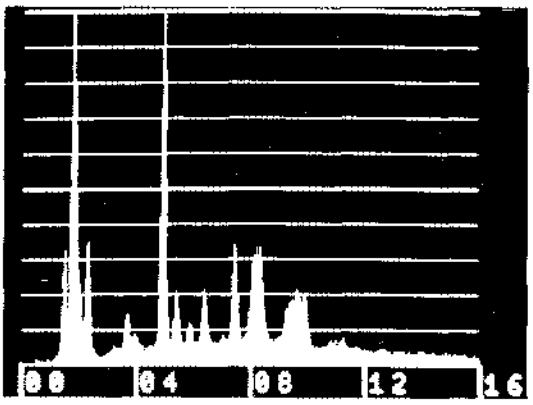
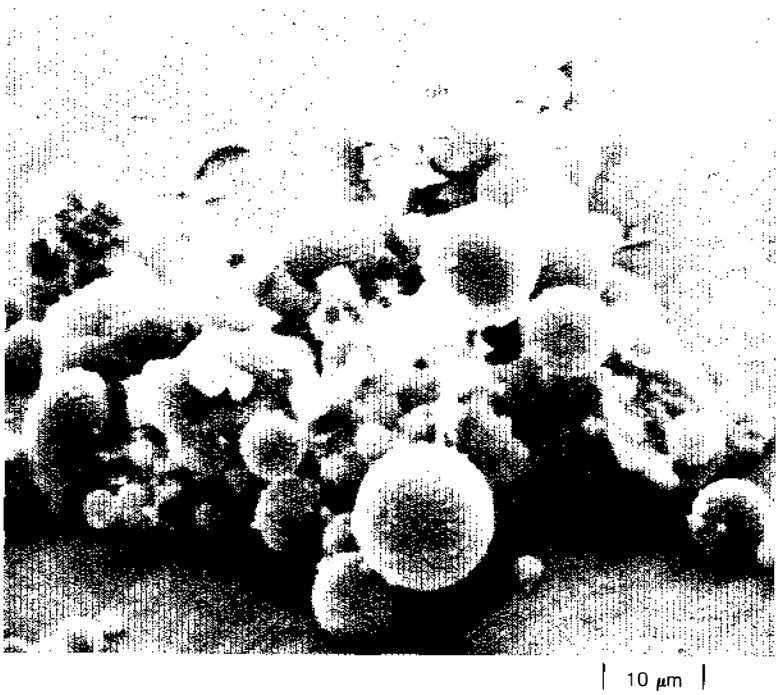


Figure 1 Spongelike fly ash particles from an oil-fired power plant are revealed by scanning electron micrograph. Fuel trace elements on the particles are characterized by X-ray analyzer spectrum. Major elements: Si, S, Cu, V, and Fe. Minor elements: Mg, Al, P, Ti, Cr, Mn, and Ni.





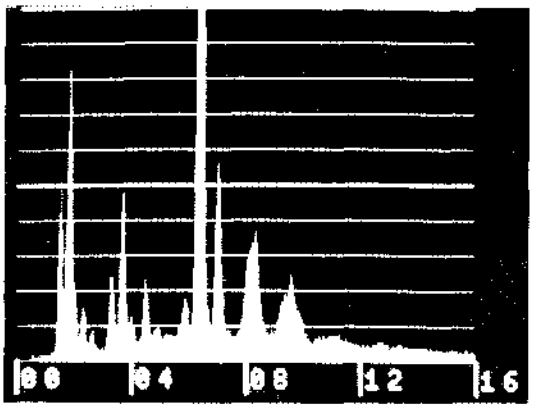


Figure 2 Smoother fly ash particles from a coal-fired plant exhibit a different profile in the X-ray analyzer spectrum. Major elements: Si, S, K, Ca, Ti, and Fe. Minor elements: Al, P, Cl, Mn, and Cu.

Ecology of Transmission Corridors

By comparing transmission rights-of-way of varying ages within comparable life zones of the semiarid southwest, new research will reveal how siting, construction, and maintenance of transmission facilities affect plant communities. Four life zones will be studied: Lower Sonoran, characterized by mesquite and creosote bush; Upper Sonoran, characterized by piñon-juniper woodland and blue grama grassland; a transition zone of ponderosa pine; and Canadian, characterized by spruce-fir forest. Results of this study should be applicable to areas of New Mexico, Texas, Colorado, Utah, Nevada, and Arizona.

Semiarid plant communities are fragile systems, highly susceptible to disturbances and generally believed slow to recover. Documenting recovery times will make it possible for utilities to develop transmission corridor siting and management practices that are cost-effective and have minimum adverse environmental impact.

This project is part of a program developed by the Environmental Assessment Department to study ecological effects along transmission corridors throughout the U.S. Corridors in forest ecosystems are being studied in California, Georgia, Louisiana, Minnesota, New Hampshire, New Jersey, Oregon, Virginia, and West Virginia (Figure 3).

ENERGY DEMAND AND CONSERVATION PROGRAM

EPRI Board actions last fall strengthened this program in two particular respects: new projects were authorized that extend the scope of forecasting capability, and proposal requests were approved for two analytic efforts related to transportation. These and other program activities—including publication of several important research reports—are summarized by energy demand sector in the following brief reviews.

Residential Sector

Several key phase reports are now available from a study of fuel utilization in residential heating (RP137) conducted by Ohio State University. Report 1, *A Study of Attic Temperatures and Heat Loss in Residential Homes,* presents the results of modeling energy and mass flows in the attic spaces of residential structures. Report 2, *Thermal Response and Model of Heating and Cooling Equipment for Residential Homes*, presents a mathematical model that can simulate the thermal load and energy consumption component of a two-story house. A third report, *Heat Transfer Models and Energy Needs for Residential Homes*, describes results of the development and field validation of algorithms to simulate heating and cooling loads and energy requirements for a split-level and a ranch-style test house.

Figure 3 This transmission corridor in New Jersey has been selectively sprayed with herbicides to prevent reestablishment of large trees. Shrub communities dominate the corridor, many of them flowering colorfully during the spring or summer.

Instrumentation is now in place for measuring heating and other energy use, indoor temperatures, and weather variables for both the Ohio State project and a related project by Westinghouse Electric Corporation. The latter (RP432) is a study of load and use characteristics of electric heat pumps in single-family dwellings. Data are now being transmitted and processed from about 48 houses in six utility service areas for the Ohio State study and from 120 houses in ten service areas for the Westinghouse work.

Commercial Sector

Data Resources, Inc., has begun work on forecasting energy usage in the commercial sector (RP662). The objective is to develop a conceptual framework and data base for forecasting commercial energy demand on both an industrial subsector and a regional or state basis. If the necessary data can be developed, dynamic demand models of both a "state adjustment" and a "capital utilization" type will be estimated. The former requires information on usage, energy prices, and the level of economic activity. The latter requires these data plus data on the floor space and the stock of energy-using equipment in each commercial activity.

Transportation Sector

Although there have been several efforts to develop forecasting models of gasoline use, there has been very little research on the demands for other energy forms derived from transportation modes. This must be remedied if we are to develop a comprehensive view of fuel supplies to be needed by electric utilities.

Proposals have therefore been requested for a study entitled "Analysis and Forecasts of Energy Used for Transportation Services," which will lead to a forecasting model covering all sources and uses. A second request is entitled "The Implications of Electric Automobiles for Utility System Loads." This project will develop forecasts of the size of the electric automobile fleet under alternative assumptions concerning economic growth, the characteristics of electric and of competing cars, energy prices, and other factors.

Manufacturing Sector

Waverman Economic Associates is beginning a two-phase project (RP683) for development of a conceptual model that will take account of adjustment time lags and endogenous technological change in the manufacturing sector. (Technological change is used here to mean the achievement of a given level of output with a reduced input of one or more factors of production.) The second phase of the project will focus on the estimation of demand functions for capital, labor, materials, and each source of energy in physical units. The last task will be the performance of tests to indicate whether this approach will yield improved forecasting results when compared to other techniques.

Agricultural Sector

As part of the objective to obtain coverage of fuel usage in all sectors, a project has been initiated to develop models for forecasting agricultural energy consumption. Dr. Laurits Christensen and Data Resources, Inc. (RP682) will develop models and forecasts of interrelationships among the following factors of production: electricity, petroleum products, fertilizer, machinery, structures, other purchased inputs, and labor. An important initial step will be to compile and rework published and unpublished data relevant to the construction of agricultural energy demand models.

