Supercooling the Generator

ELECTRIC POWER RESEARCH INSTITUTE

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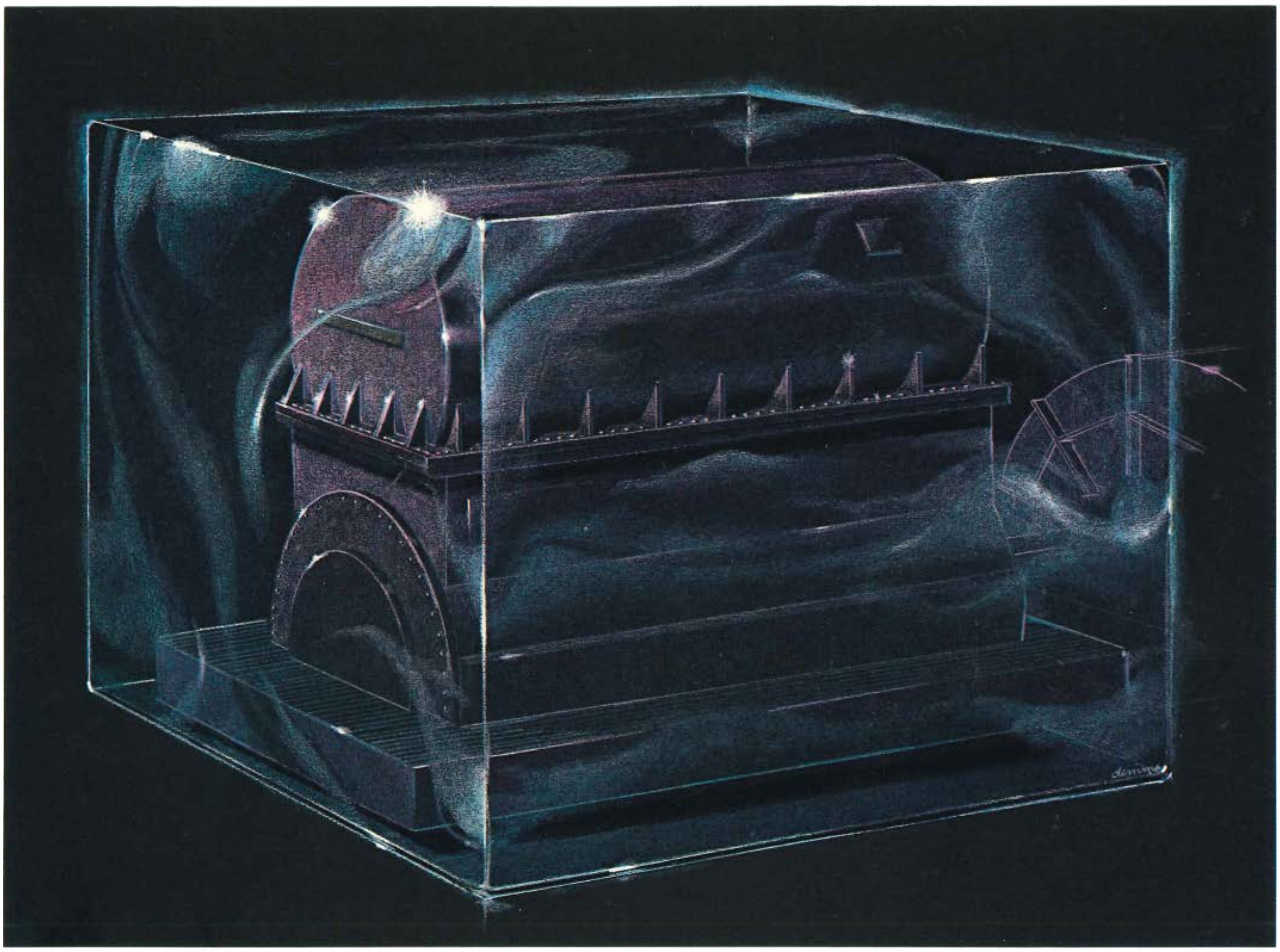

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Cover: The helium-cooled superconducting generator produces a very efficient electric power flow. It suffers fewer electrical losses than the conventional generator because of its supercooled operation.

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Superconductivity: A Portent of Things to Come

Superconductivity is not a panacea for all the loss problems in power engineering, but it does hold promise for some commercial applications. The cover story this month reports on a research project to develop a superconducting generator. Perhaps even here there is a bit of a definition problem because only the field of the generator would be superconducting, while the stator (where the useful output is generated) would remain at room temperature. Superconductivity is the phenomenon in which certain specific metals lose all apparent resistance to the flow of an electric current at extremely low temperatures.

The principle was first discovered in 1911 by Kamerlingh Onnes at the University of Leiden in The Netherlands. Working with mercury because it could be obtained in extremely pure condition, Onnes discovered that the reduced resistance of mercury to the flow of electricity did not continue on a smooth curve at extremely low temperatures. Rather, at about 4 K, the resistance dropped precipitously to an immeasurably low value. Although this was the birth of superconductivity, W. Meissner and R. Ochsenfeld later discovered that the superconductors tended to expel magnetic flux from the superconducting material. Because of the low current density and relatively small critical magnetic fields associated with the then-known superconductors, the phenomenon was just a laboratory curiosity for several decades.

Not until the 1960s were superconductors discovered that could sustain very high current densities in the presence of high magnetic fields. Over the past 20 years many scientists, both in this country and abroad, have pursued superconductivity because of its inherent promise. Much of the work has been directed toward developing metal alloys that would exhibit superconducting properties at higher temperatures. It is, of course, also necessary that a practical superconductor have the mechanical properties that will permit its manufacture in useful shapes. Perhaps the best compromise material to date is an alloy of niobium and germanium, which has a superconducting transition temperature of 23 K.

The promise of superconductivity has been pursued for many applications. One is the concept of storing energy in a magnetic field around a superconducting magnet. Another is the concept of a superconducting transmission line that could transfer almost limitless quantities of electric power with very low losses. However, both the cost and difficulty of maintaining a superconducting enclosure (a Dewar) for such a line over long distances have not yet been resolved.

Both superconducting transformers and superconducting generators have brought a gleam to the eyes of electric power engineers over the past 20 years. Perhaps the superconducting generator featured in this issue will be the first commercially acceptable product from this new and exciting technology.

John J. Dougherty
Director
Electrical Systems Division

Authors and Articles

Adding three quarters of one percent efficiency doesn't sound like much, especially when a machine routinely performs at 98.5%. The paradox is that this fractional gain can cut the losses (the 1.5% inefficiency) by half.

Electricity Generation Near Absolute Zero (page 6) explains why the effort should be an economic winner, despite the design complexities of a rotor that must spin at −453°F (−269°C) while thermally insulated from a stator at 180°F (82°C). Jenny Hopkinson, *Journal* feature writer, developed the article with the aid of James Edmonds, project manager for rotating machinery in the Power Systems Department of EPRI's Electrical Systems Division.

Before coming to EPRI in November 1978, Edmonds managed DOE research projects in energy storage and designed a research program in electrical machinery. Between 1968 and 1977 he was employed by American Electric Power Service Corp., where his last assignment involved responsibility for all electric rotating machinery on the AEP system. Edmonds is a 1968 graduate of the University of Illinois.

■

Opinions on energy conservation seem to vary according to the definitions used. Intractable environmentalists insist on an absolute reduction of energy use, while others argue that conservation is relative—more productive energy use with less waste and greater efficiency. And the electric utility? It is likely to accept both the definitions, and all the others in between.

Movement Toward Conservation (page 12) surveys a range of utility motivations and practices that are thoroughly pragmatic. Science writer John Douglas's message is that one way or another, energy conservation by utilities must work—and it does.

Two staff members with utility experience in conservation helped Douglas develop his article. Orin Zimmerman, director of the Energy Utilization and Conservation Technology Department, came to EPRI in February 1979, initially on loan from Portland General Electric Co. His 32-year utility career includes operations, distribution engineering, and marketing; after 1975 he was PGE's general manager of conservation and energy management. In that position Zimmerman developed new company programs and worked with local and national agencies on electric codes, research needs, and customer service criteria to advance conservation.

Michael Lechner, a project manager on Zimmerman's staff since March 1980, is on loan to EPRI from Public Service Co. of New Mexico. As an energy conservation engineer there since 1976, he evaluated many heating and cooling technologies and coordinated several experimental solar projects (including one sponsored by EPRI). Earlier, Lechner worked for Bovay Engineers, Inc., as a design engineer on civil and mechanical engineering projects. He is a 1971 mechanical engineering graduate of the University of New Mexico.

■

Stress corrosion cracking is a phenomenon resulting from the combination of chemical environment and mechanical stress; neither alone produces the effect. The cladding of nuclear fuel rods falls prey to such cracking. Up until now, preventing fuel rod failure has meant reduced reactor operation and costly replacement power.

Improving Fuel Rod Performance (page 18) reviews many findings of studies sponsored by EPRI since 1975 to help utilities define and avoid the most stressful operating regimes and to achieve better corrosion resistance in future designs of core components. The article was written by Howard Ocken and adapted for the *Journal* by Suzanne Knott, science writer.

Ocken has managed EPRI's research projects on nuclear fuels since he came to the Institute in October 1974. For seven earlier years he was with the Bettis Atomic Power Laboratory of Westinghouse Electric Corp., where he conducted analytic studies of the response of nuclear fuel components when irradiated. Ocken majored in metallurgical engineering and metallurgy throughout his university work; he has a bachelor's degree from New York University and a master's degree and a doctorate from Yale University.

■

There is an easy image that today's electronic gadgets and phenomena are always tiny and blindingly fast. This leads to another, comparative image that electric apparatus and functions are big and lumberingly slow.

Keeping the Surges Out of the Circuit (page 24) traces a technology development that combines attributes of both images. Feature editor Ralph Whitaker reports on a semiconductor capable of less-than-microsecond response time but big enough to handle the switching surge of an experimental 1200-kV power system—or the overvoltage surge of a lightning bolt. Vasu Tahiliani, Electrical Systems Division, guided the research and furnished technical background for Whitaker's article.

An EPRI project manager since January 1977, Tahiliani entered the R&D field five years earlier when he joined I-T-E Imperial Corp. (now a part of Brown Boveri Corp.) to work on the development of gas-insulated cable and components. From 1966 to 1971 he worked for McGraw-Edison Co. on a number of electrical component designs. Tahiliani graduated in electrical engineering from the University of Baroda (India); he earned an MSEE degree at West Virginia University.


Tahiliani


Lechner


Zimmerman


Ocken


Edmonds

ELECTRIC GENERATION NEAR ABSOLUTE ZERO

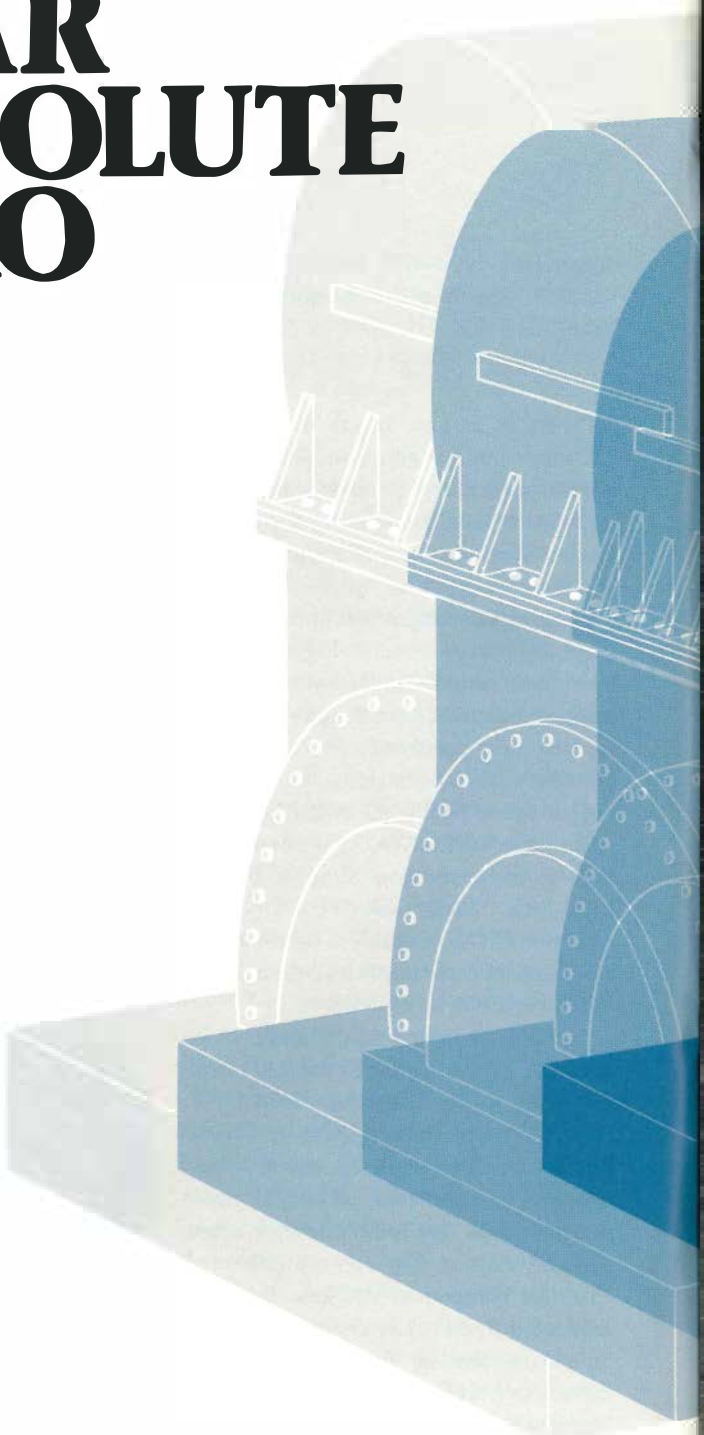
Early in the1900s a Dutch physicist, Kamerlingh Onnes, discovered superconductivity—the complete disappearance of electric resistance in certain metals when they are cooled close to absolute zero with liquid helium. Since then, this same type of liquid coolant has been used in superconductive research in many countries, among them Austria, France, Japan, Switzerland, West Germany, the United Kingdom, and the USSR.

But it will be in the United States, if all goes well, that the world's first commercial liquid-helium-cooled generator goes on-line in early 1985. The largest of its kind, the 300-MVA (270-MW) superconducting machine is being designed and built by Westinghouse Electric Corp. at its facilities near Pittsburgh, Pennsylvania. The cost of the six-year project is $19 million, which is shared equally by Westinghouse and EPRI's Electrical Systems Division. Before this project began, Westinghouse's largest operating generator of this type was a 5-MVA machine. But even though the newest generator represents a 60-fold jump in power output, it is still only a quarter the projected size of the full-fledged version, a 1200-MVA superconducting generator that has yet to be designed and constructed.

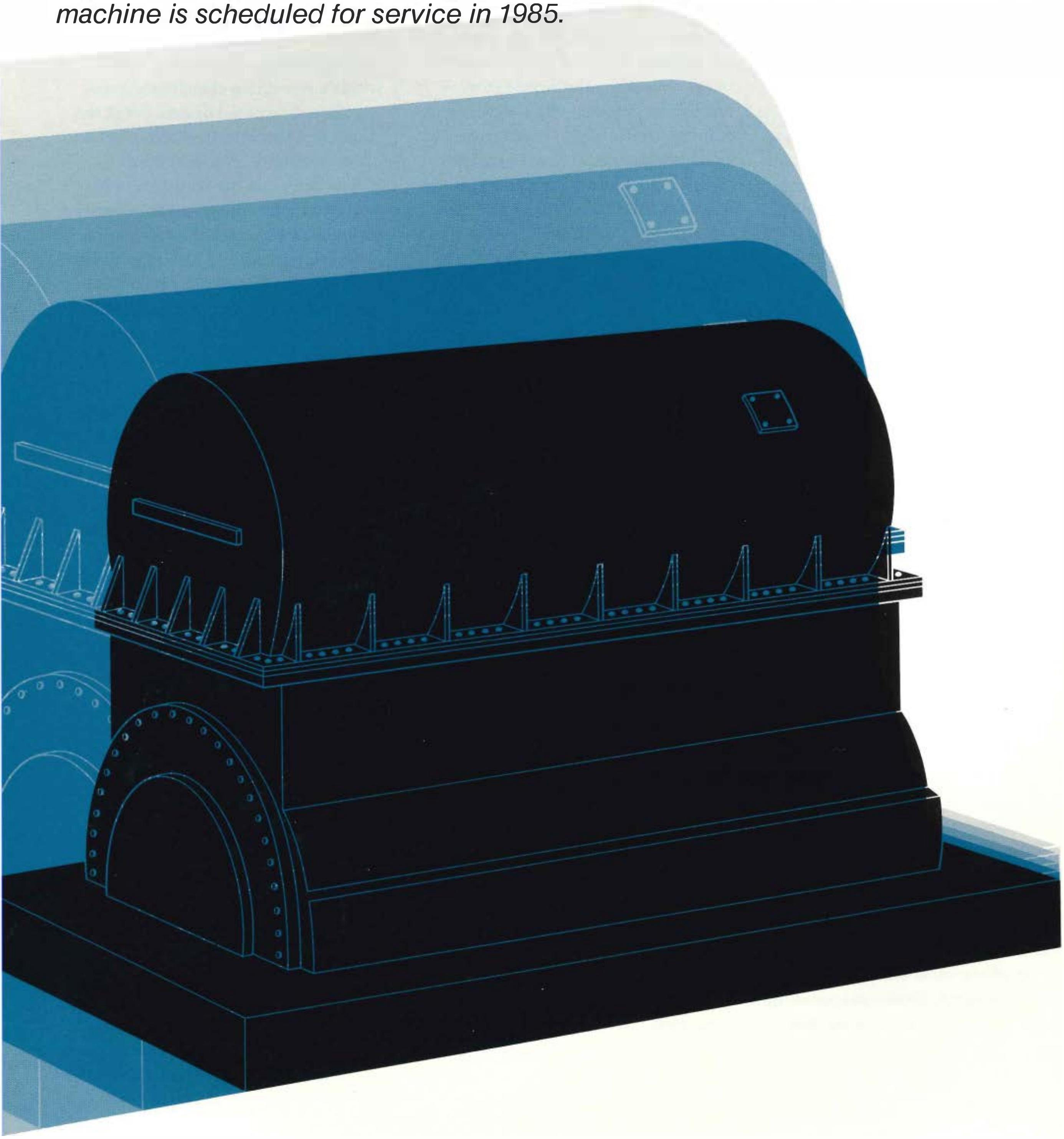
Installation plans

The 300-MVA generator, which will be capable of producing electricity for about 90,000 homes, will be installed in 1985 at an existing power plant of a large electric utility. It will replace a conventional generator at a time when routine maintenance normally takes place. In this case the outage period may have to be stretched to provide sufficient time to modify the facilities, install the new generator, and prepare the unit for operation as an integral part of the power plant, connected with the power grid.

After a year's operation, the new generator will be thoroughly inspected to determine the ability of the design to ensure long-term, continuous, and



Partially cooled by liquid helium, the superconducting generator is smaller, more efficient, and more resilient to variations in load than its conventional counterpart. And each attribute brings with it economic advantages. Commercial success will depend in large measure on a long-term field test; a 300-MVA superconducting machine is scheduled for service in 1985.



reliable operation in both the power plant and the utility system environment. In addition to a technical examination of the generator, a comprehensive economic analysis of the unit's performance will be made. Cost reduction, after all, is the incentive for developing the superconducting generator—cost reduction in manufacture, transportation, and system operation.

Factory and utility

Conventional generators are being constructed in larger and larger sizes to cope with the rising demand for electric power. In fact, some are so large that they must be transported in parts and then assembled on site. This means that after the machine is factory-tested as a unit, it must be disassembled for transportation. It also means that the manufacturer must rely on accurate reassembly of the machine at the power plant construction site—a task usually done by craft labor untrained in the complexities of generator manufacture. It is as if an aircraft manufacturer sent the sections of an airplane to be fitted together by an airline company. The higher risk of mistakes in assembly could result in less reliable operation.

The superconducting generator is between one-half and one-third the size and weight of a conventional generator. Because less material is needed, the cost of manufacture is less, and as the superconducting generator is also lighter, there are fewer problems in transporting it from factory to utility site. In addition, it has a better chance of reliable performance because it is delivered to the utility fully assembled.

In operation, the superconducting generator will have the inherent benefits of higher efficiency and superior electrical performance. These characteristics result from the interaction of extremely strong magnetic fields made possible by the loss-free flow of electric current in the superconducting rotor winding. The actual increase in efficiency is between 0.5% and 1%, a difference that does not at first seem spectacular, particularly in view of the fact that conventional generators already boast 98.5% efficiency. But the other side of the coin is the electrical loss, that is, the 1.5% inefficiency, which represents a considerable financial loss when translated into potential revenue. Energy is lost in the form of heat caused by the flow of current through resistance in the electrical parts of the generator. This wasted energy is electricity that could have been sold.

As an illustration, suppose a conventional 800-MW generator is 98% efficient; that is, 2% of the electricity it produces is lost as heat. That 2% is 16 MW, which represents about $200 million in lost revenue for a baseload plant operating at 90% availability over a 40-year life and producing revenue at 4¢/kWh.

In comparison, by raising the efficiency 1%, a superconducting machine cuts electrical losses by 50% to 8 MW and restores $100 million in revenue to the utility. The economy, as would be expected, improves for larger machines.

In addition to the efficiency aspect of improved operation, superconducting generators may allow the design of generators with high-voltage stator windings, which would eliminate the need for step-up transformers. This would enable long-distance, high-voltage transmission lines to be connected directly to the generator.

System stability

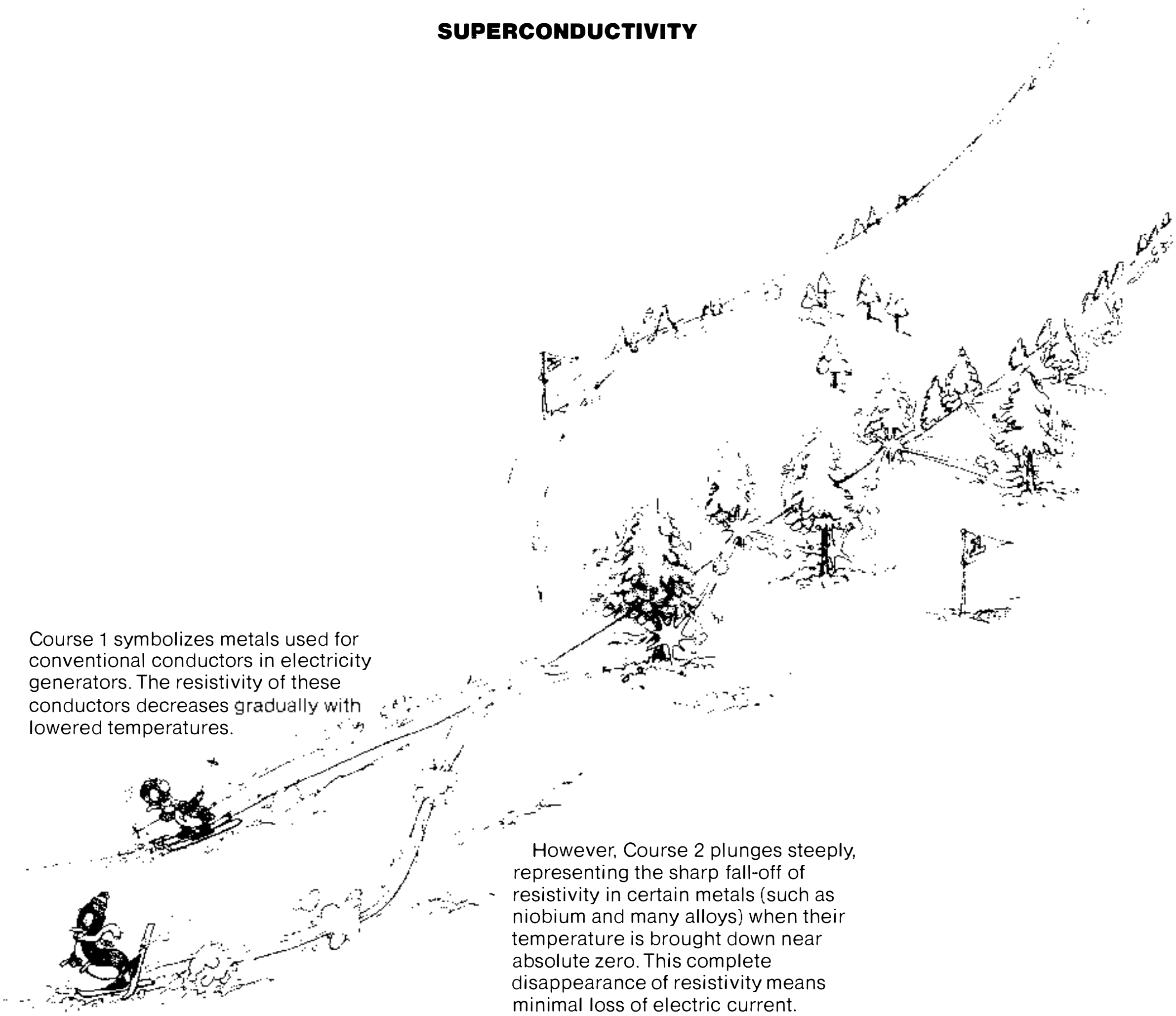
For larger blocks of electric power generation, there is a greater need to deal with the problems of system stability. When power is being generated and consumed in a balance of supply and demand, the electric system is said to be in a steady state. But when the give-and-take of electric power gets out of balance, the system can suffer a possibly damaging transient, that is, a change in electricity flow from maximum to minimum, or even a reversal in direction of flow.