Cross-Sectoral Studies

Applied Nucleonics Company, Inc., has completed a project (RP211) to produce a reference handbook summarizing existing technology for more efficient energy use. The text is organized by end-user (industrial, residential, commercial, and agricultural), by equipment and process (heating, lighting, mechanical processes, electrolytic and electronic processes), and from a systems point of view. While all energy forms are considered, the primary focus is on electrical energy. The handbook, published by Pergamon Press in February and being distributed internationally, is entitled *Efficient Electricity Use*.

The State of the Art of Electricity Consumption Models, Part I of an assessment of energy modeling by Charles River Associates (RP333), is now in draft form. This project reviews the conceptual bases of a number of econometric models intended for state or national electricity forecasting in various sectors. It also performs tests to determine the stability of estimated parameters over time and to assess the models' forecasting performance.

A third cross-sectoral report, also in draft form, is *Electric Energy Usage and Regional Economic Development: A Pilot Study,* by the School of Management of the State University of New York at Buffalo (RP334). This project investigated previously untried approaches for integrating electricity consumption forecasting into a macroeconomic model of regional growth. Its objective is to show whether these are feasible for large-scale regional energy forecasting.

Future Research

With initiation of the transportation sector projects, active work in this division will cover all sectors and all energy forms. Future research will aim at integrating these results into a unified picture of energy-usage behavior, particularly—through in-house work—in forecasts of energy consumption. The staff also seeks to increase the depth and extend the results of initial efforts. A new concern is the forecasting of seasonal and time-of-day load curves. A workshop on relevant methodologies was held in December, and its proceedings will be published shortly.

At the Institute

EPRI BOARD APPROVES $21 MILLION IN NEW ENERGY RESEARCH

Approval of $21 million in new electric energy research for 73 new projects and expansion of 17 existing projects highlighted the November 5 EPRI Board of Directors meeting in Palo Alto.

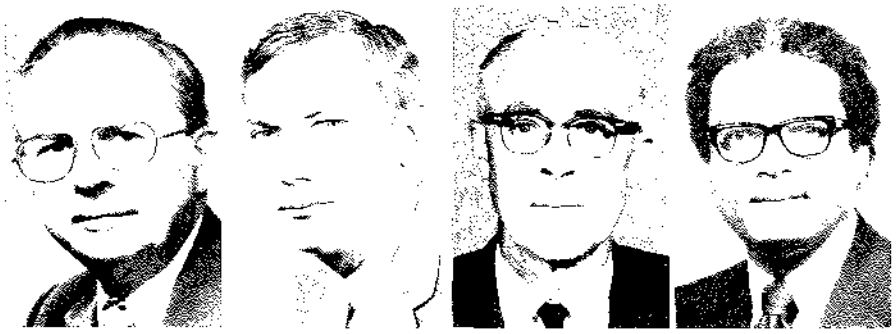
Significant expenditures were authorized to improve processes for producing clean coal and for converting coal into clean-burning fuels.

Other actions included the election of Thomas G. Ayers, chairman and president of Commonwealth Edison Company, Chicago, to the EPRI Board of Directors and approval of EPRI's 1976 program plan, which calls for research expenditures of $129 million.

A test program on nuclear fuel behavior in power reactors is included in the approved projects. The ultimate goal of this and related nuclear programs is to establish a more comprehensive data base on the behavior of nuclear fuels under various duty cycles.

Additional funds were authorized for more extensive measurement of factors that contribute to corrosion damage in steam generators. Remedies for corrosion damage will decrease outage time in power plants and result in more reliable electric service.

Another key study will compile a data base on the resources, availability, and quality of our country's water supplies. This information is necessary in planning the technology for synthetic fuel production and power plant cooling.



Ayers Bell Johnson Mitchell

Additional studies will forecast fuel and energy prices for 1985 to 2000, the implications of electric automobiles for the electric power industry, and transportation energy use in relation to electricity supply and demand.

Also authorized were funds to develop advanced equipment and computer techniques to increase the reliability, capacity, and efficiency of the nation's 500,000 miles of high-voltage electric lines. Major transmission and distribution projects will involve the design and testing of instruments to detect hot spots and thus predict the breakdown of insulating materials in transformers.

The Board also appointed three new members to the EPRI Research Advisory Committee: Robert A. Bell, director of research and development, Consolidated Edison Company of New York, Inc.; William R. Johnson, chief electric generation and transmission engineer, Pacific Gas and Electric Company; and Claybourne Mitchell, Jr., director of engineering research, Detroit Edison Company.

The total value of the 620 research projects now under management or in contract negotiation, including joint funding, is $415 million. EPRI's share of this amounts to $305 million.

EPRI Continues Participation in Norway's Halden Project

EPRI recently signed an agreement calling for a three-year continuation of its support of the Halden Reactor Project in Norway.

Under the administration of the Norwegian Institute of Atomic Energy, the Halden Project has operated for fifteen years as an international cooperative experimental facility to conduct studies on the improvement of performance and reliability of water-cooled nuclear reactors.

For the next three years, the total budget of the project is approximately $13 million. EPRI's contribution during this time will be about $900,000.

Project participants include national research organizations from Denmark,

Finland, the Federal Republic of Germany, Italy, Japan, the Netherlands, Norway, and Sweden, as well as other U.S. organizations.

EPRI was first accepted for full participation in the project on January 1, 1974. The Institute's membership in the project (1) provides the U.S. electric utility industry with an up-to-date fuel performance data base independent of fuel suppliers; (2) gives EPRI an opportunity to help formulate, to receive, and to review the results of a technical program to improve water-cooled reactor performance; (3) provides an opportunity and a facility for in-service training of EPRI staff and utility fuel engineers; and (4) gives the U.S. utility industry a voice in an extremely important project.

Jan Erik Lunde (left), of the Norwegian Institute of Atomic Energy and manager of the Halden Project, and James A. Lande, manager of EPRI's Contract Department, review some details of the new three-year agreement.

German R&D Delegation Visits EPRI

EPRI President Chauncey Starr (right) greets Minister Hans Matthofer, Federal Ministry for Research and Technology, Federal Republic of Germany, at EPRI's Palo Alto headquarters October 11. FRG Consul General Lothar Schuenke (far left) and George Hill, director of EPRI's Fossil Fuel Department, look on. The German delegation, which included the Ministry's energy technology research and development program manager, received a briefing from Starr and other senior EPRI officials on the objectives and programs of the Institute.

Advisory Council Establishes New Committees

At its November 24–25 meeting at EPRI headquarters, the EPRI Advisory Council organized four standing committees to examine topical areas that could influence the Institute's research plans: national issues, environment and ecology, power sources and utilization, and communications.

The national issues committee, chaired by Congressman Joseph L. Fisher, will be concerned with those affairs outside the energy matrix that could affect EPRI program plans.

Merril Eisenbud, director of the Laboratory for Environmental Studies of the New York University Medical Center, and Elvis J. Stahr, Jr., president of the National Audubon Society, are cochairmen of the committee on environment and ecology.

Bruce Netschert, vice president, National Economic Research Associates, Inc., was named chairman of the committee on power sources and utilization.

The fourth committee will direct its attention to EPRI's role and responsibility in communicating with the public, government, and industry. This group is being chaired by Ralph Lapp of Quadri Sciences, Inc.

The Council, composed of prominent leaders from government, labor, education, science, and business, helps to provide an effective liaison between the public served by the electric utilities and the EPRI Board of Directors and staff.

The Council meets quarterly to discuss public attitudes and needs as well as to make recommendations on EPRI's program direction. The next meeting of the Council is scheduled for February 6 in Washington, D.C.

Scrubber Wastes Subject of EPRI Meeting

How to minimize the environmental impact of scrubber wastes was discussed by Institute technical staff and electric utility managers during an October 28 meeting at EPRI.

Because different types of coal produce different types of waste problems, there are numerous disposal methods. Scrubber waste (sludge) is a mixture of calcium sulfate/sulfite, fly ash, and water left

over from flue gas cleaning processes.

U.S. power plants will produce a tremendous amount of sludge. According to Lawrence Nannen, SO_2 project manager in EPRI's Environmental Control and Combustion Program, "Burning coal containing 3% sulfur and 12% ash in a boiler would produce about 1 million tons of sludge each year from a 1000-Mw plant—assuming that the sludge is 50% water."

Nannen explains that this sludge, presently being disposed of in ponds, could possibly pollute nearby water systems. "In trying to meet government regulations on burning coal," states Nannen, "we're finding that air pollution problems are often being converted into potential water pollution problems."

The utility managers and EPRI staff discussed recent government recommendations that power companies have their sludge "fixed." This process involves converting the gel-like sludge into a concrete-like material. It's an expensive process and some participants reported that water from even fixed sludge can leach into the ground.