The enhanced electric characteristics of the superconducting generator allow a greater contribution to electric system stability than that which can be achieved by a conventional generator. For instance, if the electrical load on a conventional generator is cut by a fault (say, a short circuit or a lightning strike), this fault must be automatically cleared within a fraction of a second, that is, within a few cycles of alternating current. Usually, special devices break the circuit momentarily, then reconnect it to allow continuity of current flow.

But sometimes the fault cannot be cleared quickly enough, so the circuit remains broken, load to the generator is not reestablished, and turbine generator shaft speed builds up. The reason for this is that the generator rotor shaft is still being driven at the same mechanical power level by the steam turbine, yet little or none of the power generated is able to flow to the grid. The rotor shaft accelerates to the point where unit protective devices sense overspeed and trigger an automatic shutdown of the unit, an expensive maneuver that ultimately may entail buying power from other utilities to maintain the level of service to customers.

An alternative method of preparing for transient load interruptions is to install more transmission lines so the generator can continue feeding power to the utility grid despite the failure of one transmission line. However, this is a less and less likely option because of the high cost of land for additional rights-of-way, high manufacturing and installation costs of towers, lines, and insulators, and increasingly greater environmental opposition.

Compared with a conventional generator, the ability of a superconducting generator to enhance system stability is characterized by an increase in the machine's critical-fault clearing time. These extra fractions of a second may mean the difference between a unit shutdown or staying on-line immediately following a fault. It may also postpone the need for more transmission lines. In fact, the implications for cost savings are enormous,



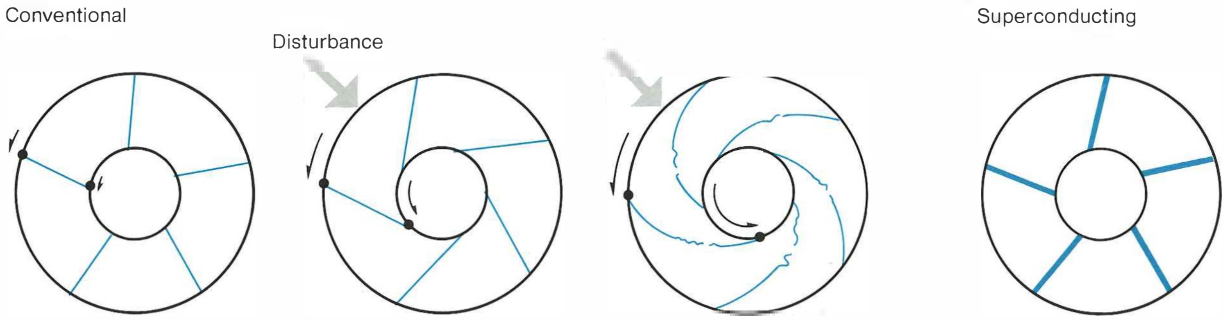
Course 1 symbolizes metals used for conventional conductors in electricity generators. The resistivity of these conductors decreases gradually with lowered temperatures.

However, Course 2 plunges steeply, representing the sharp fall-off of resistivity in certain metals (such as niobium and many alloys) when their temperature is brought down near absolute zero. This complete disappearance of resistivity means minimal loss of electric current.

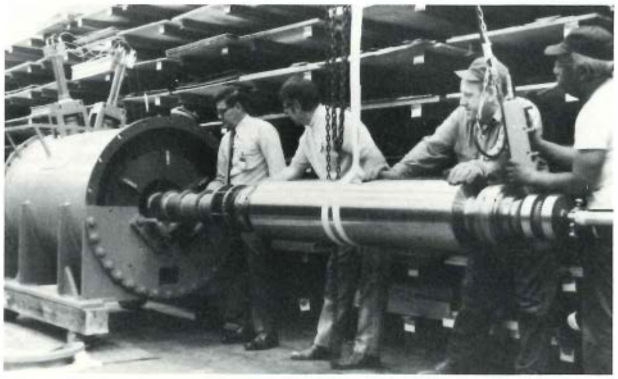
The flow of electrons that constitutes the electric current required to produce a generator's rotating magnetic field can be either relatively chaotic and wasteful or ordered and efficient. It all depends on the temperature of the material through which the electrons flow. At normal temperatures in a conventional generator (about 180°F; 82°C), electrons travel randomly through the conductor material, which is usually copper. At these temperatures, the copper's molecular lattices are also in movement, so the electrons are very likely to collide with them, producing friction and thus heat. The heat is a symptom of electrons lost, a phenomenon that reduces the current transmitted by the copper conductor. These electrical losses caused by the resistance of the conductor material constitute reduced efficiency in a generator's power production.

However, if the temperature of certain conductor materials, such as a niobium-titanium alloy, is dropped to near absolute zero (in this case, −453°F; −269°C), the flow of electric current becomes ordered and efficient. In fact, the electrons now move in pairs, and in this manner they pass easily through the very cold and comparatively immobile molecular lattices of the conductor material, avoiding collision and heat production. This unimpeded flow of current, with minimal losses, is called superconductivity. □

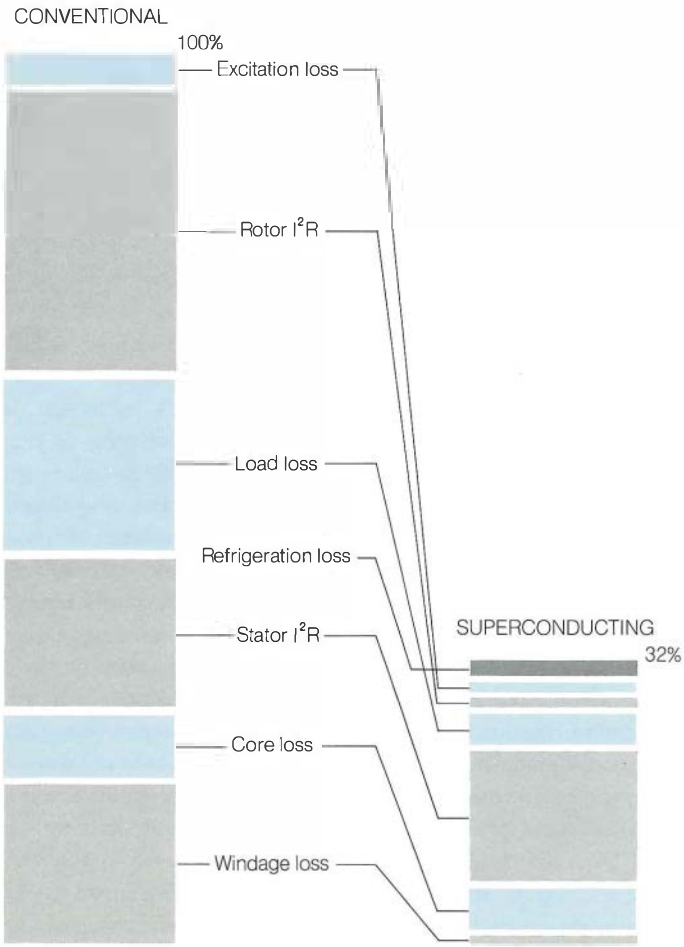
During a temporary disturbance, any electrical system relies for its stability on the inertia of spinning shafts, that is, on the electrical rotating machinery of the generating plant. A disturbance out in the transmission network can jolt the connection between the load and the generating function by upsetting the coupling effect of the electromagnetic fields between the stator and the rotor. Shown here is a simple analogy of this connection: a central wheel (the rotor) is connected to an outer wheel (the stator, or load) by rubber bands (the electromagnetic coupling effect). In a conventional generator, these bands are rather weak and loose, and they may break under stress (sudden variation in load). In a superconducting generator, however, the bands are stronger and the wheels are therefore more tightly coupled and more resilient to sudden stress.



There are a number of relatively small-scale superconducting generators under test in the United States.



A comparison of segregated losses—a 1200-MVA conventional generator and a superconducting generator with a low-voltage winding.



once superconducting generators are proved and established as a mature technology.

Initial hurdles

To begin with, the new generators are bound to have transitional troubles. The very fact that they are more complex than conventional generators predisposes them to a higher probability of startup problems.

The most obvious complexity in a superconducting generator is caused by the need to refrigerate the spinning rotor. (Superconducting generators do not have superconducting stator windings.) The liquid helium coolant has to continually bathe the rotor windings and several other parts of the rotor, and yet the components, which are at temperatures near absolute zero, must be thermally insulated from outside temperatures. The rotor shaft must therefore be constructed as a series of cylinders, one inside the other. The hollow center of the innermost cylinder is used as a reservoir for the liquid and gaseous helium. From this spinning pool, helium is fed via radial slots to the niobium-titanium windings. A vacuum space within the structure of concentric cylinders provides a thermal radiation barrier between the near-absolute-zero liquid helium and the warm ambient temperature of the rest of the generator.

These cylinders within cylinders have to withstand rotation at 3600 revolutions a minute. The centrifugal force is enormous, yet no part of the rotor winding may shift relative to an adjacent conductor or insulator, not even a minuscule amount, during steady-state operation or during an electric transient, otherwise heat induced by the friction can cause the superconductor to develop resistance and create possible damage because of the very high current flow in the winding.

As the liquid helium absorbs any heat built up in the conductors and the rotor components, it becomes less dense. Because of the centrifugal force, the less-dense liquid moves toward the center of the rotor, the helium reservoir. As it does so, at some radial distance the liquid vaporizes. This gas collects in the very center of the rotor and is then vented through a rotating transfer coupling to compressors, which reliquefy it for continuous use. (Helium is inert and nonflammable, unlike gaseous hydrogen, also used as a coolant for generators. Although liquid helium must be handled carefully, few problems are anticipated in training utility operators in its use.)

A further problem with the complexity of superconducting generators is caused by the rotor design of cylinders within cylinders—interior parts of the rotor are virtually inaccessible for inspection or repair. In addition, the material stresses on the rotor are very high. Not only do the temperatures range from ambient in the outer cylinder to near absolute zero in the inner cylinder, but the high energy density (getting more kW out of the machine per pound of weight) stresses the rotor materials. This can be compared to continually racing a standard car as though it were a formula model. Further, the bracing systems that hold the rotor together also undergo great strain.

So along with the foreseen advantages of the superconducting generator go a number of anticipated breaking-in snags, which is to be expected in the operation of equipment that is the first of its kind.

A matter of conviction

The ultimate test of any new technology lies in its value as a commercial system. In a few years' time, it will be the turn of the superconducting generator to face the risk of going on-line. Working up to that event will take a number of stages. By this summer, Westinghouse will have manufactured and tested some of the components. By year-end, the rotor forging and major rotor components will have been delivered in the unfinished state. The process of machining these components to achieve perfect balance will be one of many steps in the progress toward the proving of this new technology.

There are many who believe in the viability of superconducting generators; there are also many skeptics. The believers are convinced that the potential pluses of this technology will outweigh the initial minuses. James Edmonds, EPRI project manager for rotating electrical machinery, is optimistic. He is also realistic in his comment, "Some people have termed this an all-or-nothing project. If the generator goes into a utility and has a rather spectacular failure, then we might have set back the possibility of superconducting generator technology by decades. If one looks back at the advances of the generator as we know it today, those advances have normally taken place outside the power plant. In this case, however, the real test will take place in the power plant; successful long-term operation of the machine will prove performance reliability, thereby enhancing the long and comprehensive tests already performed by the manufacturer. If all this works, we can then say we have a major breakthrough in generator technology." ■

Further reading

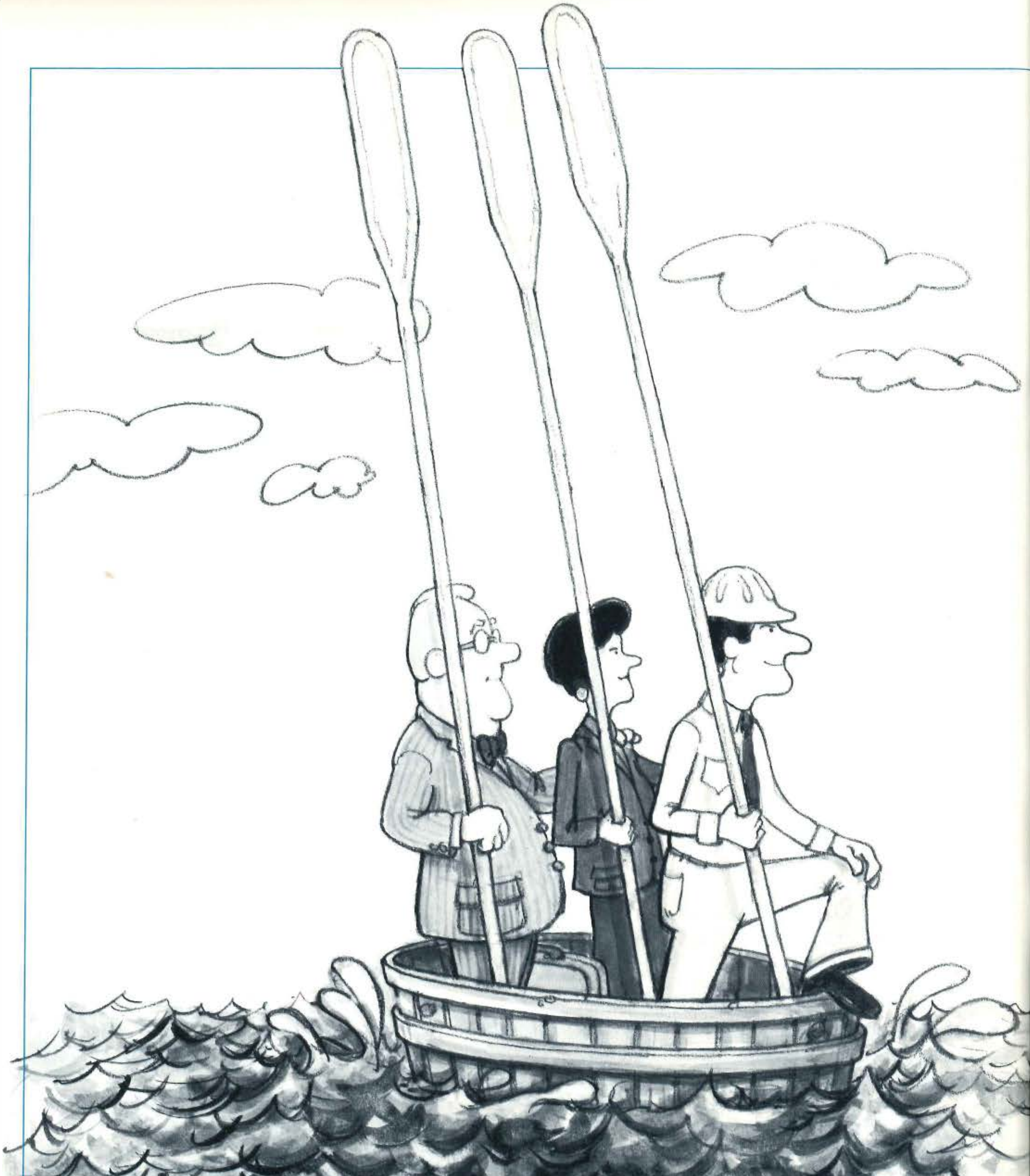
J. S. Edmonds and W. R. McCown. "Large Superconducting Generators for Electric Utility Applications—The Prospects." In *Proceedings of American Power Conference*. April 1980.

J. S. Edmonds. "Superconducting Generator Technology: An Overview." In *IEEE Transactions on Magnetics*, Vol. MAG-15, No. 1 (January 1979), pp. 673–679.

Superconducting Generator Design. Final report for RP429, prepared by Westinghouse Electric Corp., November 1977. EPRI EL-577.

Mario Rabinowitz. "Cryogenic Power Generation." *Cryogenics 17*, 319 (June 1977).

This article was written by Jenny Hopkinson. Technical background information was provided by J. S. Edmonds, Electrical Systems Division.



MOVEMENT TOWARD CONSERVATION

For conservation programs to succeed, utilities, customers, and regulators must unite in the search for the most effective use of all limited resources—fuel, capital, and the natural environment. Options now encompass load shifting and substitution, as well as improvements in efficiency.

Utilities across the country are looking for new ways of doing an old job—meeting the electric energy needs of their customers in the most cost-effective manner. An emerging factor in accomplishing this goal is conservation. And its growing importance is directly attributable to the speed of implementation. Advanced technology to use alternative sources of energy typically takes several decades, or even longer, to develop and deploy. Conservation, on the other hand, can make an important difference in the near term.

But conservation has become a catchword in modern society, and as such, a term that means different things to different people. For example, it is used by some to mean a cutback in all primary energy resources, domestic and foreign, and by others as the displacement of scarce energy resources, such as oil and gas. Still others hold alternative viewpoints and combinations thereof. Progressively, the utility industry has taken a more comprehensive viewpoint. From the utility perspective, conservation has three broad interpretations: increasing efficiency, load shifting, and substitution.

By making the processes in which energy is consumed more efficient, energy supplies will last longer. An example of this would be the development of an electric motor that would perform the same amount of work on less energy. By the same token, eliminating waste has essentially the same result—prolonging energy supplies. This is illustrated best by weatherization programs advocated for buildings.

Shifting electric energy use from peak demand times is commonly referred to as load management. Utilities are giving this approach renewed emphasis because electricity generated during peak hours is typically derived from oil or gas; during off-peak hours, from coal or nuclear. Load management could thus alleviate some of the nation's dependence on rapidly depleting and increasingly expensive fuel resources. Additional benefits from load management can come in the form of improving the efficiency of power plants already in place and thus conserving capital resources to build additional peaking capacity.

Where price and availability of an energy resource are in serious question, as they are with oil, electric energy could be a suitable substitution. National benefits can be reaped if the electric power is produced by resources indigenous to this country.

Of these three aspects of conservation, increasing efficiency and load shifting will be the quickest to be implemented and their effects the soonest to be felt. Substitution of substantial quantities of coal- or nuclear-generated electric energy for that presently being supplied by oil or gas is a more long-term proposition. As other long-term technologies are refined and improved, such as solar and wind, they may also provide for some substitution of fossil-fuel-derived electric energy. On a large scale, energy from these plants could be distributed through the existing grid networks; on a smaller scale, the customer might own and operate the alternative energy system. The effect of this substitution may not be felt for decades.

It is worth noting here, though, that some specific technologies potentially offer a range of conservation benefits across all three areas. For example, a heat pump retrofitted in place of an oil-burning furnace is an energy-efficient electric space heating system that can be adapted to load shifting. Solar heating and cooling systems for buildings and electric vehicles are also examples in this category.

Within each of these broad categories, utilities are closely examining all the various technical and strategic options open to them and their customers. The type of conservation strategy utilities will choose to pursue will depend largely on their particular energy situation, the characteristics of their customers' needs, and the area of the country they serve. The energy situation is complex and often bound up with local or regional

SURVEYING UTILITY CONSERVATION ACTIVITIES

Recently EPRI has sponsored surveys to determine how many utilities are involved in some kind of conservation program. These surveys, conducted annually, show which specific technologies are being used most frequently. The number of projects reported in 1979 was double that of the 1977 survey, and preliminary returns for 1980 show a continuing upward trend. Some projects have been going on long enough that the 1980 survey will also be able to give the first detailed look at results and benefits of such conservation efforts. The purpose of these projects is to locate problems and find solutions before large-scale applications are attempted.

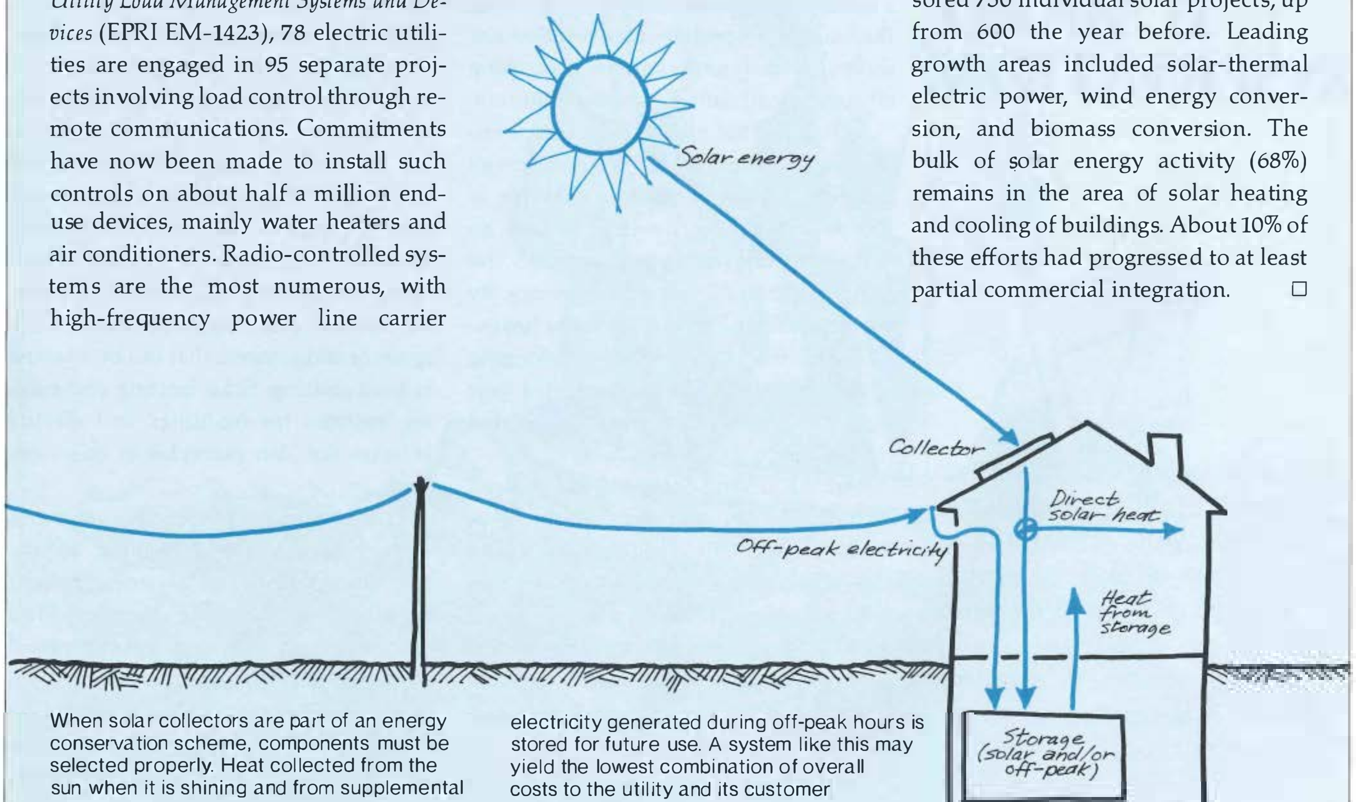
According to the report *Evaluation of Utility Load Management Systems and Devices* (EPRI EM-1423), 78 electric utilities are engaged in 95 separate projects involving load control through remote communications. Commitments have now been made to install such controls on about half a million end-use devices, mainly water heaters and air conditioners. Radio-controlled systems are the most numerous, with high-frequency power line carrier projects second. Initial results indicate that the unit costs of control decrease sharply for a system size of approximately 30,000 units and control of electric water heaters and irrigation pumps has proved most acceptable to customers. Questions remain about the acceptability of controls on air conditioners and space heaters.