"We also discussed ways to process sludge into a useful industrial material," comments Nannen. "For example, in Japan they use sludge for construction material."

According to Nannen, the utility participants provided strong direction in preparing an EPRI sludge disposal research program which will be underway shortly.

"All Available U.S. Energy Sources Needed"

"Meeting this country's electric power needs through the rest of the century will require full utilization of all available domestic energy sources," EPRI's Dwain Spencer told an October 29 Atomic Industrial Forum meeting in Boston.

"If we are to avoid major disruption of our social and economic structures, it is not a matter of selecting between nuclear and alternative energy sources," Spencer said. "Rapid expansion of nuclear power is necessary to meet our projected capacity needs in the foreseeable future. Even with this expansion, much greater use of coal and oil will be necessary to meet projected loads."

Spencer, technical manager for planning, Fossil Fuel and Advanced Systems Division, warned the AIF Public Affairs Workshop that "under the best of circumstances, the average cost of generating baseload electric power will double by 1985.

"Conservative estimates call for a total installed national capacity of 2 million Mwe by the year 2000, compared to approximately 500,000 Mwe today. We estimate that nuclear sources and coal will each account for 35% of our electric power production at the turn of the century; oil, hydroelectric, and synthetic fuels will account for most of the rest. This will call for three to four times the level of coal utilization and a tremendous increase in nuclear capacity, from 40,000 Mwe today to 700,000 Mwe by 2000.

"Although we are blessed with large, known, recoverable coal resources in this country (about 250 billion tons), approximately 50% of it will require sulfur control," Spencer said. "It is necessary to classify our various coal deposits according to the degree of cleaning required. Then we must determine in each instance whether it is best to clean the coal before burning, clean the combustion gases after burning, or some of each. At this time there is not a clear-cut answer to that problem."

Spencer explained, "Coal liquefaction, coal gasification, and coal beneficiation [chemical cleaning] show real promise as future clean energy sources but appear to be 10 to 15 years away from commercialization—and then only at costs above those of current fuels.

"Over the past few years, utilities have been forced to rely on stack gas cleanup for sulfur removal since it has been the only technology available," Spencer said. "But scrubbers today are not reliable enough for continuous compliance with recommended sulfur emission controls. The day these are enforced, utilities will have to build in costly reserve capacity to accommodate scrubber-forced outages. A critical challenge for industry is to develop systems that will get rid of sulfur with higher reliability as early as possible.

"Ever-changing standards for control of sulfur, oxides of nitrogen, and fly ash will present a constantly moving and very expensive target for utilities for the balance of the century," Spencer said. "There is a major need for closer coordination between the Federal Energy Administration, the Environmental Protection Agency, and industry to provide for regulations that will protect the environment while still allowing for production of adequate electric power at an acceptable cost. We also have to factor in state emission-control programs."

Spencer said, "Combined cycle power plant operations that use advanced gas turbines, fuel cells, or magnetohydrodynamic generators in combination with conventional steam turbines show promise of higher thermal efficiencies than present fossil fuel plants. We expect them to provide overall efficiencies ranging from 45% to 50% compared to 40% to 42% for present coal-fired plants.

"These systems, which will probably become commercial between 1985 and 1990, will reduce cooling water requirements while getting as much as 15% to 20% more electric power out of the same amount of coal. Combined-cycle system development is a major focus of the EPRI advanced systems R&D program."

Spencer also touched briefly on geothermal resources. "Today, total world electrical capacity from geothermal energy is approximately 1200 Mwe. Of this amount, 502 Mwe is in the United States, at the Geysers in northern California. Projected U.S. capacity by 1985 is from 2400 to 3800 Mwe. Estimates of total capacity by the end of the century range from 10,000 to 50,000 Mwe. The specific reserves in the U.S. are very speculative and are primarily restricted to the western states."

Balzhiser Predicts Upsurge in Coal Consumption

"Public concern with nuclear power and utility concerns over fuel and capital availability are certain to delay nuclear commitments in the next few years," EPRI's Richard Balzhiser told delegates to the recent Atomic Industrial Forum winter meeting in San Francisco.

According to Balzhiser, who heads EPRI's Fossil Fuel and Advanced Systems Division, the consequences of nuclear delays "will mean an increase in the number of coal-fired plants that will have to be ordered in the late 1970s and early 1980s to satisfy projected power demands.

"Coal must play an increasingly important role as the basic utility fuel, even though to date its supply and utilization have been constrained," he continued. "On the one hand, we have government action imposing tough air quality standards and strip-mined land reclamation requirements, and on the other hand, we have a lack of government action in recognizing multiple approaches to pollution control and in the leasing of new coalfields."

In surveying fossil fuels, Balzhiser pointed out that natural gas will become less available, even with deregulation. "I have seen no evidence that we can ever again expect domestic crude oil to equal the production levels of recent years," he added.

He further noted that neither resource constraint will decrease the projected growth of electric power consumption in the U.S. "An EPRI study has concluded that electricity demand would double every 10 to 15 years over the balance of this century if essential energy and economic demands were met."

According to the same EPRI study, by the year 2000 an electric generation mix equally divided between coal and nuclear would mean utility coal consumption six times today's level and an eightfold expansion of proven uranium reserves.

"Most near-term projections," Balzhiser said, "have assumed coal use would double by 1985. These projections have assumed a nuclear development rate which today seems unlikely. Thus, still faster expansion of coal-fired generating capacity, using today's technology, will be a necessity.

"We can expect little help from new technologies in coal utilization over the next 10 years, with the possible exception of the emissions control area. Scrubbers will be the primary sulfur control system," Balzhiser explained, "with coal cleaning and tall stacks with intermittent controls hopefully available for maintaining air quality standards over large regions of the country.

"From 1985 to 2000," Balzhiser stated, "unless the uranium reserve picture deteriorates and the breeder reactor gets derailed, nuclear should begin to assume a more substantial role in the generating mix.

"Advanced systems have promise," he said, "but their contribution to future energy supply is likely to be small before the year 2000. Today's real need in energy R&D planning," he urged, "is a game plan, not just rhetoric."

Because the stakes are so high in terms of national economic security, Balzhiser called for "creative federalism" in which government and industry collaborate to ensure that physical, organizational, intellectual, and capital resources are optimally deployed.

He concluded by telling AIF members, "We are approaching a point of diminishing returns in trying to convince the opponents of nuclear power and coal that these can be safe, economical, and environmentally compatible. Rather, I believe we must demonstrate that we have no better options for most of the United States and, indeed, most of the world."

"Superconducting Transmission May Cut Capital Costs in Half"

"Superconducting technology could offer more power at lower costs for future generation and transmission of high-density electric power," stated EPRI's Mario Rabinowitz at the International Energy Engineering Congress held in Chicago recently.

Rabinowitz, manager of superconducting and cryogenic projects at EPRI, remarked that based on the past rate of electric power growth a possible sixfold increase may be expected in the next 30 years. "To meet an estimated demand of more than 1000 Gva before the year 2000, the electric utilities will have to acquire an additional 700 Gva of generation, transmission, and distribution capacity.

"Capital costs may be greater than $400 billion if conventional means are used to deliver this increased demand. Superconducting transmission, if successfully developed, would allow higher electric power blocks to be efficiently delivered, with resulting capital costs possibly cut in half."

He emphasized, however, that superconducting transmission does not appear to be economically competitive with conventional transmission at power levels below 3000 Mva. And although the major need in the next two decades appears to be at power levels below 3000 Mva, Rabinowitz said that this "should not deter us from conducting a vigorous and meaningful program so that the technology is ready when the need is critical."

Rabinowitz explained that cryoresistive and superconducting transmission are two different cryogenic (low-temperature) phenomena. There is only a small increase in conductivity in present-day ac cryoresistive transmission. For dc superconductivity, the conductivity is infinite; and for ac, it is extremely large.

EPRI currently funds and manages 15 projects in cryogenic research technology.

"EPRI Distribution R&D Looks for Immediate Payoffs"

"The first priority for distribution R&D at EPRI," says E. Robert Perry, director of EPRI's Transmission Department, "is to complete the development of products and concepts that are already well along and hold promise of an immediate payoff."

In remarks to the Power Distribution Conference at the University of Texas in Austin on October 20, Perry stated that electric power transmission and distribution products account for a capital outlay by the utilities of approximately $7 billion per year, and power losses on T&D systems exceed 100 billion kwh per year—or over $2 billion in lost revenue. "The incentive for economies in system operation is considerable," he said. "The reduction of losses alone could easily recover the R&D dollars spent on T&D research."