The same survey shows that 56 utilities are carrying out 74 thermal energy storage projects. As such systems are in an earlier stage of development, many of the projects are rather small in scale, and the primary objective of most utilities at this point is simply to confirm operating reliability and effectiveness.

Preliminary results indicate that heat storage can be cost-effective if there is a rather modest differential between regular electricity rates and off-peak rates. Introduction of the systems would apparently be enhanced if the utility owned and maintained the equipment and then leased it to its customers.

Involvement in more general conservation programs is reported by 78 utilities. These include projects that provide economic incentives to customers who save energy, advertising and promotion campaigns, introduction of energy-efficient products and systems, adoption of efficiency standards, and heat recovery programs.

An earlier EPRI study (*EPRI Journal*, December 1979) found that more than 180 electric utilities were also engaged in solar energy research and had sponsored 750 individual solar projects, up from 600 the year before. Leading growth areas included solar-thermal electric power, wind energy conversion, and biomass conversion. The bulk of solar energy activity (68%) remains in the area of solar heating and cooling of buildings. About 10% of these efforts had progressed to at least partial commercial integration. □



When solar collectors are part of an energy conservation scheme, components must be selected properly. Heat collected from the sun when it is shining and from supplemental electricity generated during off-peak hours is stored for future use. A system like this may yield the lowest combination of overall costs to the utility and its customer economic, environmental, and political considerations. For purposes of discussion, two broad situations can be identified: resource-constrained utilities and capacity-constrained utilities.

A utility may have plenty of reserve generating capacity on-line to meet any peaks of demand but not have the primary energy resources available to use that capacity. Or the primary energy resource might be oil, available but priced at a premium. Customers may thus not be able to receive the total kilowatthours of electric energy they need, or it might be exceedingly expensive. Conservation programs that these types of utilities would pursue must be aimed at reducing consumption through greater end-use efficiency. The load management option might also be attractive if a utility has underused off-peak capacity provided by coal or nuclear resources.

A utility might be able to supply all the electric energy requirements of its customers but not have sufficient generating capacity to meet peak power demands. Such a utility would try to implement conservation measures that reduce demand peaks and fully use the off-peak capacity of existing equipment before building new plants. This implies energy storage, either at the customer's location or on the grid. Either way, the load management function is carried out.

Utility-specific examples

Among the utilities that are launching aggressive energy conservation plans to offset energy resource constraints are Portland General Electric Co., Pacific Power & Light Co., and Los Angeles Department of Water and Power. PGE and PP&L are facing shortages in total energy because of the dependence of the region on hydroelectricity, which is constrained by rainfall and terrain. Major coal and nuclear generating facilities have been added or planned, but the dominance of hydro prompts them to emphasize a reduction in total electricity consumption rather than shifting demand.

Two projects being considered to address this problem are an expanded building weatherization program, solar water heating, heat pump water heating, and an extensive water heater wrap effort. Each of these would improve the end-use efficiency of the energy needed for space and water heating. Another project is looking at variable connection charges, which would encourage construction of homes that are more energy-efficient. These strategies have the added benefit of providing some aspects of capacity conservation.

Because Los Angeles DW&P has a surplus of energy-constrained peaking capacity (oil-fired), many of the load management techniques that may be cost-effective for other utilities are not appropriate in the Los Angeles area. The department is therefore concentrating its energy management efforts on energy audit programs, a swimming pool filter pump designed to reduce the hours of pump use, and development of an interruptible rate for commercial and industrial customers. By providing such rates, a utility can shed nonessential loads when demand approaches peaking conditions that require oil-fired generators.

Another example of a utility trying to improve its efficiency of electricity use is the Tennessee Valley Authority. In 1979 the average annual TVA residential electric energy use was almost twice the national average. Much of this consumption was for electric heat used by 43% of TVA customers, compared with 16% nationally. In response to this situation, TVA developed and launched a home insulation program designed to weatherize more than 500,000 houses by 1987. All residential consumers are eligible for free home energy audits conducted by TVA advisers. Those with electric heating or cooling may then take advantage of interest-free loans that cover material and labor costs for insulation, weatherstripping, storm windows, caulking, and other repairs. For homes that are unsuitable for such whole-house treatment, TVA has launched a warm room project to insulate and heat one primary living area. Typical heating reductions of 25–30% are reported by project participants.

Typical of the utilities that are making significant efforts to minimize peak growth are New England Electric System, General Public Utilities Corp., and American Electric Power Co., Inc. To encourage shifts of electricity use away from peak periods, New England Electric is providing customers with new rate incentives, including special rates for homeowners who install heat storage devices. The company has also developed and patented its own two-way automatic communication system, which is capable of controlling selected customer loads. It plans to reduce average annual peak load growth to 1.9% through such programs, thus substantially reducing the need for additional generating capacity and subsequent capital requirements.

The fundamental theme of GPU's master plan is capacity offset, that is, considering company investment in customer end-use equipment that is load-managed as an alternative to investment in new generating facilities. The GPU companies have promoted time-of-day rates since 1973, began energy audits in 1978, have implemented off-peak control of water heaters, and have demonstrated more than 30 off-peak thermal energy storage systems.

Thermal energy storage field tests performed by American Electric and some of its customers have demonstrated the potential of heat storage devices to reduce the need for new generation and transmission facilities. The company found that customers judged comfort and equipment performance as being very acceptable.

An example of some of the savings utilities and their customers can expect through their conservation efforts can be seen in the results of the relatively long-standing load management program launched by Buckeye Power, Inc. The 1980 winter was the sixth year of operation for this system and the total net savings achieved by the end of this period amounted to more than the total capital investment required for the equipment to date. The system uses radio control to curtail the use of electric water heaters during on-peak periods, thus saving Buckeye and its member cooperatives an estimated $2.5 million annually, a good example of load shifting.

Turning to the long-term potential of substituting abundant energy resources for scarce ones, many utilities have demonstration programs. One example of substitution is the electric vehicle program being undertaken by Long Island Lighting Co. in Mineola, New York, which involves 110 vehicles. This program also addresses load management strategies, as the vehicles are being charged off-peak. Another substitution project is being carried out by Pacific Gas and Electric Co. A solar water heater retrofit demonstration program is under way. The program offers several alternatives for purchasing the equipment, targeted to different geographic areas and income groups.

Another technology being tried by several utilities—cogeneration—represents some interesting conservation potential. This entails the generation of electricity at a customer's location with the subsequent use of both the electric and thermal energy. Such dual energy-use systems promote more efficient use of the original resource, usually gas or oil. Increasing efficiency, load shifting, and substitution can all come into play here, particularly if the cogenerator uses coal or a more exotic resource, such as solar. Some of the utilities getting involved with industries in their service areas are Alabama Power Co. (with International Paper Co. and Scott Paper Co.), Commonwealth Edison Co. (with Caterpillar Tractor Co.), and Hawaiian Electric Co., Inc. (with C&H Sugar and Oahu and Waialua Sugar).

These are just a few of the many examples of the growing involvement of the utility industry in conservation. More of these efforts are highlighted in the report of research cosponsored by EPRI and DOE *Survey of Utility Load Management and Energy Conservation Projects* (EPRI EM-1606).

Some technical options

Beyond insulation and weatherizing techniques, much of the end-use technology in conservation programs is relatively new. The utility industry is therefore becoming deeply involved with equipment manufacturers in developing and testing new technology. The heat pump is one such device, and although it is already more efficient at regulating building temperatures than resistance heaters and air conditioners, it is continually undergoing testing and improvement. Notable advances in heat pump

technology include improved reliability and more efficient operation in cooler climates. Continued advances in performance characteristics of heat pumps will make them even more attractive as replacement or substitute heating and cooling systems, particularly in areas where other fuels are either scarce or unavailable.

Load management to shift the burden of end-use demand away from peak hours usually involves some type of direct or indirect control of customer loads by the utility. Many of the conservation projects now being sponsored by utilities involve new technologies that feature remote control of water heaters, air conditioners, and other end-use equipment that can be shut off with little or no inconvenience to the customer. This can be done because the load is turned off for only a short time, as in the case of controlled air conditioners or water heaters, and the energy is stored in the form of hot water that may not be needed until later. Customers are compensated by a reduction in their electricity bills.

Radio systems are the most widely used remote load control technology. The cost per control point is low, but receiver address capability is limited. Ripple control, using low-frequency signals imposed on the utility system, has been used extensively abroad; the cost is higher than for radio, but it offers greater receiver address capability and signal reliability. High-frequency power line carrier systems are similar to ripple control, but they require less power and can be either one-way or two-way systems (the latter permit automatic meter reading and other functions).

Thermal energy storage units can help in load management because they can be charged at night when demand and rates are lower. Currently available technologies include ceramic storage units for central heating or for individual rooms, pressurized water tanks for heat storage, cool storage using ice, and combined heat and cool storage systems. Tests so far indicate that in some areas commercial heat storage systems can now be considered cost-effective, but no residential cool storage system is as yet economically attractive.

Solar and other alternative energy technologies can be used as substitutes for conventional domestic water heating, space heating, and even for space cooling; the conventional system is always available as a backup. As solar systems typically have thermal energy storage integral to their design, the opportunity to control or load-manage the backup system is inherent. These systems then offer energy savings, load management, and substitution. Many utilities are researching the potential these systems may offer. However, economic feasibility varies markedly from one area of the country to another and depends on many factors. Some solar energy water and space heating applications of utility-sponsored projects are showing economic promise in the early stages of performance evaluation.

After a half-century of dormancy, electric vehicles (EVs) are being reconsidered because of their potential for conserving petroleum (about half of the oil used in the United States goes for transportation). EVs are also more efficient in their use of primary energy when compared with future transportation fuels, such as synthetic liquid from coal. Eventually they may make an important contribution to electricity load management, as battery recharge would usually occur during off-peak night hours. Considerable technology development remains to be done before a well-integrated vehicle and infrastructure support system is available to ensure EVs will be commercially competitive.

Cogeneration offers an opportunity to use heat energy that was once wasted. One way this could be done is for customers to convert their excess heat energy into electricity. They could then either use the electricity or distribute it to others through the local utility. Alternatively, low-grade steam from power-generating stations can be piped to nearby homes or factories for space heating and for running some relatively low-temperature industrial processes. In the United States the former option is gaining popularity in areas that have large heat-producing facilities, such as refineries, breweries, and chemical companies. The latter option has been tried in some European countries, but it is difficult to establish here because of the attendant social, environmental, and legal problems.

Growing commitment

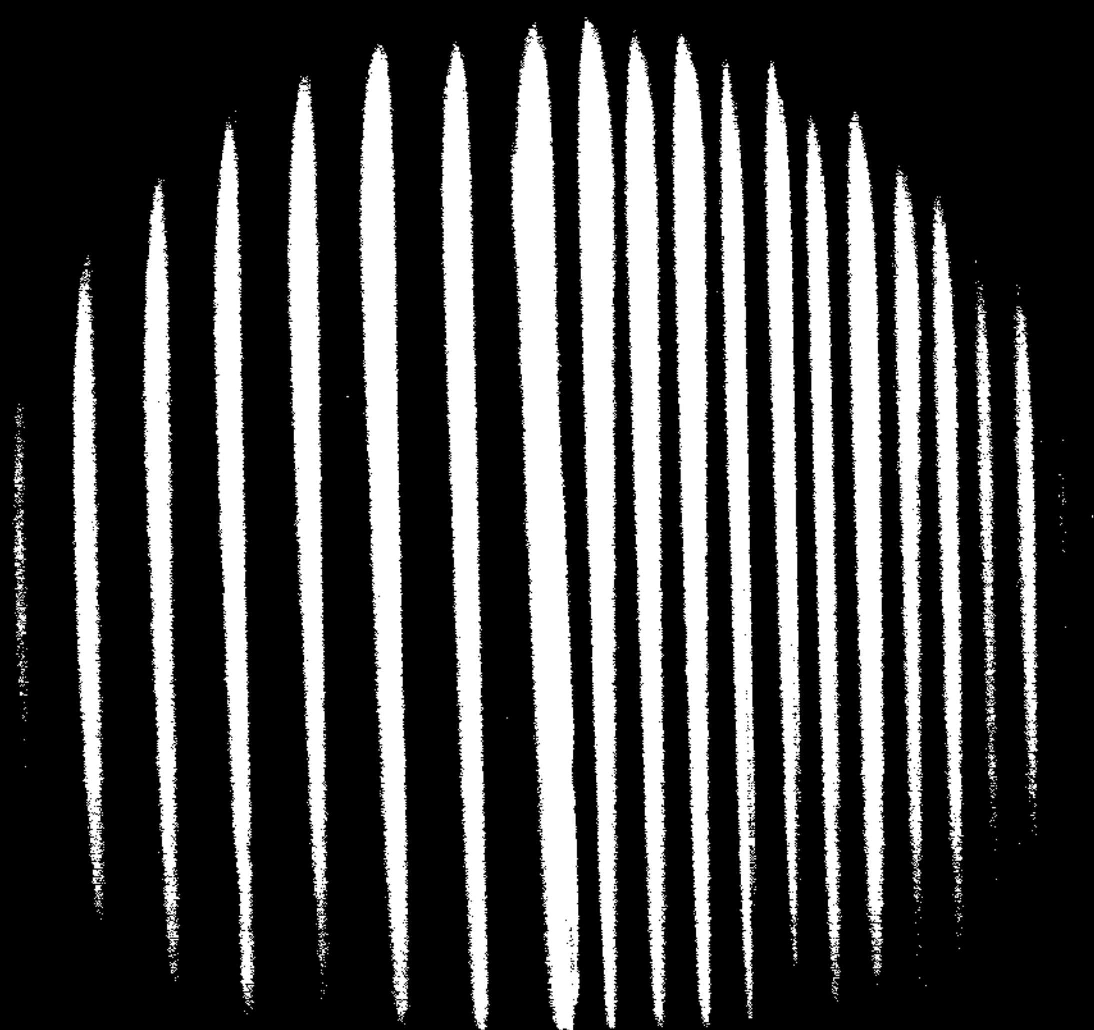
The recent shift by utilities to closely examine increasing efficiency, load shifting, and substitution in planning their futures is being paralleled by the research programs at EPRI. The Advisory Council recently expressed support for national R&D planning goals that affirm the "prime importance of energy conservation," and the Research Advisory Committee and the Board of Directors have authorized a five-year commitment for EPRI's end-use R&D that is nearly double the amount previously planned.

By making it a working reality, the utility industry will move conservation into the forefront of the national energy policy. Although there is still a long way to go before conservation makes a significant impact at the national level, the first steps have been taken. Toward this end, EPRI President Floyd Culler recently wrote, "I hope that people in each community and in various sectors of government are becoming aware of the leadership role that the electric utilities are taking in putting practical, useful, economically beneficial conservation systems into everyday use." ■

This article was written by John Douglas, science writer, and Michael Lechner, project manager. Technical background information was provided by Orin Zimmerman, Energy Management and Utilization Division.

IMPROVING FUEL ROD PERFORMANCE

To reduce the chance of fuel rod failure, utilities now operate nuclear reactors below maximum capacity, which costs millions of dollars annually in replacement power. Current research emphasis is on identifying the causes of failure and minimizing their effects.



Some fuel rods discharged from boiling water reactors (BWRs) in the early 1970s showed cracks in the Zircaloy cladding. Investigators attributed these failures to high localized strain in the cladding caused by contact with the fuel pellets after the gap between the pellets and the cladding had closed. This contact with the cladding is called pellet-cladding interaction (PCI).

The investigators believed the cladding's ability to withstand such stress was reduced because of its exposure to the intense neutron flux of the reactor core. Failures usually occurred following reactor operating conditions in which power was increased rapidly after extended exposure at low power. Subsequent studies established that such PCI-induced failures are found in all fuel rod designs that clad uranium dioxide (UO_2) pellets with Zircaloy, including those for pressurized water reactors (PWRs) and the Canadian and British heavy-water-moderated reactors.

To reduce the risk of these fuel rod failures, utilities operate their nuclear reactors within conservative limits on power increases proposed by nuclear fuel vendors. Of particular concern to U.S. utilities is that adopting these limits results in an industrywide average plant capacity loss of 3% in BWR designs and 0.3% in PWR designs. To replace lost BWR capacity by other generating means currently costs the utilities $150 million annually, and losses for PWRs are about $20 million. Efforts are therefore being made to identify the factors responsible for Zircaloy degradation under PCI conditions and to improve nuclear fuel rod design and reactor operation.

Reactor fuel rods

In a light water reactor (LWR) fuel rod about 300 cylindrical UO_2 pellets are encased in a tube of Zircaloy (a zirconium-base alloy). The fuel rods are bound together in a square array to form the fuel assembly. The heat generated by nuclear fission of the pellets is conducted through the Zircaloy to water, the coolant that flows past the rods. The cladding is designed to retain its structural integrity, maintaining the separation between the coolant and the pellets. The Zircaloy barrier thereby prevents radioactive contamination of the coolant. But changes take place in the fuel rod during operation that affect the ability of the cladding to maintain its integrity.

When power is first raised in the reactor, the Zircaloy cladding is ductile, and the space between the fuel pellets and the cladding is sufficient to accommodate expansion of the fuel. However, the gap decreases as the pellets expand and as the cladding moves inward (creeps down) in response to coolant pressure. This expansion of the fuel pellets and the inward motion of the cladding result in the pellets placing a load (i.e., mechanical stress) on the cladding.

The increase in power also raises the temperature of the fuel, which promotes release of fission products. Fission product gases such as xenon and krypton are poor heat conductors and therefore inhibit heat dissipation, which under some conditions can create a cycle of rising temperature and additional fission product release. Fissioning also forms other chemical elements that attack Zircaloy when released from the fuel. Under these conditions—loading of the cladding and fission product release—an increase in power may cause the Zircaloy cladding to fail.

EPRI launched a research program in the spring of 1975 to study conditions that result in PCI. The program included laboratory experiments on cladding materials to determine the factors responsible for PCI; test reactor experiments on the effects of fuel rod design variations, irradiation, and power ramps (i.e., rapid increases in power) on the propensity of rods to fail; examination of failed commercial reactor rods to determine factors that caused such failures in the commercial reactor environment; and analytic studies to develop a model capable of predicting fuel rod response under diverse operating conditions.

Results of earlier research carried out by General Electric Co. and Westinghouse Electric Corp. at the Bettis Atomic Power Laboratory suggested that stress corrosion cracking (SCC) was responsible for the PCI failures. SCC results when susceptible materials (in this case, Zircaloy) are degraded by the combined action of an aggressive chemical environment and an applied load. SCC is a synergistic process in which neither the chemicals nor the load alone would threaten the integrity of the material.

The EPRI-sponsored projects were undertaken with the assumption that SCC of Zircaloy was indeed the mechanism responsible for PCI failures. The effort was to identify the conditions that make Zircaloy susceptible to SCC; the source and nature of the chemicals that provide the aggressive environment; and the loading conditions required for the cladding attack by the chemicals.

Understanding PCI

Experiments carried out by SRI International and Argonne National Laboratory simulated in-reactor stress on the cladding by internally pressurizing short lengths of Zircaloy tubing and by introducing a chemical element (usually iodine) known to be aggressive to Zircaloy. The laboratory-induced stress appeared to be analogous to the power-shock-induced stress required to cause failure in reactor operation. These experiments showed the existence of a threshold stress value below which the Zircaloy specimens were immune to attack; this stress is the lowest value at which cracks form in Zircaloy. Scanning electron microscopy (SEM) studies suggested that cracks tend to form where the alloy is not chemically homogenous (generally at iron-rich or chromium-rich sites). Researchers also found that Zircaloy tubing specimens made by different vendors had significantly different threshold stress values and times to failure, even though they all met ASTM specifications for nuclear-grade Zircaloy.

Studies by Argonne on irradiated cladding showed that exposure for at least one reactor cycle (about one year) lowers the resistance of Zircaloy cladding to SCC. Although the nature of the failures observed in unirradiated and irradiated cladding is identical, threshold stress values and times to failure are lower in irradiated Zircaloy than in unirradiated Zircaloy tested under comparable conditions. SEM and optical microscopy examinations of crack microstructure in Zircaloy exposed to iodine showed that the features—tight, predominantly radial cracks with little evidence of branching—found in laboratory, test reactor, and commercial reactor SCC failures are identical.

EPRI also sponsored test reactor experiments that investigated fuel rod design features and exposure conditions to establish fuel rod propensity to PCI failure. The rods examined were fabricated to tight tolerances from well-characterized fuel and cladding. After a long-term initial irradiation, during which the rod power was carefully monitored, the rods were subjected to a power ramp. During this power ramp the fuel pellets expanded outward, stressing the cladding, and the fuel temperature increased, which increased the release of aggressive fission products.

Results from BWR fuel rod tests by Studsvik Energiteknik Ab suggested the existence of a failure threshold. Above a well-defined power shock value, rods failed; below this value, rods remained intact. When Studsvik subjected PWR fuel rods to power ramping, the PWR rods appeared to be more sensitive than BWR rods to initial design features and operating conditions—the final cladding heat treatment, fuel-cladding gap size, accumulated burnup, and power ramp peak. Postirradiation examination of failed rods from these test reactor experiments showed that the microscopic appearance of the through-wall cracks was similar to those observed in failed fuel rods from commercial reactors.

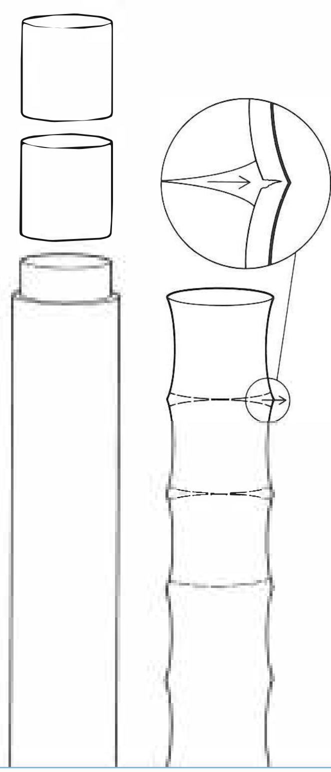
The laboratory and test reactor experiments studied cladding materials to characterize their propensity to PCI failure. Other studies were carried out on commercial reactor fuel rods to determine why particular rods failed.

An increase in the iodine level in the primary coolant of the Maine Yankee reactor, a sign of failed fuel rods, was first detected during cycle 1 operation at the end of 1973, even though the fuel rods were not subjected to significant power increases (i.e., the stresses induced in the cladding were small). A hot-cell examination by Combustion Engineering, Inc., suggested the cladding regions most susceptible to failure were ridges that formed where adjacent fuel pellets met each other and came into contact with cladding. These ridges were regions of both high local stress and accumulation of aggressive chemicals, cesium and iodine, both prerequisites for SCC. The fuel used in Maine Yankee resulted in significant irradiation-induced densification, which early in the cycle increased the pellet-to-cladding gap; this, in turn, inhibited heat dissipation and increased fuel operating temperature. Consequently, fission product release also increased, thereby providing the aggressive environment required for SCC.

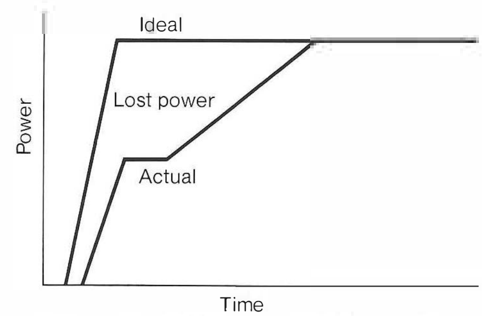
However, a similar examination of fuel

Problem

To form a fuel rod, small cylindrical pellets of UO_2 (urania) are stacked in a tube of Zircaloy cladding, and the ends are welded shut. Initially, there is a gap between the pellets and the cladding. During operation the pellets expand outward and the cladding moves inward, stressing the cladding. The pellets operate at temperatures that promote the release of fission products capable of attacking the cladding. Under these conditions an increase in power can result in fuel rod failure.



At power, the pellets expand in diameter more at the ends than at the middle. This leads to hourglassing of the pellets and ridging of the cladding at the pellet interfaces. The aggressive fission products released during fissioning tend to accumulate at these ridges, which become the regions most susceptible to failure.



To prevent fuel rod failure, utilities operate nuclear reactors with conservative power increases, which result in lost plant capacity. The lost power is the difference between the optimal rise in power and the actual rise.

rods of more recent vintage from the Point Beach-1 and Dresden-3 reactors (which used densification-resistant fuel) carried out by Battelle, Columbus Laboratories; Westinghouse; General Electric; and Argonne suggested that failures in these rods were also caused by SCC, and the crack appearance was similar to that observed in Maine Yankee, as well as in test reactor and laboratory experiments.

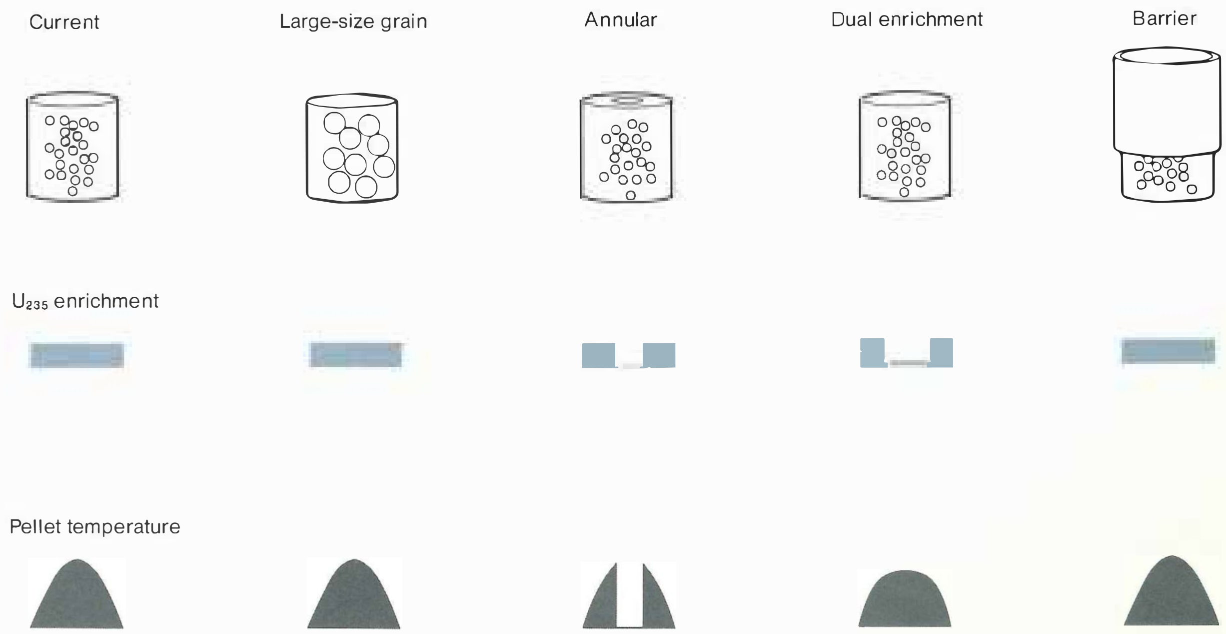
Predicting and monitoring performance

Because loading of cladding by fuel pellets is a key element of SCC, it is important to understand Zircaloy's deformation behavior under reactor operating conditions. Analytic studies at Stanford University and Failure Analysis Associates developed a constitutive equation for Zircaloy. (A constitutive equation describes the large-scale response of a material to applied loads that results from its internal constitution, or structure.) The studies led to a set of equations that predict the response of Zircaloy cladding to all conditions likely to be encountered in practice and to the effects of irradiation-induced phenomena. However, the constitutive equations do not predict conditions under which Zircaloy will fail.

The equations were combined with SCC data from experiments to develop a model that permits calculation of the time required for Zircaloy to fail when subjected to arbitrary exposure conditions. The model defines local stress, strain, and iodine concentration within a small volume of material at the cladding inner surface or at the crack tip once a crack has started. Experimental data are used to define criteria for the different observed modes of failure. The model predicts that crack formation rather than crack propagation dominates the measured times to failure in tubing that initially contained shallow flaws. Local stress at these flaws governs crack initiation. Once a crack of significant depth has formed, crack propagation can be

Solutions

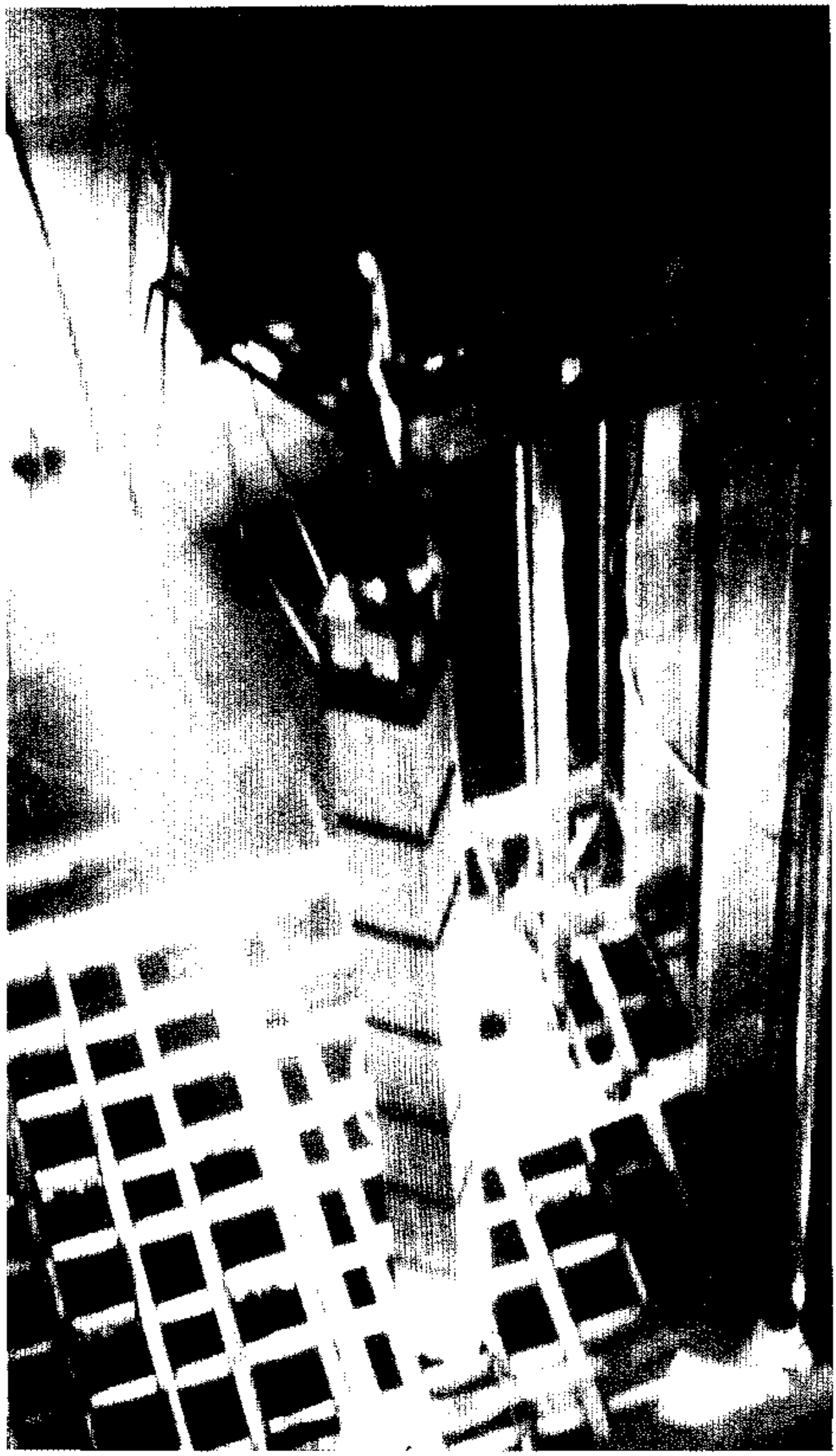
Modifying fuel rod designs to decrease the amount of aggressive fission products reaching the inner surface of the cladding appears promising as a means of preventing PCI failure. Large-grain-size fuel should delay fission product release. Annular pellets reduce fuel temperatures, hence fission product release, by removing the hottest part of the pellet. Dual-enrichment pellets achieve these goals by surrounding an inner core of natural UO_2 with an outer ring of enriched UO_2. Another approach to preventing PCI failure is to place a physical barrier between the pellets and the Zircaloy cladding to prevent its attack by aggressive chemicals.



described in terms of stress intensity at the crack tip. Intergranular fracture of the innermost region of the tubing is followed by transgranular fracture, which is then followed by ductile rupture.

The model can apply results obtained from laboratory experiments performed on limited amounts of tubing to predict the response of the large quantities of tubing exposed in commercial reactors. These predictions suggest that a fuel assembly exposed in actual reactor operation can be substantially less resistant to SCC than laboratory tubing because the probability of having a larger flaw is higher when the quantity of tubing is larger. The difference in response explains why results of laboratory experiments performed on small quantities of tubing are reproducible. (Time-to-failure values vary by only ~20% for samples of a given material exposed to identical conditions.) The response that follows in-reactor exposure of large quantities of cladding is quite variable. (Only one or two rods of the many subjected to similar duty cycles may fail.)

The analysis of Zircaloy deformation and fracture is one component of the SPEAR fuel reliability code, which is part of a larger system of computer codes—the power shape monitoring system (PSMS)—designed to monitor reactor performance. In this system a variety of core sensors provide core flow, temperature, neutron flux, control rod position, and other data. The PSMS then calculates such parameters as core power, fuel bundle exposure, and fuel rod failure probabilities. The system enables the reactor engineer to assess the effect of prospective control rod withdrawal sequences on fuel reliability, permitting selection of the sequence that will result in the least probability of fuel failure. The system also enables the engineer to estimate the conservatism of the vendor recommendations that limit increases in power. General Public Utilities Corp. is currently using the PSMS at its Oyster Creek reactor, and other utilities have



A fuel assembly being loaded into a poolside inspection stand. Such inspections use nondestructive examination techniques to confirm the performance of LWR fuel.

indicated that they will install the system at selected sites.

Reducing PCI

In addition to improving reactor operation by model prediction, efforts are under way to design fuel rods that are resistant to SCC and therefore to PCI failures. Of the three factors responsible for SCC—stress, susceptible material, and aggressive environment—design changes must address the last two because stresses at reactor operating power cannot be maintained below the measured Zircaloy threshold values. Such design changes must be able to inhibit crack initiation because it is difficult to stop crack propagation in cladding under operating conditions.

Reducing the amount of aggressive chemicals that reach the inner surface of the cladding can be accomplished by inhibiting the release of fission products. Larger assembly array designs (8 × 8 BWR; 16 × 16 and 17 × 17 PWR) result in lower fuel operating temperatures. German utilities are evaluating 9 × 9 BWR designs, and EPRI is also planning to evaluate this design. Another approach to stabilizing fuel operating temperatures is to pressurize BWR fuel rods with helium, an excellent heat conductor (which is the current practice in PWRs to compensate for coolant pressure on the water side of the cladding). This maintains the rod's ability to transfer heat across the gap from the fuel to the coolant.

Modifications of fuel pellet structure to reduce fission product release also appear promising. EPRI is evaluating three designs at the Halden test reactor in cooperation with British Nuclear Fuels, Ltd., and the U.K. Central Electricity Generating Board. One experiment will test large-grain fuel made with niobia (Nb_2O_5) as an additive. Investigators expect the large grains to delay fission product release. A second experiment on fuel pellet structure is evaluating the response of annular pellets. Eliminating the center of the pellet, which is the hottest part, will reduce operating temperatures, hence fission product release. DOE is also sponsoring an annular pellet study with Exxon Nuclear Co., Inc., and Consumers Power Co. A third EPRI experiment is assessing the performance of a dual enrichment design—a pellet with an inner core of natural uranium and an outer ring of enriched uranium. At the same operating power as applied to conventional uniformly enriched pellets, the average fuel temperature is lower and the temperature gradient is smaller in the dual enrichment design. The performance of large-grain annular fuel pellets will also be evaluated in a program jointly sponsored with the Swedish State Power Board and the Japanese Atomic Energy Research Institute.

These design changes should significantly reduce the amount of aggressive chemicals that attack the inner cladding. However, whether the amount released can be kept low enough to render the cladding impervious to attack is not clear. This concern is of particular interest to utilities contemplating reactor fuel operation of four, and possibly five, cycles. In addition, although nuclear reactors generally provide baseload power, increases in some utility nuclear generating capacity may necessitate load-following operations—that is, using nuclear plants to provide intermediate and peaking power.

A physical barrier between the fuel pellet and the cladding is another way to inhibit PCI. DOE is supporting programs to fabricate, irradiation test, and evaluate such designs. General Electric and Commonwealth Edison Co. are evaluating duplex cladding in which a thin inner liner of pure zirconium and an outer layer of standard Zircaloy-2 are coextruded during tube fabrication. Exxon and Consumers Power are evaluating annular fuel pellets in conjunction with a graphite coating on the inner cladding surface. Preliminary results suggest that these remedies act as effective barriers to fission products, preventing chemical attack of the cladding. Bundles incorporating zirconium liners are being fabricated, and a demonstration program consisting of the irradiation of 132 fuel assemblies in the Quad Cities-2 reactor is scheduled to begin in the fall of 1981. About 100 pressurized fuel rods containing annular fuel pellets and graphite-lined cladding have begun the second cycle of irradiation in the Big Rock Point reactor.

The laboratory and test reactor experiments, examination of irradiated fuel rods from commercial reactors, and model development sponsored by EPRI and others have provided a better understanding of the PCI phenomenon. Applying this knowledge to the development of PCI-resistant fuel rods should result in increased capacity in commercial reactor operation and fewer fuel rod failures. Improved designs can also make load-following operation feasible, and load-following designs should be available to utilities by the last half of the 1980s. Although these remedial designs will result in modest increases in fuel fabrication costs, utilities will realize substantial net savings because the need to provide costly replacement power will be reduced. ■

Further reading

B. Cox and J. C. Wood. "Iodine-Induced Cracking of Zircaloy Fuel Cladding—A Review." *Corrosion Problems in Energy Conversion and Generation.* Craig S. Tedmon, Jr. (ed.). New York: Electrochemical Society, 1974.

F. Garzarolli, R. von Jan, and H. Stehle. "The Main Causes of Fuel Element Failure in Water-Cooled Power Reactors." *Atomic Energy Review*, Vol. 17, No. 1 (1979). Vienna: International Atomic Energy Agency.

"Light Water Reactor Fuel Performance." In *Proceedings of American Nuclear Society Topical Meeting.* LaGrange Park, Illinois. American Nuclear Society, 1979.

J. T. Adrian Roberts and Howard Ocken. "Improving Nuclear Fuel Reliability." *EPRI Journal,* Vol. 3, No. 8 (October 1978), pp. 75–79.

J. T. Adrian Roberts. *Structural Materials in Nuclear Power Systems.* New York: Plenum Press, forthcoming.

"Zirconium in the Nuclear Industry." In *Proceedings of the Fourth International Conference on Reactive and Refractory Metals and Alloys.* Philadelphia: American Society for Testing and Materials, 1979.

This article was written by Howard Ocken, Nuclear Power Division, with the assistance of Suzanne Knott, science writer.

Keeping the Surges Out of the Circuit

Corona rings dominate the world's largest gapless surge arrester, now being tested by the Bonneville Power Administration on an experimental 1200-kV transmission line. The arrester itself is two 26-ft (8-m) columns of 4.5-in diam (11-cm) zinc oxide blocks. The lower portion of the arrester has a third column for mechanical stability.

An air gap forms the threshold resistance in most surge arresters; it withstands steady line voltage but is bridged by an arc when a damaging pulse must be shunted to ground. EPRI-sponsored research has produced a semiconductor that is faster, smaller, and cheaper, and it limits surges to lower levels.

When lightning strikes a power delivery system, it creates a sharp spike of overvoltage and disastrously high energy content. Even normal switching operations cause excessive voltage surges. In either circumstance, the overvoltage can puncture the insulation of an unprotected line, transformer, circuit breaker, or other component.

The long-standing solution to this problem is the surge arrester. This electric safety valve, more precisely a limiter, drains away the surge energy to ground, thus holding the overvoltage to as little as twice the normal level. An arrester's key features are fast action and high-energy handling capability. Without these features a surge will almost certainly result in a short circuit, meaning burned-out transformer windings, for instance, and a long outage, costly in lost apparatus and lost electric service.

Another economic aspect of surge arrester operation is that if the arrester can consistently hold surge voltages to lower levels, overvoltage design margins elsewhere can be reduced. Specifically, this means that the insulation requirements of other substation equipment—mainly transformers—can be eased, with consequent cost savings.

Lower surges, lower costs

Savings are the goal of two EPRI-sponsored R&D projects begun in 1975 and now completed. Two 1200-kV prototype surge arresters are being field-evaluated by the Bonneville Power Administration (BPA), and three 550-kV devices are being installed by the Tennessee Valley Authority (TVA). Tests at Westinghouse Electric Corp. have established the arresters' capabilities: even when passing 26,000 A (in a simulated lightning strike), the 1200-kV arrester limits the line-to-ground overvoltage to less than twice the normal level. In normal switching operations, it limits the surge to less than 1.5 times normal.

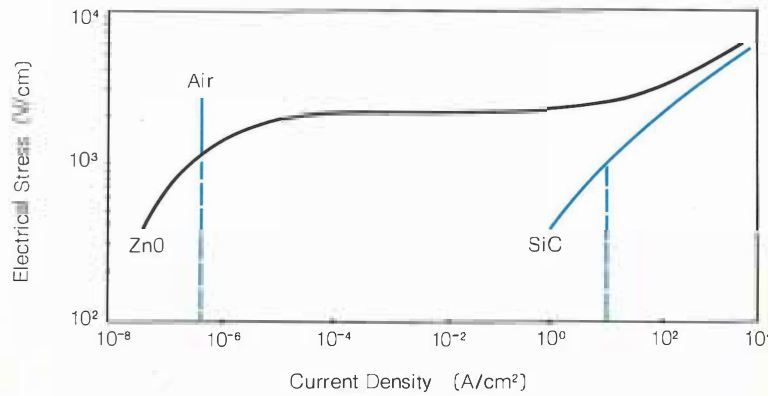
New surge arresters made by McGraw-Edison Co. for underground distribution circuits ($\leq$35 kV) illustrate the achievement another way. Because of their design, they are totally grounded on the outside surface and therefore need not be isolated from other equipment or enclosed for safety. They are thus less expensive than conventional arresters and meet the space-saving criterion for underground apparatus.

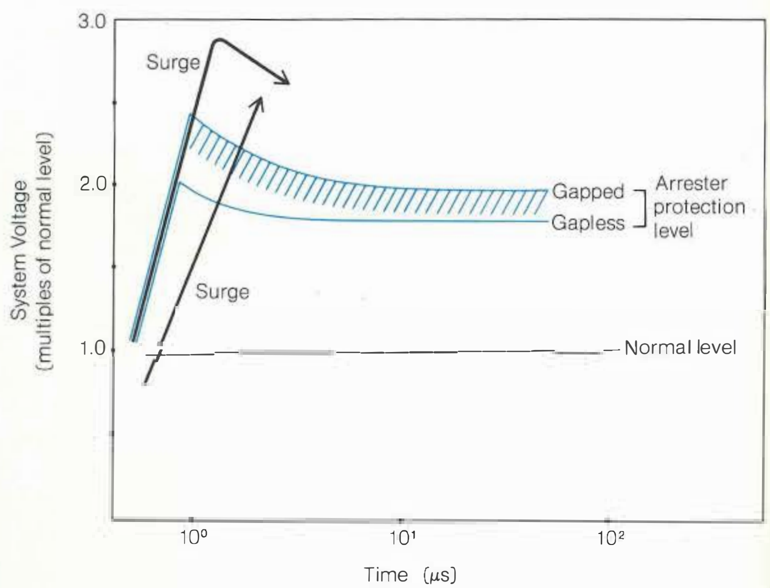
The technology used to achieve this performance is distinctive. The new arresters are made up entirely of zinc oxide blocks (and thus, incidentally, are about 20% shorter than older units). To appreciate this technology, consider how an arrester works and what components and materials are used in conventional designs.

In overall function a surge arrester is analogous to a pressure relief valve. In actual operation it works like a semiconductor; that is, depending on the voltage across it, it conducts or it does not. In the presence of normal line voltage or even minor voltage disturbances, it acts as a high resistance and conducts only 1–2 mA. It is thus virtually invisible to the power system. But in the presence of a faster voltage spike (surge) and at a predetermined voltage threshold, its resistance collapses to a very low value. A significant additional voltage increase in the power system is limited because the energy content of the surge is dissipated in the form of current across the remaining, much lower resistance. In effect, the arrester acts as a clamp on the system voltage.

Up to now the nonlinear, semiconducting operation of a surge arrester has been achieved by combining two components, a high-resistance spark gap in series with a low-resistance block of silicon carbide, both encased in a porcelain housing. In practice there may be multiple gaps and multiple blocks, carefully graded to yield the desired split-second dissipation of energy. Even the resistance of the silicon carbide itself decreases as the surge current increases. The product of that current and resistance is the measure of the successfully limited surge voltage on the transformer terminals.

The characteristic flat curve of zinc oxide shows why it can function by itself as a surge arrester. At a normal level of electrical stress, it leaks current at the negligible density of $<10^{-6}$ A/cm², while silicon carbide leaks at about 30 A/cm²—30 million times as much. Therefore, to hold off current flow at normal stress levels, a conventional arrester must include the additional resistance of an air gap (left) in series with the silicon carbide (right). When surge energy arcs across the gap, the silicon carbide becomes the limiter. Voltage and current values are shown per unit of arrester block length and cross section, respectively, so that blocks of all arrester rating classes can be compared.