Perry noted that the functional reliability of the thousands of critical components in a distribution network has motivated EPRI to conduct research into means of automatic control, fault current limiting, switchgear improvements, and improved maintenance methods.

Communications has first priority in distribution automation, he noted. "All potential communication system carriers will be evaluated—such as power distribution lines, radio, dedicated utility-owned wires, leased telephone facilities, coaxial cables, and electro-optical systems. The potential benefits from automation are almost unlimited: reliability improvement, manpower reduction, more efficient use of resources, economic system operation, and public relations enhancement."

Closely associated with distribution automation is automatic meter reading, including turnoff, turnon, and statistical control, Perry pointed out. "This technology will be developed as a follow-on to distribution automation, along with substation and distribution system monitoring and control, load management, peak-load control, and load deferral."

He also noted that the growth of fault currents has increased the duty on circuit breakers or interrupters to the extent that fault current limiters have become desirable for both transmission and distribution systems. (See feature article, page 14.) In transmission, Perry said that either a turned circuit or switched impedance device seems called for; in distribution, a switched impedance or a type of solid state device is also being evaluated.

"Other EPRI distribution R&D projects that will produce near-term results," he continued, "include separable connector tests, evaluation or transformer tank failures, concentric neutral corrosion tests, and efforts to manufacture distribution poles from foamed glass, utilizing fly ash as an additive. Other near-term projects are designed to inhibit the growth of trees and shrubs along rights-of-way or to control the biological deterioration of wood after it becomes part of the distribution system."

Perry also discussed programs at EPRI involving ways of implementing more efficient trenching and line-stringing equipment, installation procedures, and even crew deployment.

According to Perry, long-term distribution programs at EPRI are concerned with those projects that hold "the promise of truly impressive gains." In particular, he spoke of one program under consideration that will substantially improve the magnetic properties of core steel, while enhancing the retention of these properties. "The higher ratings that will then be possible could save the utility industry close to $200 million per year in both power and distribution transformers with a substantial reduction in no-load losses."

Other major research efforts discussed by Perry were for developing suitable new transformer liquids within the next few years. "Beginning in 1976," he said, "oils selected by General Electric will be tested at elevated temperatures by General Electric, Westinghouse, and McGraw-Edison in standard 25-kva distribution transformers of their design and manufacture. From this three-year research program, serviceable new insulating liquids will be developed."

He concluded that it was essential that the utility industry recognize that properly conducted and coordinated R&D, including product improvement, could be an asset and not a liability by reducing capital outlays for system construction and increased reliability. In the T&D area, this return could occur in less than five years.

Computer Code Development

Approximately 100 technical representatives from utilities, government laboratories, universities, private industry, and U.S. and foreign nuclear regulatory agencies met with EPRI Nuclear Power Division staff on November 21 to hear about EPRI's program in light water reactor (LWR) technology.

The meeting, timed to coincide with the American Nuclear Society Winter Meeting in San Francisco, emphasized the Institute's analysis and computer code development efforts in the LWR program area, along with the intended use of experimental data to validate them.

Lance Agee, project engineer in the Safety and Analysis Department, orga-

nized the meeting. At the meeting, Agee described EPRI's proposed Best Estimate Safety/Transient Computational System being developed to obtain realistic evaluations of reactor system performance under normal and off-normal conditions. This system is currently capable of performing reactor plant analysis in the areas of core performance, system thermal-hydraulics, and structured mechanics.

Reporting on another major discussion topic, Agee said, "The use of a modular system with a data base manipulator could perhaps serve as a generalized approach for simplifying the handling of large amounts of data and for expediting the linkage of the many related computer programs.

"This type of system has been successfully used at a number of national laboratories and provides greater flexibility for calculating reactor system design and performance parameters under a variety of conditions."

Project Highlights

EPRI Negotiates 64 Contracts

EPRI signed 64 new research contracts during the months of October and November. A representative sampling of these new contracts, as well as information on other current projects, follows. A list of new contracts is on page 60.

Home Heating with Electric Heat Pumps Examined

"Electric heat pumps appear to be good alternatives to commonly used heating and cooling systems, like gas, oil, or electric resistance," according to the program manager for Energy Demand and Conservation, Robert Crow. "And because of the likelihood of gas curtailments and the skyrocketing price of oil, heat pumps are looking better everyday."

EPRI is sponsoring a load research study with the Association of Edison Illuminating Companies to determine how well heat pumps perform under actual conditions in homes. As part of the study, monitoring equipment is collecting important data on the reliability, operating costs, and energy use and demand characteristics of hundreds of heat pumps installed in homes throughout the country.

Crow attributes the renewed interest in heat pumps to recent engineering advances and the satisfactory performance of heat pumps in warm climates.

"The heat pump's performance varies according to climate," Crow explains. "It works by first drawing in and then contracting or expanding heat from the outside air, depending on whether heating or cooling is desired. But when the air outside turns very cold, it becomes difficult for the heat pump to provide a comfortable environment. In most sections of the country, therefore, the heat pump requires a backup electric resistance heating system."

Data will cover one year's operation and should help to determine the impact that heat pumps will have on electricity generating requirements and to evaluate system performance under various climatic conditions.

The 12 participating utilities in various climatic areas are Southern California Edison Company, Public Service Company of New Mexico, Houston Lighting & Power Company, Florida Power & Light Company, Philadelphia Electric Company, Public Service Electric & Gas Company of New Jersey, Consolidated Edison Company, Rochester Gas & Electric Company, Consumers Power Company of Michigan, Northern States Power Company, Middle South Services, Inc., and Pacific Gas & Electric Company.

The contractor for the study is Westinghouse Electric Corporation. Walter Blumst, marketing research manager at Pacific Gas & Electric Company, is the chairman of an electric utility task force set up to provide technical expertise for the overall project.

Improved Surge Arresters Being Developed

A $1.3 million contract has been awarded for developing surge arresters using metal oxide nonlinear resistors instead of the usual silicon carbide resistors. Westinghouse Electric Corporation will perform the research.

Arresters are used to prevent transient overvoltages on electric power transmission lines. The arresters in this four-year study will be evaluated for transmission systems up to 1200 kv. The protective voltage level objective is 1.5 per unit of maximum line-to-ground voltage without using gaps.

Recent research in the U.S. and abroad has shown that certain metal oxides possess nonlinear characteristics that may be superior to silicon carbide for arrester application.

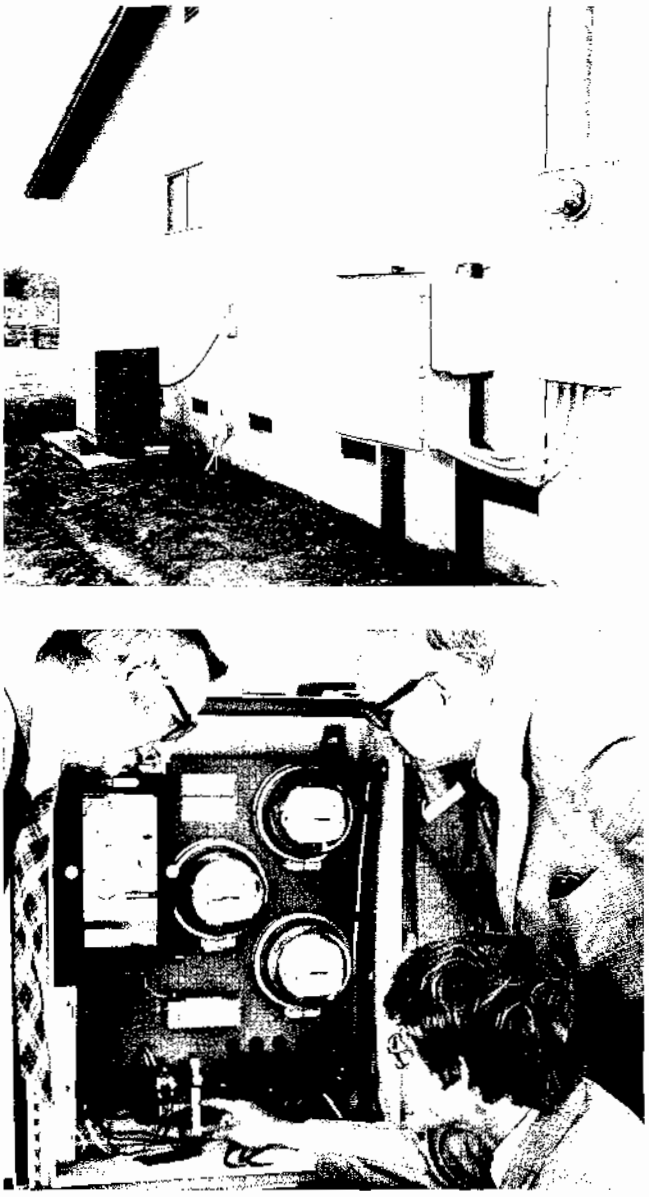
If the research is successful, insulation requirements for substation equipment will be reduced and, consequently, the utilities' costs. In addition, it will be possible to ship higher kva transmission voltage power transformers.