Surge arresters are sensitive to the rate of voltage change; the slower the surge, the better the limiting. For any surge voltage rise time, the fast response of zinc oxide means that a gapless arrester clamps the system voltage sooner and therefore at a lower level than does a gapped arrester. Consistent response of zinc oxide allows other circuit components to be designed more precisely.

Simple construction and assembly are evident in this longitudinal section of an encapsulated zinc oxide arrester for protecting underground distribution transformers. This arrester does not need to be enclosed or isolated for safety. Its carbon-base exterior coating acts as a shield around the electrostatic field created by voltage on the arrester blocks.

Two steps, one semiconductor

Why not use a single semiconductor to perform the entire function? EPRI's research contractors, McGraw-Edison and Westinghouse, have done exactly that. Their arresters are solid-state devices. Aside from their own weather casings, end seals, and terminals, these arresters consist solely of a series of identical circular zinc oxide blocks, metallized at their interfaces for conductivity and stacked together in long cylinders.

This description implies simplicity: no electromagnetic coils or other complex fabricated metal parts, no auxiliary grading capacitors and resistors, no specially shaped ceramic castings to form arc chambers, no carefully measured and pressurized dry nitrogen (the atmosphere of the spark gap). But the description belies the operating innovations: more sensitive (virtually simultaneous) response to faster front waves, more positive voltage limiting, a much narrower band of variation in the voltage-current characteristic (it resets at almost exactly the same voltage at which it earlier began to conduct), and less deterioration under either surge impulses or normal voltage. In combination, these attributes yield two additional benefits. Circuit designers can precisely predict arrester performance, and apparatus designers can precisely calculate the insulation requirements of protected equipment. Both benefits lead to better system economy.

Zinc oxide surge arresters are expected to be initially cost-competitive with gapped arresters and cheaper in the long run. The assembly is straightforward and inexpensive; however, the zinc oxide blocks themselves are scrupulously formulated and processed for chemical and physical uniformity.

Metal oxide technology began in the electronics industry, where solid-state materials were first used to replace vacuum tubes and where the nonlinear resistance characteristic is vital to protect TV, stereo, oscilloscope, and other appliance and instrument circuits. Nonlinear resistors were first adapted for power applications by Matsushita Electrical Industrial Co. of Japan in 1972, and the basic design was subsequently licensed to several United States manufacturers.

The chemical composition at the grain boundaries within a crystalline matrix is what makes any semiconductor work. The semiconducting boundaries are created by "doping" the zinc oxide matrix with minute quantities of the oxides of several other metallic elements. The dopants are diffused into the matrix during a production sequence of formulation, mixing, drying, pressing, and air sintering at 1000–1450°C (1830–2640°F). The exact material composition is selected to achieve desired degrees of nonlinearity and other electrical characteristics for various applications.

Under EPRI sponsorship, McGraw-Edison and Westinghouse have developed the zinc oxide surge arrester to function entirely without a spark gap. McGraw-Edison has also developed and confirmed a unified theory that explains its own and others' empirical findings. Moreover, the company has conducted tests to establish that the new arresters degrade only negligibly under operating conditions—either surges or normal voltage levels.

Similar work by Westinghouse has also met the particular challenges posed in production of zinc oxide blocks for energy handling at utility scale: mainly block size, which requires close control of die design and die pressure to ensure uniform density and freedom from voids or other discontinuities. Of equal importance is quality control to avoid the material impurities that would disqualify only one among several hundred tiny electronic surge arresters but would ruin the single large utility block made from an equivalent amount of material.

Housings for zinc oxide arresters are an example of the arresters' economy. Because complex shapes are not needed to accommodate metal parts or to form arc chambers, gas channels, and vents, using a simple, moldable material for external insulation and weather protection is sufficient. McGraw-Edison's new arrester for fully grounded, pad-mounted transformers is a case in point. The stack of zinc oxide blocks are soldered together and encapsulated in a molded epoxy casing. The soldering, incidentally, gets rid of one more fabricated part: the metal springs otherwise needed to maintain good electric contact between blocks.

Heat transfer from the zinc oxide is the subject of a patented design feature. Thermal sand eliminates most of the annular air space around the blocks, dissipating heat to the casing more effectively.

Application criteria

As a surge arrester, zinc oxide is amenable to fabrication and assembly for the full range of transformer protection ratings, and with a rise-time response faster than that of gapped arresters. In fact, the difference is qualitative. The American National Standards Institute (ANSI) performance criterion for gapped arresters is the impulse waveform typical of a lightning stroke: peak voltage surge (whatever its value) attained in 1.2 μs, followed by recession to half that value in 50 μs. Gapped arresters undergo extensive sparkover testing to ensure that they function within these voltage rise times and limit the resultant voltage surge in the circuit to only twice the normal level. But there is generally a wide range in which this response is not reproducible.

No such test is carried out for zinc oxide arresters—they have no gap, hence no sparkover phenomenon. Despite surge speeds, zinc oxide arresters show continuous and more rapid response.

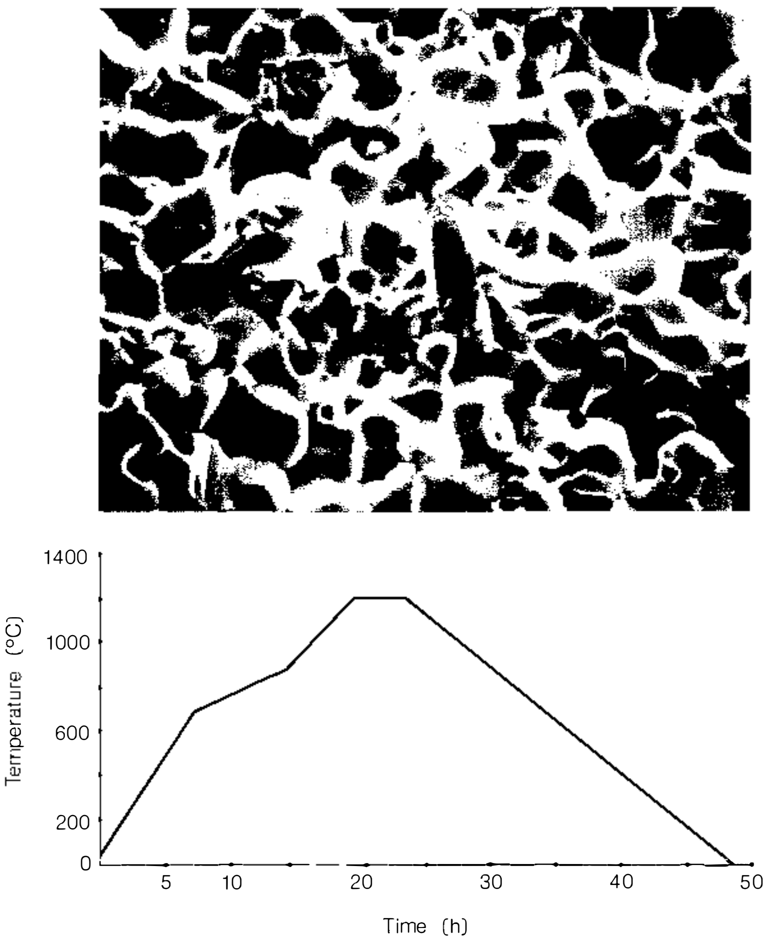
ANSI standards establish typical current crest values for a 10-μs time-to-crest. Zinc oxide and gapped arresters (governed by their silicon carbide resistance) can be made comparable in performance on this basis. But for faster rates of current rise, the zinc oxide voltage response rate is correspondingly faster; its resistance collapses sooner, and the limit voltage in the circuit (product of current and resistance at any time during the surge) is therefore lower than for silicon carbide. Furthermore, the closer lightning strikes to protected equipment, the shorter is its current time-to-crest. This similarly accelerates the zinc oxide voltage response rate, yielding progressively lower voltage limits compared with the silicon carbide of a gapped arrester in the same circumstance. This means better protection against close-in lightning strikes.

EPRI's surge arrester development over the past five years has cost approximately $2.25 million under the contracts held by McGraw-Edison and Westinghouse. Between them the contractors have contributed about an additional $500,000 to the effort. (Much of the fundamental McGraw-Edison research was subcontracted to Marquette University.) Success in these two projects completes EPRI's involvement in zinc oxide block development, but both Westinghouse and McGraw-Edison are now investing in production facilities.

The first 1200-kV prototype arrester has been in service at BPA's Lyons transmission test facility in Oregon since September 1980. The second 1200-kV unit was extensively tested under lightning conditions in the BPA high-voltage laboratory before installation at Lyons. Evaluation of TVA's three 550-kV zinc oxide arresters is expected to begin at the utility's West Point, Mississippi, substation by August of this year.

Although surge arresters have been the main R&D thrust, other utility applications for zinc oxide technology are apparent, among them dc breakers, fault current limiters, and protection of series capacitors. An example of this last application illustrates the energy-handling capability already achieved. On the strength of its early work for EPRI, in December 1978 Westinghouse delivered a 15-MJ zinc oxide protector to BPA for a bank of series capacitors.

Zinc oxide blocks could also prove useful in compact transmission line designs. If support insulators were designed with cores of zinc oxide, they would also function as surge arresters, thereby cutting insulation (and spacing) requirements all along the line and at connecting apparatus. If zinc oxide arresters are incorporated in transformer windings and switching devices, they will make possible impressive reductions in the insulation requirements of other station equipment. Additional technology developments of these kinds are under consideration by EPRI.



The all-important nonlinearity of a zinc oxide arrester block depends on its microstructure, seen in this X1000 scanning electron micrograph (SEM) and controlled by the time-temperature profile of a kiln sintering program. SEMs are useful for examining grain size and the diffusion of selected metal oxides along grain boundaries. Grain size influences electric properties; kiln firing conditions influence grain size. In this schematic, the heating rate is 100°C/h, except between about 700°C and 900°C, where it must be slowed to avoid stress cracking as some materials melt and others volatilize. The high-temperature soak may range from 1 to 4 hours; here is where grain growth occurs. Furnace cooling completes the program, which may take two full days.

Further reading

Development of a New Type of Nonlinear Resistance Valve Block for Surge Arresters. December 1980. EPRI EL-1647.

A. Courts, N. G. Hingorani, and G. E. Stemler. "A New Series Capacitor Protection Scheme Using Nonlinear Resistors." In *Transactions of Power Apparatus and Systems,* IEEE, Vol. 97, 1978, pp. 1042–1052.

E. C. Sakshaug, J. S. Kresge, and S. L. Miske. "A New Concept in Station Arrester Design." In *Transactions of Power Apparatus and Systems,* IEEE, Vol. 96, 1977, pp. 647–656.

This article was written by Ralph Whitaker. Technical background information was provided by Vasu Tahiliani, Electrical Systems Division.

Long-Term Biomass Research

DOE's long-term R&D programs for biomass include the study of farm digesters, plant hybridization, and energy farms. Economic feasibility is the key factor.

Energy from biomass is already meeting part of the nation's energy needs (reported in the December 1980 issue), but the long-term potential of this renewable resource has yet to be fully assessed. DOE is currently funding R&D on anaerobic digestion of animal waste, high-value hydrocarbon plants, silviculture, and aquatic energy farms to determine their economic and technical feasibility. These R&D activities indicate the role biomass may play in our energy future.

Beverly Berger, director of DOE's Biomass Energy Systems Division, comments that "the existing production rate of biomass is three oven-dried tons of wood per acre per year, and we have reason to believe that we could double, triple, or quadruple that. When looking at biomass the tendency is to look at existing technologies and not to consider the possibility of growing plants in the oceans or deserts. With reasonable R&D success, biomass could contribute 10 quadrillion (10^{15}) Btu a year by 2000 with an aggressive R&D program. We are now moving toward such a program."

Anaerobic Digestion

Included in the accelerated research effort is the use of anaerobic digestion, the conversion of biomass into gas by bacteria in an oxygen-free atmosphere. A common practice in waste and sewage treatment centers, anaerobic digestion releases a biogas composed of 40% carbon dioxide, 60% methane, and traces of hydrogen sulfide. To produce a gas of pipeline quality, the hydrogen sulfide and carbon dioxide must be removed. The remaining gas is almost pure methane, which has a heat value of 1000 Btu/ft^3 (corresponding to the heat value of natural gas). In most on-site farm operations the carbon dioxide is not removed because removal is a complex and expensive procedure. The hydrogen sulfide, however, is usually removed because it may cause corrosion problems when the gas is used to generate electricity.

The best biomass materials for anaerobic digestion are aquatic plants, certain types of grasses, and manure. Because manure is waste material, it is currently the most economic resource.

The Office of Technology Assessment (OTA) estimates that approximately 0.27 quadrillion Btu a year could be produced if all the collectable manure in livestock operations is digested. Yet the benefits from anaerobic digestion are actually greater than this figure suggests. The leftover material (effluent) from the anaerobic digestion process can be used for animal bedding, fertilizer, and even livestock feed. Because it is not economical to transport manure for long distances, the conversion process must occur in small digesters located on individual or community farms and feedlots. For small digesters to be economically feasible, they will have to be semiautomatic and have low installation costs.

The basic anaerobic digestion process consists of three steps: decomposition of the plant or animal matter, conversion of the decomposed material into organic acids, and conversion of the acids to methane.

There are many designs for anaerobic digesters—from a simple single-tank model, suitable for most farm operations, to a more complex multitank batch system, used on a large, commercial scale. In the single-tank plug flow system the feedstock is pumped into one end of a long digester tank and heated. Most on-farm operations have a temperature range of 68 to 113°F (20 to 45°C), although the temperature range may vary, depending on the material being digested. Higher temperatures usually increase the rate at which the biogas is produced, but raising the temperature may also decrease the fuel yield if more energy is required to heat the tank.

At the top of the digester tank is a pipe from which the gas exits. The gas can be fed into an internal combustion engine to drive an electric generator or it can be used directly to replace natural gas or propane. An anaerobic digestion system, therefore, can provide on-site electricity that would help reduce the electricity costs of livestock operation. Feedlot operators could also return the electricity and waste heat that are generated to the operation of the digester, thereby reducing the expense of the system.

The production of biogas can begin within a day or two of operation, but complete digestion may take months. After the feedstock is digested, the sludge is pumped out the other end of the tank and stored to be used for animal bedding or fertilizer.

One disadvantage of the digester system is the size of the initial investment. However, farmers can now obtain financial assistance (loans and loan guarantees) from the Department of Agriculture to offset the expense of digesters.

DOE is conducting experimental studies to show that manure can be economically converted to methane in a digester. It is cofunding experimental and pilot test units at livestock operations, including the Kaplan feedlot in Bartow, Florida, one of Florida's largest slaughterhouses and meat-packing facilities. The Kaplan feedlot has the capacity for 10,000 head of cattle, and by using the manure to make methane gas, it has been able to reduce a portion of its petroleum use since beginning operation in 1979.

As mentioned above, the digestion process also yields high-protein sludge that is used as cattle feed, fish food, and fertilizer. Kaplan is revitalizing the land surrounding its facilities by using the effluent to grow hay and grass for its cattle rather than using commercial fertilizers.

Energy Farms Short-Rotation

Another long-term biomass project that DOE is investigating is the potential of silviculture energy farms. An energy farm consists of closely spaced, rapidly growing trees or bushes that are intensively managed for harvesting at intervals or rotations for chemicals or fuels. After harvesting, the subsequent crop sprouts from the stumps, so replanting is not necessary. This practice, called short-rotation forestry, offers a real potential for increasing the supply of wood and other biomass products. DOE is conducting long-term experiments to select the plants that show the most promise as such short-rotation crops.

"There is interest in short-rotation crops not only in this country but also in Canada, Ireland, England, Finland and Sweden—in fact, in all of Scandinavia—where growing short-rotation crops is a more common practice," explains Berger. "The United States recently signed an agreement with the International Energy Agency, stating that we will cooperate with other countries by sharing our knowledge and research results of forestry projects."

Because the crop in an energy farm must be intensively managed (including use of fertilizers, irrigation, and weed and disease control), the production of an energy crop is more similiar to field crop production than to conventional forestry.

To date, the trees considered most suitable for silviculture energy farms are eucalyptus, poplars, alders, and sycamores. DOE and the Bio-Energy Development Corp. are cofunding a project in Hawaii to grow hundreds of acres of eucalyptus trees for combustion with bagasse (the residue from sugarcane). Eucalyptus trees may offer large biomass yields of 8–25 tons of dry material an acre, compared with an acre of corn, which may produce just 6 tons of dry material. One pound of dry plant material will produce an average of 7500 Btu when burned. If a pound of this material is converted to gas, it will yield an average of 5 ft^3 of methane.

The potential energy contribution of biomass farms is based on the yields that can be produced annually per acre and the total area of suitable land that can be devoted to energy farming without competing with other land use. If energy farms are seriously developed in the United States, they could begin to contribute to our energy resource base by 1995, according to OTA. Total woody biomass supplies could increase from about 7 quadrillion Btu per year in the near term to about 13 quadrillion Btu by 2025. However, this figure depends on the correct management of the farms and is subject to variations in regional and local conditions.

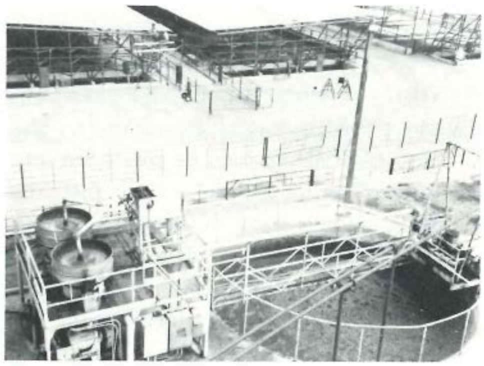
The federal government is also interested in the development of hybridization techniques and bioengineering to help increase the yields of those plants suitable for energy farms. "Plant breeding is not a major thrust of our program," Berger notes. "But we do know that the resource can be expanded by increasing

Development activities in biomass cover a broad range of organic species and processing technologies.

One activity is the anaerobic digester at the Kaplan feedlot, Bartow, Florida (top left). Under the shed are the gas-handling system, steam boiler, and centrifuge for drying the effluent to be used for cattle feed. Manure is placed in a mixing pit (bottom left) prior to being pumped into the digester.

Mature *euphorbia lathyrus* (top right), a member of the poinsettia family, can be processed to produce petroleum. Euphorbia grows well in semiarid areas.

A lagoon of water hyacinths (bottom right) filters industrial wastes. The experiment is part of NASA's biochemical research program at the National Space Technology Laboratories in Bay St. Louis, Mississippi.



productivity per acre. For example, if you plant a nitrogen-fixing tree near a non-nitrogen-fixing tree, they may take care of each other very nicely, depending on the species. We are trying to find out which trees will result in high yields. Currently, we have 23 different contracts for growing trees in different areas under different climatic conditions."

U.S. agricultural production is greatly influenced by plant hybridization, which affects corn, grain, legumes, and almost all other types of vegetables now grown. In the future, plant breeders may want to maximize the food potential of a plant and its residue potential. In fact, sugarcane is now bred to produce maximum sweetness and also maximum residue for use as fuel. As Berger states, "What it amounts to is that we no longer feel that residues are something to minimize."

Plant breeders are also experimenting with plants that are rich in hydrocarbons, such as rubber plants, euphorbia, and jojoba shrubs, which grow wild in California. Either these latex-bearing plants can be harvested or their latex can be tapped and converted into a synthetic liquid fuel. The many plants that contain hydrocarbons (and there appear to be about 300 species of latex-bearing plants) could be grown on an energy farm, harvested frequently, and then supplied to a processing plant. At the processing facility, the hydrocarbon plants would be processed to recover an oily material for synthetic fuel and a cellulosic residue, which could be used for direct combustion. *Euphorbia lathyrus,* which is an annual and can be harvested like a field crop, is currently being studied at the University of California for the feasibility of such a cycle.

In addition to studying plants that have a high hydrocarbon value, plant breeders are also exploring the growth of high-yield grasses and legumes that could be used for animal feed, which would release more pastureland for energy production. Additional research is being devoted to plants that can be cultivated on land that is not now used for food or feed production. According to OTA, the development of plant hybrids should warrant special attention by the government because these new plants may offer unique potential for the future of biomass energy supplies.

Aquatic Energy Farms

One seemingly more exotic scheme for increasing future biomass supplies is the cultivation of aquatic energy farms. These farms may be very practical because aquatic plants do not require fertilizer or irrigation, nor do they use large areas of land, unlike their terrestrial counterparts. Solar energy is easily and efficiently fixed by aquatic algae because of their simple structure and high surface-to-volume ratio. Marine and freshwater algae can be grown all year under the proper conditions and thus can offer a continuous supply of biomass material. Also, it is possible to produce great amounts of these simple plants, as Berger explains. "Aquatic plants have the potential for high yields because of their physiology. They may produce yields that are four or five times that of trees. The trick is to sustain the yields and to learn to harvest the algae in a way that does not require much energy. It is possible to grow millions of tiny algae, but if you have to centrifuge them to produce oil or gas, you are expending more energy than the algae are worth." DOE is investigating both marine and freshwater biomass sources, including brown, red, green, and blue-green algae, giant sea kelp, and water hyacinths.

Because biomass from marine energy farms may have the greatest potential for contributing large quantities of synthetic natural gas (SNG) to the current gas supply (through its conversion by anaerobic digestion into methane), the Gas Research Institute (GRI) and DOE have cosponsored the development of a kelp farm off the California coast. As of 1979 the program had received $9 million in research funding. The GRI-DOE research program is acquiring both biological and engineering data, which will determine the economic feasibility of future kelp farms. In 1981 GRI will continue to coordinate activities with DOE but will assume all the expenses of the open-ocean farming project.

The kelp test farm consists of a mechanical buoy that supports an umbrella-shaped substrate on which the kelp grows. The structure is submerged to a depth of 30-100 ft (9-30 m), which is equivalent to that of natural kelp beds. The kelp is fertilized by bringing up deep ocean water, which is full of nutrients, through a 1500-ft (457-m) pipe. The kelp grown on the test site is then processed for conversion into SNG. Test farms of different designs will be installed and operated by GRI in the near future.

Another aquatic plant that DOE is studying is the water hyacinth, whose uncontrolled growth in the waterways of the South is a severe and expensive problem. In experiments conducted by the National Atmospheric and Space Administration (NASA), it was found that water hyacinths grown in one acre of sewage water can produce enough nutrients to yield 800-1600 lb (360-725 kg), dry weight, of water hyacinths a day. The dry material can then be converted into 3500-7000 ft^3 (99-198 m^3) of methane gas plus half a ton of effluent fertilizer. The energy obtained from these water plants was actually only a byproduct of the process. The main focus of the experiment was to clean the sewage water by the absorption of the sewage contaminants and chemicals. The ability of water hyacinths to develop in sewage treatment water and their nutrient-rich composition make further research on their biomass potential a likely prospect.

Microalgae, which produce lipids (oils) and other chemicals, are another promising aquatic plant for biomass cultivation. Microalgae can be grown in large brackish ponds and then harvested for use as chemical feedstock. Microalgae ponds have been used for several years in U.S. wastewater treatment centers. The high concentrations of nitrogen and phosphorus in these plants make them useful in removing nutrients from waste water. In fact, one way to improve the economics of microalgae biomass development is to combine the process with a wastewater treatment facility. With the recent development of better microalgae harvesting techniques, there is an opportunity for more fuel recovery from the harvested microalgae.

OTA finds that green algae and diatoms are the most suitable microalgae for mass cultivation because these plants may achieve production rates of 20 tons per acre per year. But the harvesting and cultivation of these primitive plants are still significantly more expensive than the cost of harvesting terrestrial plants. DOE's continuing R&D program in this area should begin to reduce the cost of developing this potential biomass resource.