Environmental Impacts of Solar Power Plants Being Assessed

Assessing the environmental impacts of solar energy power plants is the goal of two recently commissioned EPRI projects. The contractors are Black & Veatch of Kansas City and Woodward-Clyde Consultants of San Francisco.

Black & Veatch, a consulting engineering firm, will explore five processes for solar radiation conversion in a 20-month, $323,000 project: (1) solar-thermal conversion, the use of

On the left is the heat pump and on its right is a locked box that encloses meters and a three-track recorder for measuring the compressor load for heating and cooling, which connects with a smaller box that holds a similar recorder for measuring the temperature and the total load for the house, including the indoor fan. On the far right is the usual house meter that measures the kwh transmitted from the electric power company.



Robert Crow from EPRI (left), Richard Batey from Westinghouse Electric Corporation (upper right), and Walter Blumst from Pacific Gas & Electric Company (lower right) examine the metering installation at one of 10 homes in the Oakdale, California, area. This metering installation measures and records the heat pump compressor load for heating, cooling, and auxiliary heating. The heat pumps installed in the homes are part of a national EPRI study to examine the performance of home heat pumps.

the sun's radiation to make steam for driving a conventional turbine generator; (2) photovoltaic conversion, the use of solar cells to convert solar radiation directly into electricity; (3) ocean-thermal-gradients, the use of different depth temperatures of the ocean to produce electricity; (4) wind energy; and (5) photosynthesis (biomass), the growing of crops for use as power fuel.

The 19-month, $293,000 Woodward-Clyde study calls for an environmental assessment of solar-thermal and wind conversion.

The two contractors will use different methods for assessing impacts: Woodward-Clyde will develop a new and advanced methodology while Black & Veatch will use a more conventional approach. The primary objectives of both projects are to establish a basis (including environmental impact assessment, cost comparisons, and site evaluation studies) that will allow electric utilities to objectively analyze solar energy plants as alternatives to other plant types.

Both beneficial and adverse environmental impacts will be assessed for each alternative system. These environmental assessments will then be generalized by the two contractors according to the regions of the nation in which there are potential locations. The range of environmental effects for applicable geographic regions can then be developed.

Secondary impacts will also be assessed, including the resource and manufacturing requirements for each solar energy system and the probable degree of market penetration for various regions of the nation.

All findings from the studies ultimately will be integrated and summarized so that the data requirements for preparation of solar plant environmental impact statements and other plant licensing documentation can be defined.

The Woodward-Clyde study is the first EPRI interdivisional project, being cosponsored and comanaged by EPRI's Fossil Fuel and Advanced Systems Division and the Energy Systems, Environment, and Conservation Division. Staff from EPRI's Solar Power Program are examining the technical aspects of the study while ESEC staff look at the economics of the study and examine the environmental implications.

"Even though some solar concepts show promise," says Piet Bos, manager of EPRI's Solar Power Program, "they are not yet cost-competitive with other energy sources for large-scale electric power generation. Basically, this is because of the problems involved in using the sun's diffused rays, its unavailability on a 24-hour basis, and its low reliability on a daily basis due to possible cloud cover."

Study Examines New Type of U.S. Power Plant

Whether it is possible to use underground geothermal hot water as an energy source to drive new U.S. power plants is being explored in a new $595,000 study commissioned to the Ben Holt Company and Procon, Inc.

There are several forms of geothermal energy, including hydrothermal convection systems, geopressure, dry hot rock, magma, and normal gradient. The most abundant form that may yield to present drilling and power conversion technology is found in hydrothermal convection systems. This is where the heat of the earth, in combination with running water, has formed both natural underground dry steam and hot water reservoirs at high pressure.

Although dry steam reservoirs are now being used to produce electric power at the Geysers in northern California, as well as in Italy and Japan, such reservoirs are relatively rare. On the other hand, hydrothermal or hot water reservoirs are much more abundant, and although they generally have a lower heat content, power plants in Mexico, New Zealand, and Japan are using this type of resource. In these plants, a portion of the underground hot water is converted (flashed) to steam and used for electric power generation.

"Those countries which have demonstrated the flashed-steam technology do not have the same environmental constraints imposed on them as would be the case in the U.S.," according to Vasel Roberts, EPRI's program manager for geothermal projects.

"The focal point of the EPRI study," says Roberts, "is to determine whether the existing power conversion techniques will work effectively with the types of geothermal hot water resources found in the U.S. in terms of being cost-competitive with other energy sources and in terms of meeting environmental constraints."

The ultimate goal of EPRI's "low-salinity" hydrothermal program, which encompasses the Ben Holt-Procon project, is to select a site for a demonstration plant after first identifying geothermal site characteristics. "This will be followed by the development of detailed plant requirements and a preliminary design," says Roberts. "After this is done, EPRI would expect the participating utility or utilities to help finance the demonstration plant, which is expected to be in operation by 1980."

The greatest technical problem in using underground hot water for power purposes lies in the water's chemical characteristics. Generally, the more dissolved salts there are in the water, the more difficult it becomes to extract energy and minimize the effects of scaling, corrosion, and erosion.

Roberts predicts that the utilization of our country's geothermal resources could triple every five years, reaching 20,000–100,000 Mwe of electric power by the year 2000. "The Geysers field in northern California now supplies about 500 Mwe of electricity, which is roughly equivalent to meeting the power needs of a city of half a million," says Roberts. "The western third of the U.S., including Louisiana and Texas, has significant amounts of geothermal energy resources," concludes Roberts.

EPRI to Study Steam Plant Surface Condenser Leakage

Increasing the reliability of both nuclear and fossil fuel power plants is the ultimate goal of a 12-month, $237,000 EPRI-funded research project (RP624) started by Bechtel Corporation in November 1975 to study steam plant surface condenser leakage.

Tube failures in surface condensers continue to cause leakage that creates major reliability problems for the utility industry. Accelerated corrosion of system materials and fouling of heat transfer surfaces result in substantial downtime to repair condensers, steam generators, and other components that deteriorate as a result of condenser leakage.

To determine what data presently exist on the subject, this broad study will encompass all the factors that contribute to deterioration and leakage of condenser tubes. The results will be summarized in a state-of-the-art description of the best methods available to curtail condenser leakage. The study will provide guidelines for selection and operation of condensers and will highlight areas requiring increased R&D effort.

The study is mainly concerned with nuclear units 100 Mwe and larger and fossil fuel units 600 Mwe and larger. There are about 50 nuclear units and some 70 fossil fuel units in these

The Geysers Power Plant of Pacific Gas & Electric Company, Sonoma County, California. The turbine-generator units are installed singly or in pairs with evaporative cooling towers in the center of groups of steam wells. This helps to minimize the heat loss in piping the steam from geothermal wells to the plant.

categories. Although most of these are relatively new plants (in commercial operation less than 10 years), the field survey will also include some older fossil fuel units from utilities that have shown strong technical interest in the field.

To select the survey sample, Bechtel will prepare a matrix of all the units under consideration, including several units with a significant number of titanium condenser tubes. It will contain pertinent data on plant age, size, and type; on condenser configuration, design, and materials; on circulating water system characteristics and approximate water composition; and on turbine cycle treatment procedures and controls. This flow of information will be expedited by using telephone and mail questionnaires.

The exact number of stations to be included in the survey is not definite at this time but will be no less than 30. The survey list will be submitted to EPRI for review and comment.

When the list of stations to be surveyed has been completed, the selected stations will be contacted to schedule plant visits. Well in advance of scheduled plant visits, a survey form will be sent to the station so personnel can assemble records, drawings, and other pertinent information. Following the visits, supplementary information will be gathered by mail and telephone. The success of the study will depend greatly on the cooperation and interest demonstrated by the various stations during the field survey.

The survey will also include information obtained from other sources in the power industry, such as vendors, consulting engineers, and manufacturers. Concurrent with the plant survey, a literature survey will be conducted to augment the information obtained from the field.

The EPRI project manager is William L. Lavallee. Reports, communications, and questions of a technical nature should be directed to him at EPRI headquarters in Palo Alto, California.