In considering the range of organic sources that can be converted into energy—manure, eucalyptus trees, euphorbia, algae, kelp, and water hyacinths—it can be seen that many of these materials have their greatest potential in specific regions. To facilitate the development of regional energy technologies, DOE has set up four regional solar energy centers in Atlanta, Boston, Minneapolis, and Portland (Oregon). The centers assist local organizations in developing sources of solar energy, including biomass projects, and encourage both commercial and residential conservation efforts. Berger explains further, "We work through the regional solar energy centers, which makes us sensitive to the needs of the various regions. Different areas of the country have different crops and resources—in the Midwest it is crop residues and animal waste; in New England it is wood; in the South and Southeast, in addition to wood, there is potential for arid land plants and perhaps aquatic plants; and in the northern states it is wood. But then, this fits with my idea that the energy problem cannot be solved by one simple solution. We need to work in all areas of the country and explore every energy option available so that we can one day rely on our own resources and stop our dependence on imported oil." And DOE believes that the energy attained from biomass may help to reduce that dependence. ■

Briefing on the Status of EPRI Research

The Research Advisory Committee recently participated in an all-day review of research results and the status of major research programs. Six technical divisions and NSAC reported and fielded questions.

Progress of research in each technical division was presented to the Research Advisory Committee (RAC) at an all-day briefing in December. Richard E. Balzhiser, vice president for research and development, chaired the review session, which he said was organized to present RAC members with an overview of the "proliferation of results" now coming from EPRI's programs.

Attendees also included members of six division committees, whose meetings preceded the RAC meeting. Balzhiser indicated that based on the favorable reaction to this pilot run, EPRI plans to make similar reports annually to RAC and the six division committees. The following topics were among those discussed at this review.

Energy Management and Environment Division Director René Malès reported that energy analysis has shifted from its earlier focus on national problems and fuel resources toward regional considerations, conservation, and problems of fuel delivery. Recent results of the division's programs include these items.

□ Application of the over/under capacity planning model to technology decisions (e.g., small coal versus large coal versus nuclear) and assessment of impacts of load management on reserve margins

□ Testing a model to predict regional load curves

□ Developing methodologies of risk assessment

□ Development of remote sensing equipment for air pollutants

□ Continued monitoring, data gathering, and assessment of the causes and effects of acid rain

□ Studies of the socioeconomic impact of new power plants, which could lead to simplification of licensing

□ Increased emphasis on measuring the effects of toxic substances

□ Continued monitoring, data gathering, and assessment of the ecological effects of electric fields

Coal Combustion Systems Division Director Kurt E. Yeager outlined the division's outstanding results and ongoing projects, which include the following.

□ Development of monitoring equipment to detect incipient failures in boilers, turbines, and auxiliaries, thus increasing power plant availability

□ Setting guidelines for minimizing boiler fouling and slagging

□ Development and commercial introduction of continuous real-time coal assay technology (CONAC)

□ Publication of manuals on the safe disposal of polychlorinated biphenyls (PCBs)

□ Demonstration of a low-cost dry sulfur dioxide (SO_2) removal process

□ Publication of baghouse design and operating guidelines for improved air pollution control

Plans for the next five years include demonstration of improved SO_2 scrubber processes, development and demonstration of coal slurry fuels to replace fuel oil used in boilers, improved technologies to control corrosion and erosion in steam turbines, and demonstration of practical dry-cooling methods for power plants.

Advanced Power Systems Division Director Dwain Spencer told the meeting that by supporting and joining cooperative synfuel efforts around the world, EPRI is now in a position to take advantage of new opportunities. He then outlined several major accomplishments.

□ Startup of the H-Coal and Exxon Donor Solvent (EDS) coal liquefaction pilot plants, each representing a 250-t/d operation

□ Tests run at the Wilsonville (Alabama) 6-t/d pilot plant in support of the solvent-refined coal (SRC-1) demonstration plant

□ Progress in the design of the 100-MW gasification–combined-cycle plant at the Cool Water station (California) and the successful operation of the 150-t/d Texaco gasification unit (using Illinois and Utah coals) at Oberhausen, West Germany

□ Combustion turbine tests of methanol, heavy fuel, shale oil, and distillates

□ Completion of a mobile geothermal chemistry laboratory, which was available for RAC members to tour

Electrical Systems Division Director John Dougherty described several pieces of hardware that have been developed to improve power and transmission systems.

□ Development of two-phase-cooled transformers

□ Composite wood utility poles and methods for extending their life

□ Testing a field-usable PCB detector for low concentrations in transformer oil

□ Field tests of 500-kV and 150-kV gapless zinc oxide arresters at TVA and testing a 1200-kV unit at BPA

□ Development of an ice release coating for disconnecting switches up to 500 kV

□ Development of laterally loaded, drilled-pier tower foundations

□ Demonstration of an improved water-jet concrete cutter

□ Development of a compact HVDC converter and advancements in transformer technology

Energy Management and Utilization Division Director Fritz Kalhammer outlined several major achievements of the division during the past year.

□ Significant new developments in the use of fuel cell technology, led by completion of a 4.5-MW test facility in New York City

□ Advanced storage battery development through progress at the Battery Energy Storage Test (BEST) Facility in New Jersey and through development of a zinc chloride battery test production line, both cosponsored with DOE

□ A methodology for screening low-head hydroelectric sites

□ Continued verification and monitoring of solar/HVAC/load management systems in 10 solar homes

□ Establishment of electric vehicle (EV) road tests and pilot demonstration projects; design and installation of EV data acquisition systems

□ Completion of detailed preliminary design projects for compressed-air storage (CAS), using salt and rock caverns, and for underground pumped hydro (UPH), using high-head designs

Nuclear Power Division Director Milton Levenson discussed new studies that indicate the risk of radioactive releases from a nuclear reactor accident has been generally overstated, and as a consequence, the whole area of risk assessment needs to be reexamined. When giving several examples of projects now ready for utility application, Levenson described the development of a detector to locate condenser leaks and a turbine rotor insepction system.

Nuclear Safety Analysis Center NSAC was established in the wake of the accident at Three Mile Island. Although housed at EPRI headquarters, it is funded separately. Deputy Director Robert Breen reported that an analysis of the TMI-2 accident has now been completed and indicates the potential for public disaster was greatly overstated. NSAC is now concentrating on defining priorities and resources for the action plan announced by the Nuclear Regulatory Commission in response to TMI. Current efforts also include screening and evaluating licensee event reports for broader significance. ■

New EPRI Members

Eight utilities were recently added to EPRI's membership rolls. Four of the new members are subsidiaries of the Central and Southwest Corp.: Central Power and Light Co. (Corpus Christi, Texas); Public Service Co. of Oklahoma (Tulsa); Southwestern Electric Power Co. (Shreveport, Louisiana); and West Texas Utilities Co. (Abilene). These utilities serve more than a million and a quarter customers in Arkansas, Louisiana, Oklahoma, and Texas.

The other four new members are Atlantic City Electric Co. (New Jersey), with over 360,000 customers; Edison Sault Electric Co. (Sault Ste. Marie, Michigan), with 150,000 customers; Santa Clara Electric Dept. (Santa Clara, California), with 36,000 customers; and United Power Association (Elk River, Minnesota), a rural electric cooperative. ■

Renewable Resource Update

Richard L. Rudman, director of EPRI's Policy Planning Division, addressed members of the Environmental Committee of the Western Systems Coordinating Council at a recent EPRI seminar. The session was a technical update on trends and new developments in electric power production and focused specifically on the environmental impacts of renewable energy resources.

Achievement in Energy Award

Margaret Bush Wilson, member of EPRI's Advisory Council since 1978, received the Woman of Achievement in Energy award at the 1981 annual meeting of Women in Energy, held in Wichita, Kansas. Among her numerous activities, Wilson is chairman of the NAACP National Board of Directors.

CALENDAR

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

APRIL

8
Nuclear Fuel Performance—Contractors' Overview Meeting
Boulder, Colorado
Contact: David Franklin (415) 855-2408

8–10
Workshop: Rate Design Study—Costs and Rates
Atlanta, Georgia
Contact: Nancy Hassig (415) 855-2176

14
Seminar: Synfuels for Utility Application
Washington, D.C.
Contact: Tasia Toombs (415) 855-2510

15
Seminar: Synfuels for Utility Application
Chicago, Illinois
Contact: Tasia Toombs (415) 855-2510

22–24
Workshop: Rate Design Study—Costs and Rates
Kansas City, Missouri
Contact: Nancy Hassig (415) 855-2176

MAY

13–14
Workshop: Coal Liquefaction Contractors
Palo Alto, California
Contact: Cheryl Landers (415) 855-2511

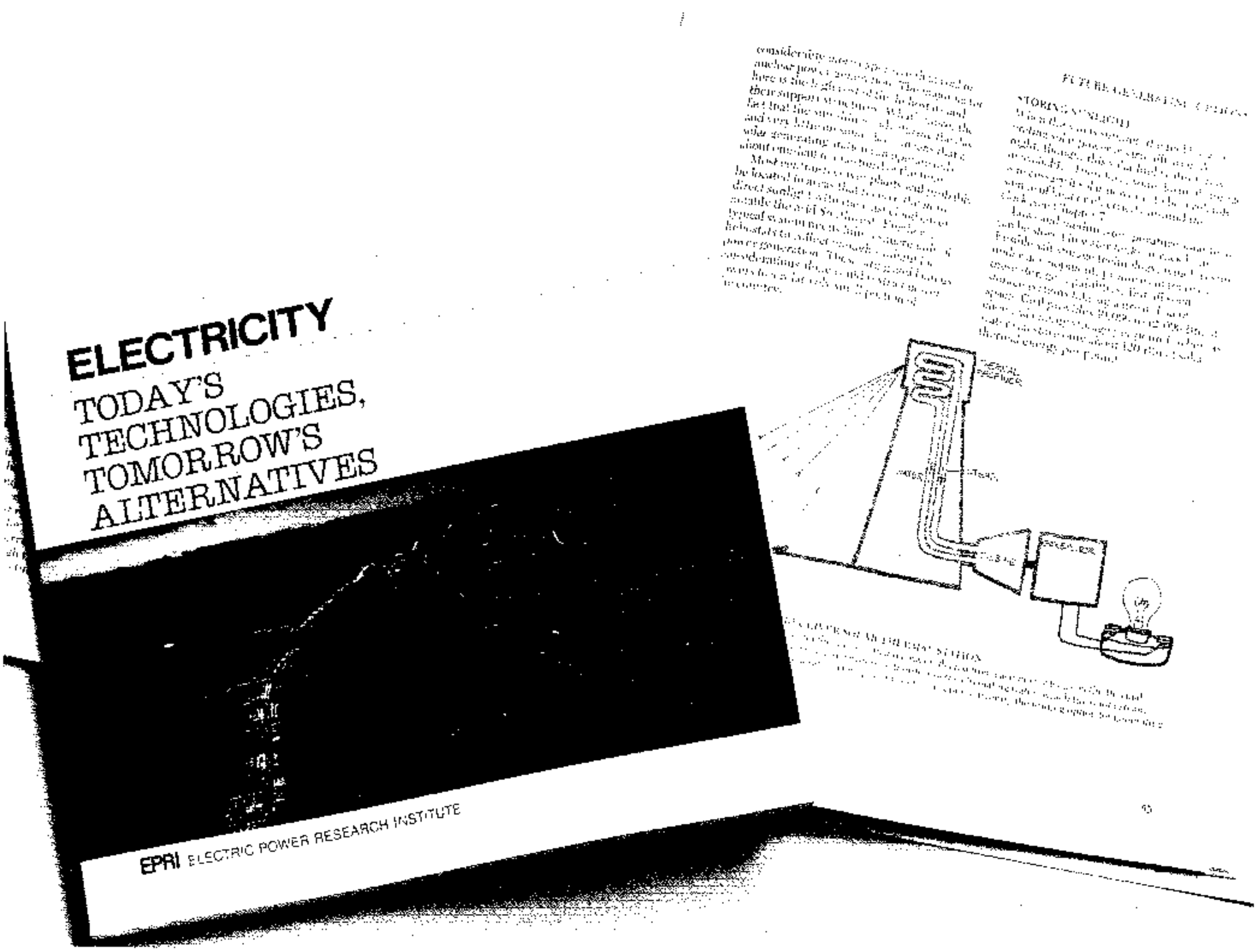
JUNE

2
Seminar: Synfuels for Utility Application
Los Angeles, California
Contact: Tasia Toombs (415) 855-2510

2–4
Technology Seminar I: Communications Systems for Distribution Automation and Load Management
Atlanta, Georgia
Contact: A. Johnson (415) 855-2833

3
Seminar: Synfuels for Utility Application
Houston, Texas
Contact: Tasia Toombs (415) 855-2510

16–18
Technology Seminar II: Communications Systems for Distribution Automation and Load Management
Denver, Colorado
Contact: A. Johnson (415) 855-2833



Energy Primer Available

EPRI has recently published a book on energy fundamentals, *Electricity: Today's Technologies, Tomorrow's Alternatives.* Intended for the lay person and written at the high-school level, the 120-page book has a simple, direct style and is illustrated with easily comprehended diagrams.

As an introduction to the world of electricity generation, the book serves the needs of the public by encouraging a better understanding of energy technologies. This understanding may then prompt greater and more-informed participation by the public in national decision making on energy policy.

The book is divided into short sections within its nine chapters—it can be used as a reference or read as an overview of current technology.

The first chapter discusses reasons for future energy needs (e.g., in supplying the energy required for an expanding labor force). "Bureau of Labor Statistics data suggest a labor force of roughly 130 million workers in the year 2000, up from about 85 million in 1975." The next few chapters cover energy demand and conservation, energy supply, and principles of electric power generation.

The central portion is devoted to descriptions of present and future generation options, as well as electricity storage and delivery. Some examples are combined-cycle power systems, water-cooled nuclear reactors, fuel cells, magnetohydrodynamics, compressed-air storage, and high-voltage direct-current cables. The concluding chapters of the book treat environmental concerns and energy policy decision making.

The text also includes some basic laws of physics, expressed in ways that catch the imagination. For instance, the need for energy conversion is described as follows.

"The kinetic energy of the wind . . . is well suited to the work of propelling sailboats. But consider the task of toasting a slice of bread. Holding the bread in the wind will not do the work of toasting it, even if the kinetic energy of the wind is increased to hurricane proportions. In this case, the form of energy we have is totally unsuited to the type of work we want done.

"Wind energy *can* be used to toast bread, but only if it is converted to other energy forms first: the kinetic energy of the wind is converted by a windmill to mechanical energy, which is converted by a generator to electric energy, which is converted by the heating element of a toaster to heat energy. So the wind energy must undergo three transformations before it finally emerges as heat energy that can toast the bread in an electric toaster."

A later section on conversion efficiency explains:

"During any process, energy moves to a more random, less-concentrated state. This means that whenever energy is converted from one form to another, we always end up with a smaller amount of useful energy.

"Suppose you have a wooden board that you want to convert to another form—say, two smaller boards. If you saw it in half, you end up with two boards that together add up to *almost* the same amount as you started with. But a small amount of board has been changed to sawdust in the conversion process, and this sawdust, though still wood, is not suitable in its present form for building things. Every time the board is cut—that is, during every conversion process—a little more of the board is lost."

Single copies of the book are $7.95. Quantity discounts are available. Orders should be sent to William Kaufmann, Inc., One First Street, Los Altos, California 94022; (415) 948-5810. ■

Fate of LOFT Facility

Ivan Catton (left) of the University of California at Los Angeles and Denwood Ross, director of NRC's Division of Systems Integration, during a recent meeting of nuclear experts at EPRI. The group, of which Ross is chairman, is preparing a report on whether or not the loss-of-fluid test facility in Idaho Falls, Idaho, should be decommissioned in 1983.

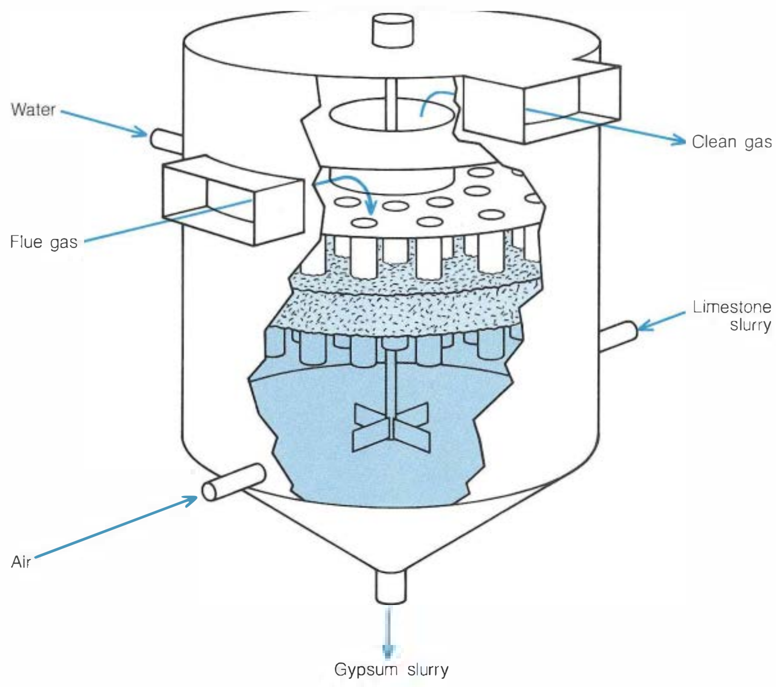
R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

ADVANCED SO_2 CONTROL

Frequently cited complaints about the conventional wet scrubbers used to control SO_2 emissions in utility stack gases are that they are expensive to operate and maintain and their reliability is low. These problems are particularly pronounced if the scrubber uses limestone rather than lime. In conventional limestone wet scrubbers, a slurry with a relatively high concentration of solids must be pumped at high rates and about 30% excess limestone is needed to ensure adequate SO_2 removal. Even with these problems, limestone scrubbing is generally less expensive than scrubbing with lime because of the considerably lower cost of limestone. In view of this incentive, EPRI has been investigating new technologies for a reliable, cost-effective limestone scrubbing system that yields an oxidized, more easily handled by-product. The Chiyoda Thoroughbred-121 (CT-121) limestone scrubbing process, developed by Chiyoda Chemical Engineering & Construction, Ltd., and its U.S. affiliate, Chiyoda International Corp., has been identified as a promising candidate for eliminating or minimizing several of the disadvantages associated with wet scrubbing systems.

Figure 1 Jet bubbler reactor. Flue gas enters the reactor, where it is sparged through a limestone slurry pool to ensure good contact between the gas and liquid. After the scrubbed gas leaves the reactor, it proceeds through a mist eliminator and finally to the stack.



CT-121 evaluation

The CT-121 system incorporates an absorption vessel called a jet bubbler reactor (Figure 1). As the result of a novel sparger design, flue gas is introduced below the slurry, producing a froth where the SO_2 is absorbed. The pumps used in conventional scrubbers to recycle slurry to an absorption tower are eliminated.

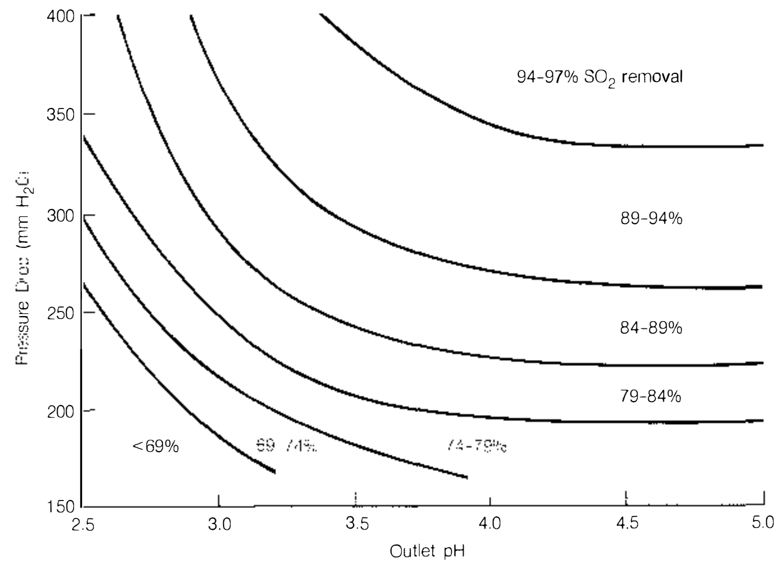
Air is introduced into the bubbler reactor to oxidize the SO_2 to sulfate, which then combines with calcium from the limestone to form gypsum, a common, physically stable mineral compound that can be easily dewatered. When dewatered, gypsum has the physical characteristics of damp beach sand and lends itself to conventional handling and disposal methods, as well as to stacking. Moreover, it can be used as an additive in cement or wallboard and thus is potentially salable.

On the basis of favorable preliminary assessments of the CT-121 process, EPRI sponsored an evaluation of a prototype system at 23-MW scale. Part of the flue gas stream from a 47.5-MW coal-fired unit at Gulf Power Co.'s Scholz plant was used for the testing, which was performed by Radian Corp. under subcontract to Southern Company Services, Inc. (RP536-4).

The evaluation program was designed to test the prototype scrubber under a wide range of operating conditions and to measure its reliability. Site-specific and some general parameters were varied to define the operating envelope in which the system can successfully function. This performance evaluation provides a basis for cost evaluation, as well as for the definition of some of the design parameters required for commercial units.

Three parameters—pH of the limestone-gypsum slurry at the outlet, pressure drop, and inlet SO_2 concentration—were fit to a theoretically derived expression of SO_2 removal efficiency. The basic form of the mathematical equation was developed by Chiyoda in 1978. Because air and gas flow tests were short term and these parameters were not varied in conjunction with other process conditions, they were not incorporated in the mathematical model. The Chiyoda equation enables a utility to quantify pH and pressure drop trade-offs, which can be important in optimizing CT-121 operating costs. Figure 2 shows the fairly wide ranges of pH and pressure drop that can result in equivalent SO_2 removal levels.

Figure 2 Predicted SO_2 removal efficiency as a function of pH and pressure drop, assuming 2000 ppm SO_2 in the inlet gas.



Evaluation results

Five critical performance criteria were used in assessing the CT-121 scrubber: SO_2 removal efficiency, limestone utilization, solid-waste quality, degree of chemical scaling, and reliability. The system performed well throughout the evaluation program. SO_2 removal efficiencies of 95% were achieved with an SO_2 concentration of 3500 ppm in the inlet flue gas. The gypsum product settled rapidly, dewatered easily, and generally contained over 97% gypsum. The system showed an overall on-line reliability of 97.5%. Limestone utilization in the reactor averaged over 98%. A detailed inspection after nine months of testing revealed minimal chemical scale deposition and no adverse scaling effects.

To put these results in perspective, the reliability of conventional limestone systems ranges from 50 to 90%. The level of limestone utilization in these systems is approximately 70%, and if the systems employ a special subloop to produce gypsum, the gypsum is 90–95% pure.

Detailed results of the evaluation program are presented in *Evaluation of Chiyoda Thoroughbred-121 FGD Process and Gypsum Stacking* (CS-1579, Vol. 1). On the basis of these results, EPRI has decided to participate in a 100-MW demonstration project, and negotiations are under way with a potential host utility. It is anticipated that the demonstration will be cofunded by EPRI, the host utility, Chiyoda, and perhaps DOE.

Two architect-engineers have used the operating parameters identified in the prototype evaluation program to make independent economic assessments of the CT-121 system. These studies confirm its potential economic advantages (CS-1428; CS-1677). Also, a laboratory-scale study has recently been initiated to determine whether certain additives to the scrubbing slurry can further reduce the operating costs of the process through increased SO_2 absorption and reduced pressure drops (RP536-5). Results from these further studies are expected to be published in mid-1981. *Project Manager: Thomas Morasky*

ADVANCED PULVERIZED-COAL POWER PLANTS

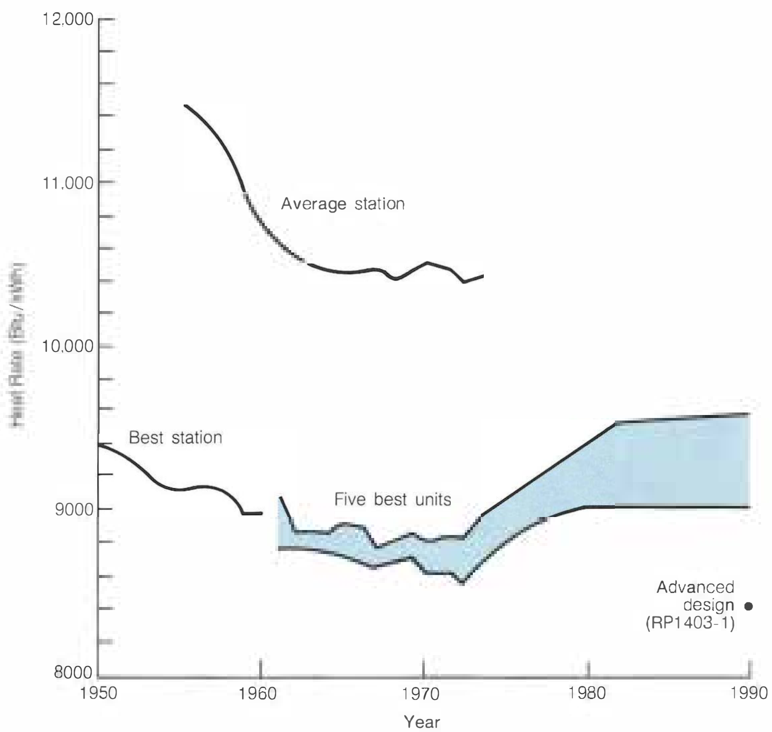
Two independent research teams—each consisting of a turbine generator manufacturer, a boiler manufacturer, an architect-engineer, and a utility—have clarified the prospects for the next generation of coal-fired power plants (RP1403). The objectives of the project were to identify the limits of current technology, assess the availability record of present-day supercritical plant designs, and develop conceptual designs and accurate costs for an advanced plant. Each team has completed conceptual designs for an advanced plant equipped with all necessary environmental controls and having a nominal operating net heat rate of 8500 Btu/kWh. In addition, the critical technology needs and their development costs have been defined. On the basis of this research, it appears that the advanced plant could be commercially available in five to seven years.

Current coal-fired plants

Fossil-fired steam plants produce 75% of the electric power generated in the United States. Until the early 1960s, there was a continuous trend toward lower heat rates in fossil-fired plants. In the subsequent period, however, there was little incentive to continue the effort because of the expected increase in nuclear power generation for baseload application and the availability of relatively inexpensive fossil fuel. Now it appears that much of the future increase in U.S. generating capacity will be dependent on coal-based technologies. Electric power generation, like all forms of energy conversion, is being affected by the scarcity and rising costs of fuels, by inflation in plant costs, and by the recently added costs necessary to protect the environment against pollution.

For these conceptual design studies, base plants were selected against which to compare advanced cycles. Operating heat rates have worsened in the last 10 years because of a slowdown in technological development, increased environmental controls, and poorer coal quality. As Federal Power Commission statistics show (Figure 3), the

Figure 3 Operating heat rates for large coal-fired plants, 1950–1990, based on Federal Power Commission statistics. The shaded area (1960–1980) represents the range of heat rates for the five best units and (beyond 1980) the trend of the best designs. EPRI has sponsored studies to develop conceptual designs for an advanced plant with a nominal operating heat rate of 8500 Btu/kWh (RP1403). These studies have used a plant with a heat rate of 9400 Btu/kWh as a base plant.



five best currently operating fossil plants have heat rates of 9000–9400 Btu/kWh (without flue gas desulfurization); 9400 Btu/kWh was used as the base rate for the study. The base plants were assumed to have a steam pressure of 3500 psig (24.13 MPa), a throttle temperature of 1000°F (538°C), and reheat temperatures of 1025°F (552°C) and 1050°F (566°C).

These steam conditions are typical of the majority of the over 150 supercritical units in the United States. It is well known that higher pressures and temperatures can lead to improved unit heat rates, but pressure and temperature values have leveled off in the past decade. The EPRI work has examined the goal of improved heat rate, with emphasis on advanced steam conditions.

Supercritical units preferred

On the basis of utility operating records, the design studies conclude that (contrary to traditional opinion) today's supercritical steam plants can be expected to produce availability levels at least equivalent to those of subcritical plants. This reinforces results presented in an earlier *Journal* article (December 1979, p. 18), in which several leading utilities reported excellent availabilities with their highest-efficiency units. It has been shown that with advanced boiler and turbine designs, simplified startup and shutdown procedures, and improved operating practices, supercritical units can be designed and operated to yield both high efficiency and high availability.

Although the U.S. utility industry has remained cautious, utility companies in Japan and Europe are being more aggressive in opting for the advantages of supercritical plants. It is hoped that the joint EPRI-industry project will lead to a similar level of acceptance by utilities in the United States.

Advanced plant designs

The two teams produced separate conceptual designs for advanced steam plants, but the concepts are based on similar principles. Team 1 (Westinghouse Electric Corp., Combustion Engineering, Inc., Gilbert Associates, Inc., and Philadelphia Electric Co.) has recommended a steam pressure of 4500 psig (31.03 MPa), a throttle temperature of 1100°F (593°C), and reheat temperatures of 1050°F (566°C) for a station heat rate of 8421 Btu/kWh and a net power output of 762 MW. Team 2 (General Electric Co., Babcock & Wilcox Co., Stone and Webster Engineering Corp., Boston Edison Co., New England Gas and Electric System, and Jacksonville Electric Authority) has recommended a steam pressure of 4500 psig (31.03 MPa), a throttle temperature of 1050°F (566°C), and reheat temperatures of 1075°F (579°C) and 1100°F (593°C) for a station heat rate of 8877 Btu/kWh and a net power output of 674 MW.

The two studies indicate that these advanced plants, which represent an improvement in heat rate of approximately 10%, could be available for commercial order within five years with a small R&D investment. Additional gains in heat rate are possible, but they will require significant increases in R&D expenditures and considerably longer development time.

Variable-pressure boilers

Both teams have recommended boiler designs that permit variable-pressure operation over the load range. This permits much more flexibility in plant operation because the system can be designed for specific startup and shutdown sequences, wide load swings, and cycling duty; damaging temperature transients are minimized and efficiency is improved. C–E (Team 1) proposes a vertical-tube boiler, and B&W (Team 2), a boiler with spiral-wound tubing. Both designs use a pumped recirculation system for startup and low-load operation.

In the B&W design, the water-wall tubes spiral around the four walls of the furnace so the fluid always flows upward (Figure 4). The water is completely vaporized in the upper part of the furnace. Because all the tubes spiral up the furnace and cross the four walls, they all receive the same heat flux. This ensures a minimum fluid temperature difference at the outlet of the tubes. The first U.S. boiler to use this design (pioneered in Europe) is currently being installed at Jacksonville Electric Authority.

The C–E sliding-pressure boiler achieves a similar objective with vertical circuitry. It uses rifled tubing to improve heat transfer

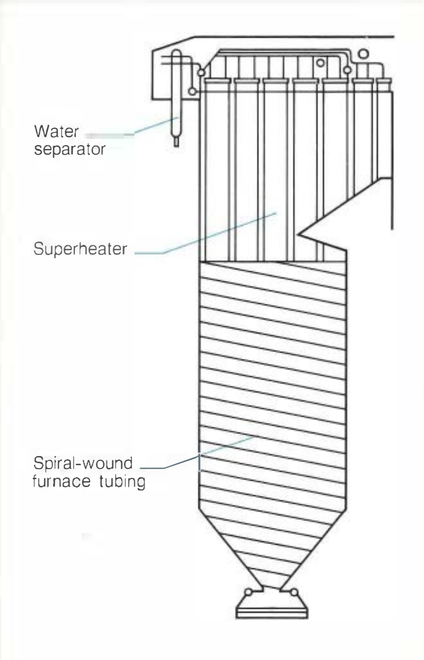


Figure 4 Spiral-wound tubing in a supercritical boiler designed for variable-pressure operation.

and valves in the steam circuit between the water walls and the superheater to balance the fluid flow.

Improved turbine cycle efficiency

The studies have shown that increasing both steam pressure and steam temperature improves cycle efficiency. Both teams recommend the practice of double reheat, which is commonly used in supercritical units. There is a basic difference in the steam temperatures for the two advanced plants, however. In the Team 1 design, the throttle temperature is higher than the reheat temperatures; in the Team 2 design, the throttle temperature is lower than the reheat temperatures.

Concerns about materials in the turbine high-pressure unit (receiving steam at throttle temperature) and the intermediate- and low-pressure units (receiving reheat steam) lead to limitations on steam temperature, and one team has proposed innovative cooling schemes for highly stressed turbine components. For advanced plants with very high steam temperatures (>1200°F; 649°C), new high-strength rotor-forging materials will have to be developed. This is not considered necessary, however, for the next generation of pulverized-coal plants.

Other advanced concepts

Additional efficiency gains can be made in the generator by using superconducting field windings of niobium-titanium cooled by liquid helium. This new concept, which essentially eliminates all resistive heat losses in the windings, is being developed under RP1473. An efficiency improvement of up to 1% may be possible.

The conceptual design studies have shown that modifying the plant thermodynamic cycle by using more heat exchangers can lead to significant heat rate improvements. One team identified four promising types of heat exchanger: (1) a very high pressure heater in conjunction with a low-level economizer, (2) topping desuperheaters, (3) crossover heaters, and (4) intermediate desuperheaters. Such additional heat exchangers have the potential to improve heat rate by more than 200 Btu/kWh, but not all are economically or technically viable at this time. One recommended plant feedwater cycle is shown in Figure 5.

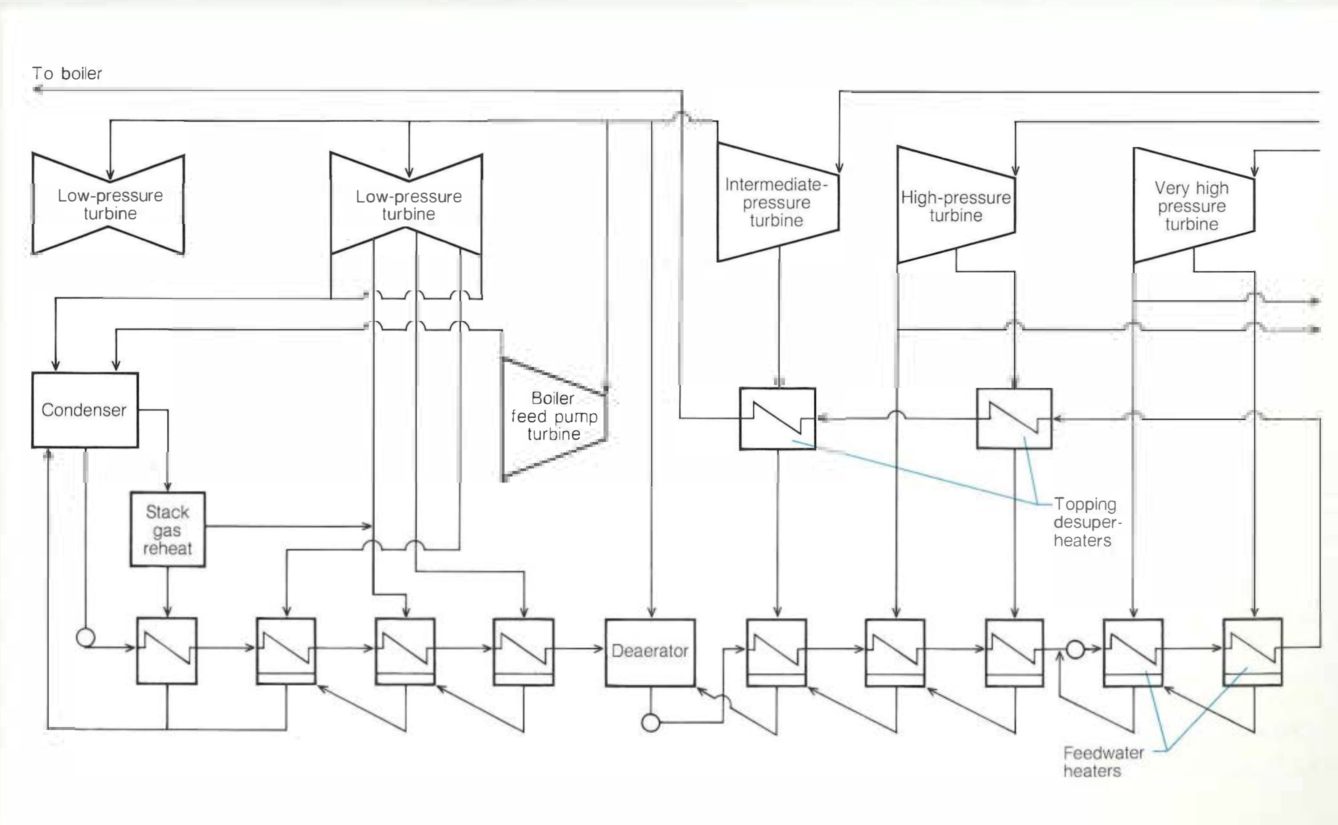
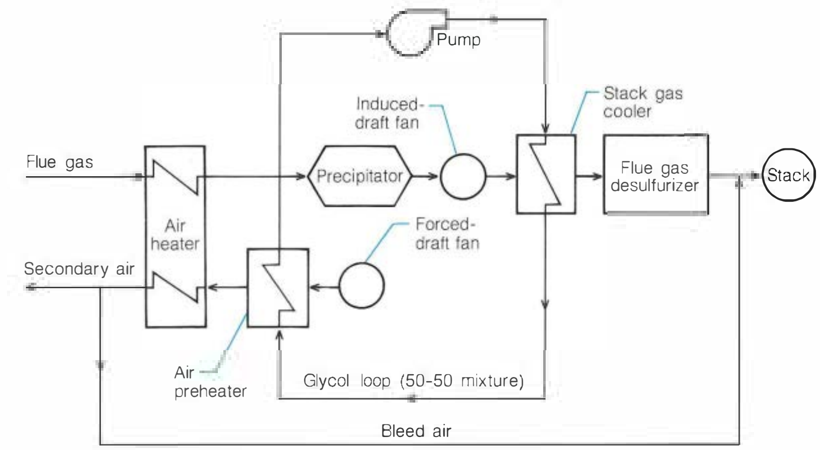


Figure 5 Feedwater train for an advanced plant. Topping desuperheaters improve cycle efficiency.

Overall plant heat rate can also be improved by innovative back-end designs, as one team has shown. Various ways to reheat exiting flue gas and to preheat primary and secondary inlet air were evaluated, and motor-driven and steam-turbine-driven induced-draft fans were compared. A steam turbine drive would allow the turbine exhaust to be used for flue gas reheat and inlet air preheat. Depending on the system chosen, heat rate gains of up to 150 Btu/kWh may be possible. (If gains at this level are to be achieved, some material R&D will probably be required to overcome corrosion problems.) One recommended system uses an ethylene glycol loop for stack gas reheat and steam from the low-pressure turbine crossover for inlet air preheat (Figure 6). This system can improve heat rate by 144 Btu/kWh with negligible increase in capital cost.

Figure 6 Heat recovery system for stack gas reheat and air preheat. This system can improve plant heat rate by 144 Btu/kWh.



Potential economic benefits

To predict the fuel savings that could result from an advanced plant cycle, 14 economic scenarios representing a broad range of future inflation and fuel price escalation rates were investigated. EPRI-supplied premises related to capital costs and fuel costs defined the amount of extra investment that is justified to gain improvements in plant heat rate. The studies concluded that the payback from each of the selected advanced designs over the life of the plant always justified the extra capital costs incurred. Depending on the economic scenario selected, lifetime savings ranged from $74 million to $159 million for a plant of this size. For the inflation and fuel price escalation rates considered most likely (9% and 10%, respectively), one team concluded that savings in the cost of electricity would average 2.30 mills/kWh, or about $82 million over the life of the plant.

An important related conclusion was that the availability of these advanced plants can be as high as or higher than that of existing plants. This is achievable despite the advanced steam conditions by careful equipment design, component and subassembly pretesting, and adequate design margins for the expected duty. Plant availability can be further enhanced by effective use of redundant components, design for ease of maintenance, comprehensive spare parts practices, and new on-line diagnostic monitoring techniques.

R&D requirements

To realize the advantages of improved thermodynamic cycles and advanced steam conditions, R&D in specific areas is considered necessary. Regarding the boiler, for example, one team recommended efforts to develop improved tubing materials for superheaters and reheaters, alternative coal-ash-resistant clad tubing, and corrosion-resistant tube attachments. Recommended objectives for turbine R&D include advanced cooling methods for highly stressed rotating components, improved materials for piping valves and nozzle box, and (for the more advanced concepts) new materials for turbine rotor forgings. The necessity of developing new materials that are compatible with increased steam temperatures was a notable conclusion of both teams. This need was also emphasized at a recent EPRI workshop on rotor forgings for turbines and generators.

The minimum effort one team felt to be necessary to develop the advanced plant was about $14 million over 5–6 years. The other team felt that an advanced plant might take $9–$30 million over 4–15 years, but a smaller gain—(defined as a plant with a steam pressure of 4500 psig (31.03 MPa), a throttle temperature of 1000°F (538°C), and reheat temperatures of 1025°F (552°C) and 1050°F (566°C)—might be possible now with no R&D expenditure.

Future efforts

The benefits of advanced concepts for pulverized-coal plants, as perceived by the two research teams, go beyond lower operating costs and fuel savings. Because of their efficiency, for example, advanced pulverized-coal plants will produce less pollution. Comparison of such an advanced pulverized-coal power plant with other advanced coal-based generation options (e.g., gasification–combined-cycle plants and pressurized fluidized-bed combustion) indicate similar cost, efficiency, and environmental improvement potential. The advanced pulverized-coal power plant has a unique advantage, however, in being an evolutionary improvement in current coal-fired power plant design practice. As such, it builds on a proven design base that requires no major design extrapolation or breakthroughs in technology. In addition, it has been designed for today's utility operating needs in terms of start-stop cycles, load swings, and system flexibility (based on a thorough understanding of design, availability, and operability characteristics).

These conceptual design studies, for which final reports will be published early in 1981, are the first step toward application of high-efficiency pulverized-coal power plants. After further assessment of this work by utilities, development efforts are expected to begin in 1982. An advanced plant of this type could be on order by 1984.

The Coal Combustion Systems Division plans a workshop in 1981 to present these new concepts and other ideas for improving plant efficiency. Input from utilities and equipment manufacturers will be solicited for this workshop. *Project Managers: Anthony Armor and Dan Giovanni*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

POWER SYSTEM PLANNING AND OPERATIONS

Transient and midterm stability

Large-scale power system disturbances have become of greater concern to both the industry and the public during the last decade. One approach to minimizing the effects of such disturbances is to analyze their causes. Unfortunately, today's system analysis tools are still unable to do this effectively; new and better tools are needed.

The goal of a five-part research project is to develop new analytic tools to facilitate studies of large-scale disturbances (RP1208). Development of new concepts in computation structure, network simplifications, and numerical analysis and incorporation of these concepts into a new computer program are the specific objectives. The contractors involved are drawing on the results of RP670, RP745, and RP763 for improved techniques involving transient stability and midterm stability computations, dynamic equivalents, and numerical methods.

As the lead contractor on RP1208, Arizona Public Service Co. (APS) is responsible for coordinating the efforts of four other contractors on the project, in addition to providing the computer program coordination, evaluation, and documentation. As part of this work, APS is incorporating an improved, two-terminal dc transmission line model, as well as improved machine models and auxiliaries. Arizona State University (ASU) has completed the research efforts involving network reduction and output analysis. Boeing Computer Services, Inc. (BCS) is providing the numerical integration algorithms, step-size control, machine model modularization, and system relative-angle computations. Systems Control, Inc. (SCI), in conjunction with Energy Systems Computer Applications, Inc. (ESCA), has developed algorithms for midterm generator aggregations and generator bus reduction. ESCA has extended the aggregation-reduction process to include the external system on a prefault basis. In addition, ESCA is adding the uniform-frequency procedure that was developed in RP764. This option will allow the automatic step-size selection to function better in the midterm simulation region.

The project was started during the first quarter of 1978 and is scheduled to continue through June 1981. As the work has progressed, ASU, BCS, SCI, and ESCA have been providing APS with new and revised computer subprograms for implementation and evaluation.

Transient and midterm stability computations use large amounts of computer storage and time, so parallel processing is also being investigated as an alternative that will provide results with shorter run times and reduced costs. Both BCS and SCI have been working on algorithms involving array processors. A workshop on models and algorithms for stability calculations is being planned for mid-1981. *Project Manager: John Lamont*

Load modeling

The U.S. electric power production, transmission, and distribution system is among the largest, most complex mechanisms ever built. To comprehensively plan and operate this system, computer simulations are made to predict how it will act during normal conditions, and how it will react to disturbances (e.g., short circuits or loss of a generating plant). How the system reacts to disturbances is called its transient (or dynamic) response characteristic.

Simulations are made by modeling the generators, controls, transmission lines, and loads and expressing them as mathematical equations. These equations are then solved with a computer to predict total system behavior. The models presently used to represent generators, controls, and transmission lines have been heavily researched and are well established. However, because loads are not centralized, predictable, or consistent, the load models have had to be derived empirically or through experience and judgment. Historically, it has not been possible to relate load models to the actual numbers and types of devices in the situation being studied. This has forced the analyst to choose a conservative model, and the added margin of safety often results in premature (and therefore costly) installation of facilities and restrictive operating precautions.

An EPRI project to examine load characteristics during transient performance was initiated to help analysts devise load models that more accurately reflect the response of load to disturbances (RP849). In this recently completed four-year effort, four contractors and several utility companies developed a new procedure for modeling the characteristics of load during abnormal voltage and frequency conditions.

It was found that an effective load model can be devised by forming a composite of the characteristics of individual components that make up the load (e.g., pumps, air conditioners, and heaters). This procedure is less expensive and more versatile than performing field tests to measure load characteristics because the new procedure can account for response at different times of day or year and under different weather conditions; in addition, new load types, such as battery chargers for electric vehicles, can be easily incorporated. The large number and diversity of load elements, which have discouraged analysts in the past, can now be dealt with through the use of statistical techniques.

The first information required for using this new procedure is the knowledge of which load components are "on" at any given location and time. EPRI researchers have found that these data are being assembled at many utilities for load research and load management studies and in response to regulatory and government requirements, such as the Public Utilities Regulatory Policies Act (PURPA). Appliance saturation surveys, census data, and standard industrial classification (SIC) codes were identified as good information sources.

Once the individual pieces of the total load have been identified from these data, the response characteristics of each piece must be combined to form a composite model. To do this, dynamic response characteristics of load components, such as air conditioners, refrigerators, and heaters, were measured in the laboratory and in cooperation with Texas Power & Light Co. The voltage and frequency response characteristics recorded in these tests form a valuable data base for the modeling procedure. The results of some of these tests were discussed in an earlier *EPRI Journal* article (October 1978, p. 68).

Because no confidence can be placed in any mathematical model until its performance has been verified, tests were run at several substations to serve as a basis of comparison. Small voltage changes were induced and recorded by switching capacitors and changing transformer tapes. These tests were performed at various times of day and year to check how well the load modeling procedure tracked these changes. A radial feeder open/reclose operation and a staged-fault test were performed to check the large-disturbance prediction capability of the model. These tests were performed at selected sites by Long Island Lighting Co., Rochester Gas and Electric Corp., and Montana-Dakota Utilities Co. The tests showed that the whole procedure is valid but that further research is needed to improve model performance.