New Method Developed for Evaluating Structural Flaws

A new, more efficient method for stress analysis of flawed structures that can result in a savings in cost and time of nearly 50% has been developed as part of an EPRI nuclear research project performed by Failure Analysis Associates.

The project completed the development and application of an improved Influence Function (IF) method for calculating stress intensity factors for complex three-dimensional cases. The IF method has been previously applied to two-dimensional problems. Comparisons between this new method and other more standard methods, including finite-element and "near-exact" classical methods, show very similar results (within 1.3%).

The improved IF method was applied to an important current problem documented in EPRI RP217–1 (Technical Report 6) *An Engineering Fracture Mechanics Analysis of Pilgrim-1 Nozzle-to-Pressure Vessel Weld Discontinuities.* The reviews by Boston Edison Company and Teledyne, Inc. (the stress analysis consulting firm that conducted the original finite element analysis) were favorable.

As part of still another EPRI project, the IF technique was evaluated against present-day methods. These evaluations showed that by using the IF method in completing the project, results were not only more accurate but the cost of the analysis was reduced by nearly 50%.

The IF method is fully documented and being submitted to code committees for use under Section XI, Appendix A, of the Boiler and Pressure Vessel Code. The application of procedures detailed in this code can evaluate what kinds of flaw indications (detected by inspection) are significant for simple cases. For those cases involving more complex geometries and stress distributions, the Appendix A method is inadequate and more sophisticated techniques are required and permitted by the code, provided they are fully documented. The IF method is documented in EPRI RP217–1 (Technical Report 2) *Fracture Mechanics and Residual Fatigue Life Analysis for Complex Stress Fields.*

According to the author of the Pilgrim-1 study, Phil Besuner of Failure Analysis Associates, "Elastic fracture mechanics analysis forms the basis of predicting the residual strength of remaining fatigue life of a structure containing a flaw under either nominally elastic conditions or after elastic 'shakedown' with subsequent steady or cyclic loading.

"As a general procedure for elastic fracture mechanics analysis of structures with flaws in regions of complex stress, the IF method computes the stress intensity factor (K), a parameter which includes the effects of the stress field, the flaw size and shape, and the local structural geometry."

Besuner also said, "Considerable effort in analytical fracture mechanics has been devoted to the computation of K for complex stress and geometry combinations of actual flawed structures. Traditional approaches have been to use literature solutions or to obtain numerical solutions of K with a finite element or boundary-integral equation model of the actual flawed structure. There are inadequacies in both of these approaches for a large class of problems.

"Literature solutions lack generality, while repeated two-dimensional or three-dimensional numerical stress analyses of cracked idealizations are costly, time-consuming, and subject to a variety of sources of errors.

"The key to the IF method is the determination of the influence coefficients, h, which are independent of loading. Once h has been determined for a given flawed geometry, K can be calculated for any flaw size and shape from the 'uncracked' stress field. Through use of elastic superposition, the IF method properly accounts for stress redistribution as the crack dimensions increase due to propagation through the structure."

New Contracts

Fossil Fuel and Advanced Systems Division

No.	Title	Duration	Funding ($000)	Contractor
RP522-1	Load-Leveled Coal Gasification for Power Generation	6 months	49.0	Fluor Engineers & Constructors, Inc.
RP526-1	Continuous High-Pressure Lump Coal Feeder Design Study	14 months	118.8	Gard, Inc.
RP527-1	Boiler Firing Test with Coal/Oil Emulsion	15 months	100.0	General Motors Corp.
RP532-1	Electrostatic Precipitator Plate Rapping and Reliability	28 months	173.7	Princeton University
RP536-1	Evaluation of Three Prototype Flue Gas Desulfurization Processes	10 months	250.0	Southern Services, Inc.
RP537-1	Development of Improved Lime/Limestone Scrubbing Technology	18 months	450.0	Tennessee Valley Authority
RP543-1	Design of Materials for Use Under Erosion/Corrosion Conditions at High Temperatures in Coal Gasification and Coal Combustion Systems; Task II—Design of Alloys and Coatings for Use in Gas Turbines	2 years	198.7	United Technologies Corp.
RP544-1	An Investigation of Methods to Improve Heat Pump Performance and Reliability in a Northern Climate	1 year	479.7	Westinghouse Electric Corp.
RP545-1	Coal-Fired Prototype High-Temperature Continuous Flow Heat Exchanger	1 year	960.0	Airesearch Manufacturing Co. of Arizona
RP546-2	Fusion Power Reactor Control Analysis	2 years	299.9	Charles Stark Draper Lab., Inc.
RP547-2	Evaluation of Utility System Interface with Fusion Reactors	2 years	184.3	Bechtel Corporation
RP551-2	Environmental Impact Assessment of Solar Energy Conversion Systems	19 months	293.4	Woodward-Clyde Consultants
RP580-1	Feasibility Study for a Low-Salinity Hydrothermal Demonstration Plant	5 months	594.8	Ben Holt Co.
RP625-1	Design of Refractories for Resistance to High-Temperature Erosion/Corrosion	2 years	283.5	Westinghouse Electric Corp.
RP626-1	Physical Property Improvement of Coal Liquefaction Products	1 year	200.0	Atlantic Richfield Co.
RP631-1	Characterization of Fly Ash by Auger Electron Spectroscopy	5 months	30.0	Stanford University
RP634-1	Transition Metal Oxygen Electrocatalysts for Fuel Cells	2 years	150.0	Case Western Reserve University
RP636-1	High-Strength, High-Toughness Austenitic Alloys for Generator Retaining Rings	1 year	47.1	University of California, Berkeley
RP645-1	Exploratory Studies of High-Efficiency Advanced-Fuel Fusion Reactors	27 months	211.1	University of Illinois at Urbana-Champaign
RP647-1	The Measurement of Density Profiles in Plasmas by Particle Transmission	18 months	244.6	Lockheed Missiles & Space Co., Inc.
RP648-1	Requirements Definition and Impact Analysis of Solar Thermal Power Plants	2 months	32.4	Westinghouse Electric Corp.
RP650-1	Commercial Solar-Assisted Heat Pump Instrumentation Project	30 months	30.0	Boston Edison Co.
RP725-2	Advanced Electrostatic Precipitator Pilot Plant	4 months	75.0	Kaiser Engineers Division of Kaiser Industries Corp.

Nuclear Power Division

No.	Title	Duration	Funding ($000)	Contractor
RP216-2	Halden Reactor Project	2 years	900.0	Norwegian Institute for Atomic Energy
RP394-1	Effects of Restraints on Nuclear Piping Systems	1 year	136.7	Control Data Corp.
RP492-2	Experimental Fission Product Gamma-Ray Deposition	13 months	60.5	University of Virginia
RP493-1	Basic Investigation of Two-Phase Pump Performance	1 year	67.0	Massachusetts Institute of Technology
RP503-1	Sensor Time Response Verification	8 months	69.5	Nuclear Services Corp.
RP513-2	Study of Remote Multiplexing for Nuclear Power Plant Application	15 months	217.4	TRW, Inc.
RP598-1	Model Pump Tests and Analysis for LOCA Application	1 year	133.6	Babcock & Wilcox Co.
RP599-1	Multifluid Flow Analyses Related to Reactor Safety	8 months	90.0	JAYCOR
RP602-1	Numerical Analyses of Welds	5 months	30.0	Marc Analysis Research Corp.
RP602-2	Numerical Analyses of Welds	5 months	26.2	Science Applications, Inc.

No.	Title	Duration	Funding ($000)	Contractor
RP603-2	Fundamental Study of Crack Initiation and Propagation	1 year	128.0	Science Applications, Inc.
RP604-1	Field Demonstration of Section XI Weld Repair	4 months	79.3	Combustion Engineering, Inc.
RP607-1	Assessment of Thick Section Radiography	10 months	99.0	Science Applications, Inc.
RP608-1	EPRI-NBS Cooperative Program on Acoustic Emission	3 years	1,040.0	National Bureau of Standards
RP613-1	Concentration of Transuranics in Commercial Nuclear Plant Wastes	2 years	106.7	Science Applications, Inc.
RP615-1	Study of Nonlinear Effects of Earthquake Response Using Explicit Numerical Techniques	1 year	29.6	Dames & Moore
RP615-2	Study of Nonlinear Effects of Earthquake Response Using Explicit Numerical Techniques	1 year	19.9	Science Applications, Inc.
RP616-1	Tornado Missile Risk Analysis	18 months	143.0	Carolina Power & Light Co.
RP693-1	Dynamic Modeling of Pressure Suppression Pools	4 months	65.0	Stanford Research Institute

Transmission and Distribution Division

RP281-2	Development and Testing of Fault Current Limiter	23 months	685.7	I-T-E Imperial Corp.
RP477-1	Gas-Insulated Transformer Study Utilizing a Fluidized Particulate Bed	26 months	350.0	Allied Chemical Corp.
RP579-1	Transformer Noise Abatement	16 months	354.6	Allis-Chalmers Corp.
RP654-1	Analysis, Development, and Construction of a Controlled Impedance Short-Circuit Limiter	2 years	299.0	Westinghouse Electric Corp.
RP657-1	Development of 1200-kv Ceramic Oxide Voltage Limiter for Power System Application	4 years	1,295.2	Westinghouse Electric Corp.
RP668-1	Electronic Current Transformer for High-Voltage DC Lines	3 years	244.8	General Electric Co.
RP669-1	Light-Triggered Thyristors for Electric Power Systems	16 months	245.0	General Electric Co.
RP670-1	Power System Dynamic Analysis	1 year	177.0	Boeing Computer Services, Inc.
RP671-1	Research and Testing of URD Cable of Various Neutral Designs with Insulating and Conducting Jackets	11 months	343.0	General Cable Corp.
RP907-2	Research in Long-Term Power System Dynamics	1 year	115.0	General Electric Co.

Energy Systems, Environment, and Conservation Division

RP98-3	Biological Effects of Exposure to High-Intensity Electrical Fields	6 months	90.0	Johns Hopkins University
RP103-3	Ecology of Transmission Line Corridors	2 years	108.1	West Virginia University
RP662-1	Analysis of Demand for Energy in the Commercial Sector	16 months	204.0	Data Resources, Inc.
RP664-1	Critical Assessment and Modification of the "Energy Supply Planning Model" of Bechtel Corporation	11 months	47.7	Stanford University
RP665-1	Review of Oil Supply Studies	6 months	33.7	Mathematica, Inc.
RP666-1	Cost Evolution and Price Formation in Coal and Uranium Industries	16 months	235.3	Charles River Associates, Inc.
RP673-1	Long-Term Effects from Exposure to Tritiated Water at the Maximum Permissible Level	3 years	79.0	University of Chicago
RP675-1	Evaluation of a Segmented Plate Flame Ionization Detector for Aerosol Monitoring	10 months	72.5	Midwest Research Institute
RP676-1	Laser-Induced Fluorescence to Study Power Plant Plume Chemistry	1 year	96.7	University of Maryland
RP677-1	Air Quality Models: Required Data Characteristics	6 months	36.5	Xonics, Inc.
RP678-1	Development of a Continuous Particulate Sulfate Analyzer	10 months	184.8	Environmental Research & Technology, Inc.
RP682-1	Development of Models for Forecasting Agricultural Energy Consumption	11 months	54.6	Data Resources, Inc.

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

New Publications

Fossil Fuel and Advanced Systems

EPRI 318 ASSESSMENT OF FUELS FOR POWER GENERATION BY ELECTRIC UTILITY FUEL CELLS Final Report

This report presents the results of a comprehensive assessment of fuel supply options and costs for electric utility fuel cells. Petroleum, natural gas, coal, municipal solid waste, oil shale, and nuclear power are considered as raw energy sources for production of five secondary fuels (hydrogen, synthesis gas, SNG, methanol, and naphtha), which represent suitable input fuels for fuel cell power plants. The major conclusions stated are that (1) naphtha should be available for first-generation dispersed fuel cells in the 1980s, but increasing competition for this resource could require that future dispersed fuel cell generators be sufficiently flexible to use low-sulfur distillate fuels; (2) coal-based electric utilities should consider coal gasification to SNG or methanol as central fuel conversion options to produce fuel for dispersed fuel cells; (3) coal-derived fuels, although attractive in terms of fuel availability and of compatibility with dispersed fuel cells, will be higher in price than refined petroleum products through 1990 unless oil prices rise faster than inflation rates; and (4) there also appears to be a significant opportunity for central fuel cell power plants which, integrated with coal gasifiers, could reach coal-based efficiencies of 45% at total power system costs in the range of conventional fossil steam generating plants. *Contractor: Arthur D. Little, Inc.*

EPRI 320-1 UTILIZATION OF OFF-PEAK POWER TO PRODUCE INDUSTRIAL HYDROGEN Final Report

This study was conducted to determine the economic and technical feasibility of using off-peak power to generate electrolytic hydrogen for sale as an industrial fuel or commodity. Hydrogen markets through 1975–1990, and the economics of hydrogen production, storage, and transportation are analyzed, and a methodology developed that can be used by individual utilities to calculate hydrogen costs and to match costs with the range of likely market prices. The overall conclusion is that, in the near term, electrolytic hydrogen will be high-priced due to the cost levels anticipated for off-peak power and electrolysis equipment. An expanded market potential beyond specialty uses might develop in the longer term, provided that low-cost, nonfossil baseload power becomes available. *Contractor: Institute of Gas Technology*

EPRI 376 TEST AND EVALUATION OF A GEOTHERMAL HEAT EXCHANGER Final Report

A tube-in-shell counter flow heat exchanger was tested with low-salinity geothermal brine at Heber in the Imperial Valley of California. The purpose of the test was to investigate any change in thermodynamic performance, as well as tube material degradation caused by scale deposition and corrosion. Under conditions of simulated binary-cycle operation, test runs were made, two of 560 hours' duration, and one of 300 hours' duration, using different tube material types in each run. The tube material types included mild carbon steel, titanium, and an alloy of 90% copper-10% nickel. The brine inlet temperature was about 355°F and the exit temperature close to 150°F at a flow rate of 5 fps. Additional test runs were made to investigate the effect of brine flow rate on performance and the practicality of using chemical cleaning techniques to remove scale.

Of the three tube materials, titanium developed the least amount of scale and no corrosion. The results indicated that the mild carbon steel would be acceptable with regard to scaling, but may have a reduced life due to pitting. The copper-nickel performance was unacceptable. The heat transfer coefficient was expected to be in the range of 500 to 600 Btu/hr/ft² °F with the brine at startup, and somewhere between 4000 and 6000 hours of operation could be achieved before having to remove the scale. The scale was amenable to chemical removal at reasonable cost. *Contractor: San Diego Gas and Electric Company*

EPRI 390-1 AC/DC POWER CONDITIONING AND CONTROL FOR ADVANCED CONVERSION AND STORAGE TECHNOLOGY Key Phase Report 1

This report reviews the technology options available for converting dc power produced by fuel cells, batteries, magnetohydrodynamics (MHD), and superconducting magnetic energy storage (SMES) to ac. Westinghouse concludes that any of the several technologies analyzed, ranging from conventional high-voltage direct-current (HVDC) technology to conventional force commutated technology, can be configured to accomplish the power conversion tasks.

Based on the technical performance parameters considered and the cost projections made by Westinghouse, no. one candidate emerges as the clear-cut, best option for interfacing with all the sources. Common technology should be applicable to both batteries and fuel cells, and the same technology approach would also be applicable, in most cases, to MHD and SMES—although equipment configuration and ratings would be different.

Dc/ac converter equipment is projected to cost around $70/kw for batteries, $65/kw for fuel cells, $55/kw for SMES, and $50/kw for MHD. Work continues to determine which option will result in the lowest specific cost and best performance when designed to be applicable to all the sources of interest. *Contractor: Westinghouse Electric Corporation*

EPRI SR-24 EXPLORATORY DISCUSSIONS CONCERNING A POSSIBLE EPRI/KURCHATOV INSTITUTE JOINT PROGRAM ON FUSION POWER

This Special Report summarizes the findings of an American delegation that was commissioned to examine the possibility of a joint U.S.-USSR program in fusion. Specifically, the delegation explored the feasibility of a joint program to blanket module elements of the T-20 Tokamak. The report includes a general introduction, the chronology of the delegation's trip, a summary of the meetings in the USSR, a list of American questions and Soviet answers on details of the T-20 modules, a list of relevant EPRI projects, a technical description of the T-20 Tokamak, a technical report on a series of visits to Soviet laboratories by the American delegation, and a bibliography of fusion-fission reactor literature.

Nuclear Power

EPRI 248-1 HEAT TRANSFER DURING THE REFLOODING PHASE OF THE LOCA State-of-the-Art Topical Report

The loss-of-coolant accident (LOCA) has been established as the definitive, or design-basis, accident for light water reactors. The method for analyzing this accident has been regulated in considerable detail. The evaluation model requirements specify a number of conservative assumptions that must be made in the analysis of the LOCA; these assumptions can often be penalizing.

This report reviews the analytic methods and experimental data available to support an analysis of the "reflooding" phase of the LOCA in pressurized water reactors, and identifies areas of experimental measurement and methods development that could lead to less conservative design criteria. *Contractor: University of California at Berkeley, Department of Nuclear Engineering*

EPRI 348 EXPERIMENTAL POWER NORMALIZATION FACTORS FOR BATTELLE PLUTONIUM RECYCLE MEASUREMENTS Key Phase Report

Measurements carried out by Battelle, Pacific Northwest Laboratories at their Plutonium Recycle Critical Facility (PRCF) have provided a significant amount of neutronics data relating to the recycle of plutonium in light water reactors. In these experiments the relative power distributions are deduced from measurements of the fission product activities in fuel rods following low-power irradiations. In cases where only a single type of fuel is used, the relative power generation is directly proportional to the fission product gamma activities. Measurements involving more than one type of fuel require the use of normalization factors to account for differences in fission product yields from the different fissile nuclei.

The purpose of the first phase of project RP348 was to measure factors relating power to fission product activity for the five different types of uranium dioxide (2.35% ^{235}U) and mixed-oxide fuel used in this project and earlier experiments. The factors, measured by two different methods (calorimetric and ^{140}La activity) up to an accuracy of ±.5%, indicate that values in use prior to this experiment were in error by as much as 8% in relating the UO_2 rods to the mixed-oxide rods. *Contractor: Battelle, Pacific Northwest Laboratories*

EPRI SR-20 LIQUID METAL FAST BREEDER REACTOR: DECISION PROCESS AND ISSUES

This report presents a suggested structure for national decision making on the timing of the LMFBR program, taking into consideration the principal uncertainties and variables. The process examines the key issues that affect current decisions.

An analysis of the issues indicates that the key parameters in the decision process are electricity demand, the availability of uranium, and the availability of a clean coal technology. The predictive uncertainties in these three parameters result in eight possible future energy situations. Six of these outcomes support the acceleration of the LMFBR, and two favor slowing the program.

EPRI SR-22 FINITE ELEMENT TECHNIQUES FOR POSTULATED FLAWS IN SHELL STRUCTURES

This study reviews the basis and limitations of current linear fracture mechanics methods. The fundamentals of linear elastic fracture mechanics are summarized and their limitations and restrictions identified. The role of finite elements is examined, with a comparison of the various methods used in the analysis of shell-type components. The availability of finite element software is also summarized. *Contractor: Marc Analysis Research Corporation*

EPRI-309 REVIEW OF THE METHODOLOGY FOR STATISTICAL EVALUATION OF REACTOR SAFETY ANALYSIS Key Phase Report

The objective of the statistical assessment project is to evaluate the conservatism in the models. This overall effort may be divided into three broad areas: (1) obtaining and characterizing the required basic data; (2) development of best-estimate analytic techniques; and (3) development of methodology for the statistical propagation of input uncertainties through the analytic model.

The third area is the concern of this report, which provides a state-of-the-art review of the methodology for estimating the probability of a specified outcome, given the uncertainties associated with the initiating events and the relationship between the outcome and the initiating variables. *Contractor: Westinghouse Electric Corporation*

Transmission and Distribution

EPRI 7825 OPTIMIZED DESIGN FOR GAS CABLE SYSTEMS Final Report

The project defines many of the parameters associated with gas-insulated transmission systems and demonstrates that, even with relatively modest power levels, a very competitive system is available. At the power levels envisioned for the future, gas-insulated systems will be very economic and their relative simplicity indicates they will satisfy utility industry needs for many years to come.

A series of computer programs was developed to allow optimized gas-insulated systems to be designed on a consistent basis. Both single-conductor and three-conductor designs were evaluated and aboveground and underground installation modes were considered. Designs were compared on the basis of energy transportation costs and it was found that, as expected, significant economies were realized at the higher voltages. While the optimum power level was

sharply defined at 138kv, the higher voltage systems tended to preserve their cost minima over a relatively broad range. Aboveground systems offer a 30% advantage in energy transportation costs with both single-conductor and three-conductor systems. In general there was little cost difference between single-conductor and three-conductor systems, particularly when higher power levels were involved. Cross bonding can reduce the energy transportation costs by approximately 40%, while forced cooling can also generate some savings. While cross bonding is only applicable to single-conductor systems, forced cooling can also be applied to three-conductor systems.

The present state of the art for gas-insulated transmission systems is described in the companion design guide. *Contractor: I-T-E Imperial Corporation*

EPRI 7825 GUIDE TO THE USE OF GAS CABLE SYSTEMS Technical Report

This guide provides the utility systems designer with the basis for selecting and specifying gas-insulated transmission systems. Quick reference is given for economic application in terms of voltage, power level, and transmission distance. In addition, ampacities are tabulated with correction factors for a wide range of installation parameters. Prices of standard designs are given for estimating purposes.

The design criteria related to thermal, dielectric, and economic factors are summarized. A computer program for optimized design of gas-insulated transmission lines has been developed into a practical tool, and the procedures for installation, testing, operation, and repair are described in detail.

The results of advanced research and development are described in the Final Report, *Optimization of and Guide to the Design and Use of Gas Cable Systems. Contractor: I-T-E Imperial Corporation*

EPRI 908-1 LONG-TERM SYSTEM DYNAMICS HYBRID SIMULATION Final Report

This project successfully demonstrated the feasibility of a faster-than-real-time hybrid simulator to perform long-term system dynamics. The approach is feasible and practical for a wide range of additional studies. The sample system consisted of 16 machines and 68 buses. A 16-bit digital minicomputer was used for input, output, and control of the analog simulation. The final report presents a description of the hybrid simulator, operating instructions, and results of the studies. Although the project provided the preliminary steps in the development of an on-line security monitor, more work will be necessary to fully develop this potential. *Contractor: University of Missouri-Columbia*

EPRI 92-2 SUPERCONDUCTORS IN LARGE SYNCHRONOUS MACHINES Final Report

This report assesses the application of superconductors in large synchronous machines as compared with conventional construction. It concludes that superconducting generators have many advantages for central station power generation. Specifically, the superconducting machine concept can be practically realized; acceptable designs are now available for the critical areas of the machine; and existing engineering analyses predict the basic machine behavior. *Contractor: Massachusetts Institute of Technology*

Energy Systems, Environment, and Conservation

EPRI 381-1 BIOLOGICAL EFFECTS OF HIGH-VOLTAGE ELECTRIC FIELDS Final Report

This report presents a review and evaluation of completed and current research into the biological effects of power-line-generated electric fields. Approximately 800 U.S. and foreign papers were reviewed by the investigators and are summarized in the report. No convincing evidence has been found that indicates adverse effects from 60-Hz fields as normally encountered. However, the report concludes that more precise research is needed before we can confidently dismiss consideration of electric fields as a potential environmental hazard. Accordingly, a research plan has been developed that identifies 23 specific projects and arranges them by priority. Management guidelines for the conduct of the research are also presented. *Contractor: IIT Research Institute*

EPRI 381-1 BIBLIOGRAPHY ON BIOLOGICAL EFFECTS OF ELECTRIC FIELDS Final Report

This publication is an annotated bibliography of the 800 research reports cited above. Approximately 80 ongoing research efforts are also identified. The following areas are emphasized: biological effects from ac fields between 45 and 75 Hz, biological effects of dc electrostatic fields, and effects of ac power-line fields and radio-frequency waves on patients with implanted cardiac pacemakers. *Contractor: IIT Research Institute*

EPRI SR-17 SIGNIFICANCE OF ZERO POWER GROWTH IN 1974

This study examines the significance of the fact that for the first time since 1946, the total electricity supply in 1974 did not increase appreciably over that of the preceding year. The implications of this for the future growth of electric power are unclear, but it has undoubtedly played a role in recent reductions in forecasts of power growth. Two simple historical growth models are used to evaluate the significance of this occurrence: one relates total electricity made available to aggregate economic activity (real GNP); the other relates it to the passage of time. In both models, electricity supply is highly correlated with the independent variable.

According to the economic model, electricity output in 1974 was higher than expected, even though it was no greater than in 1973. This leads to the conclusion that the substitution (broadly defined) of electricity for other fuels more than offsets the depressing effects of both higher electricity prices and conservation. On the basis of this model, there is no reason to believe that the rate of long-term growth of electricity relative to real GNP has declined; in fact, the contrary is indicated. Use of the other model, in which time is the independent variable, leads to exactly the opposite conclusions.

Detailed analysis by utility experts of the various factors affecting demand in their areas will be necessary to fully explain the 1974 behavior of demand. General models, such as those used here, can help identify aggregate trends but cannot identify the more fundamental factors.

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February 1976

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