A major challenge in this research was to devise a means of reliably recording and storing test data at different locations in highly disruptive electromagnetic environments. To do this, a real-time digital data acquisition system (RTDDAS) was designed, built, and tested (Figure 1). The RTDDAS, housed in an easily movable trailer, is a complete digital recording system that fulfills all standards for safe operation in substations up to 765 kV. Digital computers are used to sample up to 16 channels of information at 480–9000 samples per second per channel. This trailer was found to be a very valuable and powerful tool for recording and analyzing power system phenomena. EPRI is now seeking host utilities to perform tests to measure the reaction of individual or composite loads to momentary variations in voltage or frequency.

Figure 1 Interior of the mobile trailer that houses the real-time digital data acquisition system. Using the computer equipment shown, test data can be safely and accurately recorded in substations up to 765 kV.

The RP849 effort has identified a method of using available knowledge and information to improve the quality of power system simulations. Details of the results of this research, including field test results, are given in three EPRI reports (EL-849, EL-850, and EL-851). Field tests can be arranged on specific utility systems by contacting the EPRI project manager. Follow-on EPRI research is planned to improve the performance of some elements of the modeling procedure, to extend the support data available, and to develop this procedure for routine use by utility engineers. *Project Manager: James Mitsche*

DISTRIBUTION

Effect of voltage on energy conservation

Many state regulatory agencies are either suggesting or requiring utilities to look into voltage reduction as a possible means of conserving energy. In response to this development, EPRI is sponsoring a project that will provide utilities with basic data and analytic methods for dealing with such evaluations (RP1419). The objectives of the project are to quantify the energy consumption of electric loads as a function of supply voltage and to provide a means for predicting energy changes as a function of voltage at the circuit level. These objectives effectively divide the project into two phases (*EPRI Journal*, July/August 1979, p. 53), the first of which is now approaching completion.

In the first phase, a wide variety of load components were tested at seven input voltages ranging from 100 to 126 V (120-V base). When appropriate to normal operation, equipment was regulated to provide identical outputs at each voltage level; for instance, air conditioners were set to provide the same temperature and humidity conditions at each voltage. Furthermore, the effects of loading were considered—three outdoor ambient conditions were used for the air conditioner tests, with indoor conditions being held constant. For loads without controllable output, the actual output was measured in whatever terms were appropriate. Subjective evaluation of performance was made if changes were prominent. The following loads were tested.

- Air conditioners (residential and commercial)
- Heat pumps
- Refrigerators and freezers
- Washing machines and dryers
- Conventional ovens and electric ranges
- Microwave ovens
- Television sets
- Incandescent, fluorescent, and street lights
- Water heaters
- Induction motors
- Distribution transformers

The tests were designed to approximate normal use patterns of each appliance. When possible, standard test methods were used, with some modification to meet the additional requirements of this project. Of utmost importance in the performance of the tests was the accuracy of the instrumentation and the readings taken by the tester. Data were tracked as the tests proceeded so apparently anomalous readings could be rechecked. Most of the measured quantities varied smoothly with voltage, as was expected.

The data to be presented in the final report show how the efficiency of certain appliances (e.g., air conditioners) changes not only as a function of voltage but also as a function of loading. In addition, current, energy, motor temperatures and speeds, air flow, and other appropriate operating parameters are given as functions of voltage and loading for all appliances tested.

The results of the testing indicate that at less than full load, some saving in energy consumption can be realized by moderately reducing the supply voltage to below rated voltage. At full load or overload, energy consumption can increase as voltage drops below rated voltage. These conclusions are very general and vary with the type of appliance. More specific information will be available in the Phase 1 final report, scheduled for publication in March 1981. *Project Manager: Herbert Songster*

UNDERGROUND TRANSMISSION

Measuring degradation of electric insulation

When electric insulation ages in service, its insulating characteristics change and its dielectric properties, such as ac, dc, and impulse strength, are reduced. Dielectric losses often increase also. Testing of cables to evaluate the integrity of electric insulation is performed on new cables in the factory. However, this provides little information as to how the cable will respond on aging.

The changes in dielectric properties that result from aging are a result of very subtle, fundamental chemical transformations within the polymer itself that can lead to physical or chemical alterations in the molecular structure. As these alterations precede changes in dielectric properties, a better understanding of the aging process would result were it possible to evaluate them and learn their nature. Such measurements are complicated by the fact that many of these changes only occur immediately prior to failure.

Unfortunately, the changes that result in the loss of dielectric integrity are extremely minute and highly localized. The tests generally performed on polymeric cable insulation to measure loss of tensile strength, deformation resistance, or sol fraction level (for cross-linked insulations) are insufficient guides for fingerprinting such minute changes. These tests depend on rather substantial bulk changes in the insulation structure, and it has not been demonstrated that measurable alterations in these properties appear during normal aging. More subtle techniques for testing materials have been developed by the chemical industry but have not been generally employed for cable characterization.

To develop a better understanding of polymeric testing and its potential applicability to insulation problems, EPRI contracted with the National Academy of Engineering to evaluate the state of the art of relatively new experimental techniques (TPS79-723). NAE then established a panel to investigate this area, and in 1979, as part of its evaluation, NAE sponsored (and the panel coordinated) a workshop in cooperation with the annual conference on electric insulation and dielectric phenomena.

The final NAE report is being prepared, but on the basis of the workshop conclusions, the panel has made the following recommendations on procedures and the potential future of such new experimental techniques.

- Additional basic research should be conducted on the treeing phenomenon.
- Standard materials should be established for use in future round-robin tests, aging evaluations, and other experiments and assessments. Utilities should maintain lengths of pristine cables for use as base-line reference samples and for comparisons and studies of life histories. The establishment of a standard materials bank should help in evaluating the sensitivity, accuracy, and precision of various analyses.
- Accelerated-aging tests performed in the laboratory should be modified to reflect actual behavior more closely. Different stress modes can be used—thermal, mechanical, and chemical (including moisture-induced stresses).
- In addition to the development of characterization techniques to monitor physical and chemical changes and to determine impurities, more emphasis should be placed on experimental techniques for investigating morphology and the role of morphological changes in degradation processes.
- A data base on the behavior of operating cable systems should be developed and maintained.
- Analysts should be required to measure gradients of composition, reactions, and physical properties of the insulation (e.g., variations in cross-linked density across an insulation wall), which can vary with insulation thickness and result in different morphologies.

The best polymeric testing results are likely to be obtained by using a number of experimental techniques in skillful combinations. It should be recognized that most of these tests are destructive in nature. Enough samples should be employed to establish a confidence level for the measurement.

Electron spin resonance is an excellent, direct experimental technique for evaluation of degradation mechanisms involving free radicals; at present this method is limited to some extent in sensitivity.

Chemiluminescence is an extremely sensitive experimental technique, but the emitted light on which the results are based may arise from unknown events, reactions, or species; hence interpretation of results can be potentially misleading in the absence of adequate supporting information. With appropriate information, chemiluminescence can possibly be used to qualitatively correlate changes with service life.

Fourier transform infrared spectroscopy is a sensitive technique for monitoring reactions that occur during degradation, particularly when used in the difference spectra mode. This technique can generally be used to fingerprint and identify chemical species that disappear or develop during chemical aging.

Nuclear magnetic resonance is a powerful technique for determining the nature of cross-links and for studying changes in other features over time.

Gel permeation chromatography is valuable for characterization, although it is limited in its ability to detect minute or localized changes; measurements made by this process must be calibrated. A laser light-scattering detector, now in the final stages of development, could be used to obtain results without calibration and to analyze branching of polymer molecules and changes with time.

Rheological tests can give information to corroborate and supplement those obtained by other techniques, such as gel permeation chromatography and molecular weight distribution.

High-performance liquid chromatography is a very useful method for examining impurities and additives, as well as changes in their nature with time.

The work of the panel and results from the workshop have helped identify areas of need and potential means for approaching solutions. When the final NAE report is available, EPRI will review methods for implementation. *Project Manager: Bruce Bernstein*

Soils stability

A new project on the thermal stability of soils adjacent to underground transmission power cables was recently initiated by Georgia Institute of Technology.

The objective of this project is to provide a simple, predictive, analytic method for accurately determining soil stability and for correlating changes in the earth's thermal circuit with cable thermal and electrical capabilities. Although advanced instrumentation is available for measuring the parameters that affect stable and unstable conditions, there are no means of interpreting the data to make a definitive decision about the suitability of a soil for cable applications.

A computer model will be validated with full-scale laboratory tests performed by Georgia Power Co. All tests will be performed on Ottawa sand or on a mixture of Georgia Kaolin and Ottawa sand so the tests can be easily and consistently duplicated by other researchers. *Project Manager: Ralph Samm*

OVERHEAD TRANSMISSION

Transmission tower foundations

Foundations for supporting transmission line towers represent a significant portion of the overall cost of constructing a transmission line. However, it is still not clear that presently available design procedures can be used to produce foundation designs that are optimal in terms of both economy and reliability. This uncertainty led the electric utility industry to request that EPRI actively pursue research in this area.

As noted in a past *EPRI Journal* article on transmission line structure foundations (July/August, 1979, p. 33), there are two predominant types of loading conditions for which these foundation systems must be designed: high-moment loads (associated with single-pole towers and longitudinally loaded H-frame structures) and uplift/compression loads (associated with multilegged towers and transversely loaded H-frames). A new project with Cornell University has been designed to address many of the questions regarding the design of foundations for uplift/compression loads (RP1493). EPRI is also funding research under other contracts to improve the economy of high-moment foundations.

Many types of foundations are presently being used by the electric utility industry in designing for uplift/compression loads. These foundations include drilled shafts (both belled and straight), grillages, piles, spread footings, anchor systems, and many combinations of these basic types. Because so many types of foundations are in use (with a wide range of design theories and analytic models associated with each), it is imperative that the present state of the art be identified for each type of foundation. Input from electric utilities on which types have been used and which are expected to be used in the future is also required to derive the greatest benefit from the R&D funds expended.

To determine the extent various foundation types are used across the industry, EPRI sent out over 200 questionnaires to electric utilities. Every utility known to include overhead transmission lines as part of its system was included. Responses were received from 130 electric utilities, with over 30 of these offering to furnish results of foundation tests performed on their systems.

After the technical state-of-the-art review has been completed and the responses to the questionnaire have been evaluated, a cost-effective program can be developed to direct research on those types of foundations that will provide the greatest benefit to the electric utility industry at the earliest possible date.

The results of this project will be a document that offers designers a technical assessment of the presently available design methods as well as a record of the testing that has gone into the validation of each. This document is anticipated to be available in mid-1981 and will form the basis for any future foundation research program that might be funded by EPRI. *Project Manager: Phillip Landers*

Transmission line grounding

Three distinct but interrelated projects on transmission line grounding are under way to enhance present understanding of the flow of fault current to ground and to improve grounding system designs in terms of efficiency and cost.

The initial project, RP1494-1, was described in an earlier issue of the *Journal* (September 1980, p. 38). Two additional projects have started that will add significantly to present knowledge of the behavior and design of substation grounding systems (RP1494-2, RP1494-3).

Two approaches may be taken in designing and analyzing substation grounds. One involves the construction of physical scale models that represent the grounding grid and the earth; the other is based on the development of mathematical models. EPRI is sponsoring projects using both approaches because each has its own advantages and limitations. Also, agreement of results from the analytic method and measured results from the scale model would be a validation of the design method.

An early example of scale modeling is a series of tests done by Walter Koch in the early 1950s. The results of his work are incorporated in the design methods recommended in the *IEEE Guide for Safety in Substation Grounding*. However, Koch's tests were performed with very small models, and much of the data was not published and is therefore unavailable. Other tests have followed that prove the validity, and possible problems, of scale modeling, but a well-planned and carefully executed series of scale-model tests is needed that uses larger models, sophisticated measuring techniques, better documentation, and models based on practical applications. In response to this need, Ohio State University is starting to work on a comprehensive series of scale-model tests to determine the effects of grid configuration, burial depth, use of ground rods, and soil resistivity (RP1494-3). The earth's geology will be modeled, using both one- and two-layer representations.

The second approach to substation grounding design is to use analytic methods. The mathematical model, while complex, can be readily handled with the help of computers and is much more flexible than the scale models. Substations differ from one another to some degree in size, layout, soil resistivity, or connection to other grounds, and building individual scale models for each installation would be expensive and time-consuming. The substation designer requires analytic methods that will give accurate results over a wide range of variable conditions. To fill this need, the Georgia Institute of Technology is developing user-oriented computer programs for the design of complex grounding schemes (RP1494-2).

To verify the accuracy of the computer program and to demonstrate its practical value for substation grounding design, staged-fault tests will be conducted on a Georgia Power Co. substation. Step and mesh voltages measured at the substation will be compared with the computer-generated values.

The final report and computer programs for optimal design of substation grounding systems will be available in late 1982. *Project Manager: John Dunlap*

Transmission line inspection system

The importance of line reliability has received much attention in line design and construction, but the evaluation of transmission line integrity still depends largely on visual inspection; this method may no longer be adequate for today's large, sophisticated power delivery systems. Furthermore, because it is not clear how much money will be available in the future for new lines, there is greater incentive to increase the reliability of existing lines.

In spite of the industry's best efforts to prevent line failures, they do occur and usually at the worst times—in high winds, snow, icing, or bitter cold. Such conditions may cause aircraft to be grounded or prevent patrolmen from driving to the fault location. Each hour of waiting for power restoration may cost thousands of dollars in incremental generation cost or lost revenue. A reliable, cost-effective system to locate and characterize the fault under any weather condition would greatly facilitate line restoration.

A major objective of an inspection program is the early discovery of problems before they adversely affect the operation of the line. This is difficult to accomplish through visual inspection; therefore, more sophisticated methods are needed. One example involves the detection of hot spots. No reliable method exists to detect incipient failure of splices and dead-ends, a problem that has been further aggravated by heavy line loading. Another conductor problem is overhead ground wire strand breakage, particularly when the break occurs under hardware, where it is difficult to detect.

In a minimum-effort feasibility study, Westinghouse Electric Corp. will assess the application of the most modern technologies to overhead transmission line inspection procedures (RP1497-2). Discussions with utility personnel will be conducted early in the project to produce the list of inspection information needed to determine the condition of conductors, overhead ground wires, hardware, and other items normally subject to inspection. Then symptoms for each line problem will be identified and potential detection techniques determined. An assessment will be made of the feasibility of applying automation to line inspection, taking into consideration the performance of each detection device in the transmission line environment and its potential for cost-effective application.

Successful development of a reliable, cost-effective line inspection system not only would reduce a major transmission line operating expense but also may help realize the more important goal of improved line reliability. *Project Manager: John Dunlap*

TRANSMISSION SUBSTATIONS

Paper insulation for transformers

The insulation employed in liquid-filled transformers is derived from wood pulp cellulose, which has been used for over 60 years for this application. Cellulose derived from different wood species differs primarily in the nature and quantity of other substances present (e.g., lignin and hemicellulose), but the cellulose itself is not different. The wood pulp is processed to remove natural impurities and converted into a paper insulation, called kraft paper, which is used by transformer manufacturers.

Insulation integrity is an important underlying requirement for reliable transformer operation. About 15–20 years ago, after much R&D, the cellulose-based paper employed in this application was modified with additives to impart improved thermal properties to the insulation. Most paper used today for conductor (turn) insulation or layer insulation is thermally upgraded by these additives.

Because cellulosic insulation represents a relatively small market for the paper producers, little R&D has been performed in this area in recent years. A need exists not only to further upgrade thermal properties (so the insulation can withstand hot spot temperatures) but to impart superior dimensional stability, improve mechanical strength, and reduce the insulation's tendency to absorb moisture. Such improvements must be achieved without degrading the material's dielectric properties.

To investigate this area further, EPRI has initiated a three-year multiphase project with McGraw-Edison Co. to seek methods for improving the conventional papers employed as transformer insulation (RP1718). McGraw-Edison will be assisted in this effort by Riegel Products Co. and the Institute of Paper Chemistry (which will serve as consultant to both McGraw-Edison and Riegel throughout the program). This opportunity to combine the expertise of a paper research organization, a paper producer, and a transformer manufacturer should lead to the first improvements in transformer insulation in many years. *Project Manager: Bruce Bernstein*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

EXTRACTION PROCEDURE FOR UTILITY SOLID WASTE

Coal is used to generate nearly half the electricity produced in the United States and is the country's most abundant fossil fuel resource, so the treatment of solid waste from coal burning is of great importance to the electric power industry. The industry now produces about 60 million tons of this solid waste annually; by 2000 this could increase to about 250 million tons. Coal waste is subject to federal regulation under the Resource Conservation and Recovery Act of 1976, the final version of which was released in May 1980. In December 1978 EPA proposed an extraction procedure to be used in assessing the hazardous nature of solid wastes. Because this procedure involves measuring metals present in trace amounts, there is concern that the results of waste analysis may vary from laboratory to laboratory and the analyses may be overly sensitive to variations in technique. Therefore, EPRI has sponsored an assessment of the procedure (RP1487).

The extraction procedure proposed by EPA in December 1978 involves leaching a solid waste with acetic acid for 24 h and then analyzing the leachate for eight metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver) and six organic compounds (endrin; lindane; toxaphene; methoxychlor; 2,4-D; and 2,4,5-TP silvex). The proposed rule stipulated that if the leachate (or extract) from a waste contains any of these metals or organics in concentrations exceeding 10 times the National Interim Primary Drinking Water Standards, it would be classified as hazardous. The final rule, which was published in May 1980, classifies a waste as hazardous if its extract contains any of the specified contaminants in concentrations 100 times the drinking water standards.

The EPRI study had two phases. In Phase 1, which examined the reproducibility of test results, samples of five utility waste types were analyzed by four laboratories. The results were then statistically evaluated to determine the intra- and interlaboratory precision of the extraction procedure itself and of the techniques used to analyze the extracts. In Phase 2, which examined the sensitivity of analytic results to modifications in laboratory procedure, three types of utility waste were divided among the four laboratories. In analyses of these wastes, the extraction procedure was changed in one of five ways, and the results were statistically evaluated to compare the five alternative procedures with the EPA standard method used in Phase 1.

The four contractors on the study were Acurex Corp., Camp Dresser & McKee Inc., Radian Corp., and Systems, Science & Software. An advisory committee made up of representatives from utilities, universities, EPA, a coal company, and a national laboratory guided the project from the writing of the RFP to the evaluation of the results.

Phase 1: Reproducibility of analysis results

For the study, five types of coal-fired power plant waste were obtained from plants in the vicinity of St. Louis, Missouri: alkaline dry fly ash, acid dry fly ash, alkaline wet bottom ash, acid wet bottom ash, and scrubber sludge. Each laboratory received four samples of each of the five waste types and prepared 20 waste extracts by using the EPA extraction procedure of December 1978. Each extract was divided into eight aliquots (portions); two aliquots from each extract were retained and two were sent to each of the other three contractors. Thus each laboratory had for analysis two aliquots from each of the 80 extracts prepared.

Each aliquot was analyzed by both flame and furnace atomic absorption spectroscopy for the eight metals specified in the EPA regulations: arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver. The results were statistically evaluated to identify the sources of their variability. Considered were (1) interlaboratory extraction variability, (2) intralaboratory extraction variability, (3) interlaboratory atomic absorption analysis variability, (4) intralaboratory atomic absorption analysis variability, and (5) unallocated variability.

The statistical analyses of the Phase 1 data led to the following conclusions.

- Different laboratories that extract and analyze the same waste commonly produce results that differ by hundreds of percent.
- Regardless of whether the flame or the furnace technique is used, the variation in results is not consistently higher for any one type of waste than for another. In other words, the magnitude of the variance between laboratories is not a function of waste type.
- When the furnace technique is used, the results on lead and selenium commonly show the lowest variance and the results on barium and cadmium the highest.
- When the flame technique is used, the results on cadmium and chromium commonly show the lowest variance and the results on barium and mercury the highest.
- The interlaboratory analysis variability (i.e., the variability arising when different laboratories analyze aliquots from the same extract) typically represents the greatest cause of variability in results. Something in the final analytic procedure contributes most to differences in outcome.
- The intralaboratory extraction variability typically represents only a small part of the total variability in results—about 8% for the flame technique and 15% for the furnace. (The furnace value drops to 9% if the exceptionally high values for chromium are deleted.) These low values indicate that sample inhomogeneity is not a problem.

Under the EPA regulations proposed in December 1978, some of the wastes used in this study would have failed the hazardousness test. There was little consistency; the classification of a sample as hazardous or not depended on the laboratory doing the analysis and on the analytic technique used. Under the EPA regulations adopted in May 1980, all the wastes would have passed the test. It must be emphasized, however, that the Phase 1 data are useful only for evaluating the extraction procedure. Because the samples were not representative of any particular waste type, the data cannot be used to draw conclusions about the nature of utility waste.

Phase 2: Effects of modifying the extraction procedure

The purpose of Phase 2 was to evaluate the sensitivity of final analytic results to modifications in the extraction procedure. Modifications considered were (1) no agitation of waste samples during extraction, (2) use of deionized water instead of acetic acid, (3) grinding of waste in a ball mill for two hours before extraction, (4) addition of all the acetic acid at the beginning of the extraction procedure rather than in steps, and (5) centrifugation instead of filtration to separate liquid and solid phases. The modifications were evaluated separately, not in combination (i.e., no extraction involved more than one modification at a time).

Each of the five modified extraction procedures was compared with EPA's standard procedure in terms of the amount of metal extracted and the variability of the final analytic results. The comparisons are summarized in Table 1.

It was found that each modification tends to result in an increase in the amount of metal extracted. Not unexpectedly, grinding always resulted in the extraction of more metal than the standard procedure. Surprisingly, however, using deionized water as the extractant (instead of acetic acid) also yielded higher concentrations of metal in 78% of the cases for which comparisons could be made. Using the standard EPA procedure without any modification typically results in the extraction of the lowest amount of metal from the waste.

It was also found that using the standard procedure leads to greater variability in final results than using any of the five modified procedures. Of the modifications, centrifugation most commonly results in a lower variability in comparison with the standard procedure.

The overall statistical analysis of the data from Phase 2 involved comparing each modification individually against the standard procedure. Analysis of the effects of combining two or more modifications was considered to be beyond the scope of this project. *Program Manager: Ralph Perhac*

Table 1
COMPARISONS OF MODIFIED EXTRACTION PROCEDURES WITH EPA STANDARD EXTRACTION PROCEDURE

Modification	Comparisons With Standard Procedure (number)	Lower Metal Concentration (%)[1]	Lower Variability in Results (%)[2]
No agitation	10	40	70
Water extraction	9	22	78
Grinding	5	0	60
All acetic acid added at once	13	31	62
Centrifugation	12	33	83

[1]Percentage of comparisons in which the modified procedure results in a lower concentration of metal in the final extract.

[2]Percentage of comparisons in which the final results from the modified procedure showed lower variability.

ENERGY MODELING FORUM: AGGREGATE ELASTICITY OF ENERGY DEMAND

EPRI created the Energy Modeling Forum (EMF) to improve the understanding of energy models for the study of vital energy issues affecting the electric utility industry (RP875). Administered by Stanford University and now cofunded by DOE, EPRI, and the Gas Research Institute, EMF operates through ad hoc working groups of energy model developers and users that conduct comparative tests of a variety of energy models. A senior advisory panel recommends topics for study, and each working group is organized around a single topic to which several existing energy models can be applied. The group constructs a series of tests to illuminate the basic structure of the models, the necessary conditions for their use, and their capabilities and limitations. This report describes the fourth EMF study, which examined the aggregate elasticity of energy demand.

Study objectives

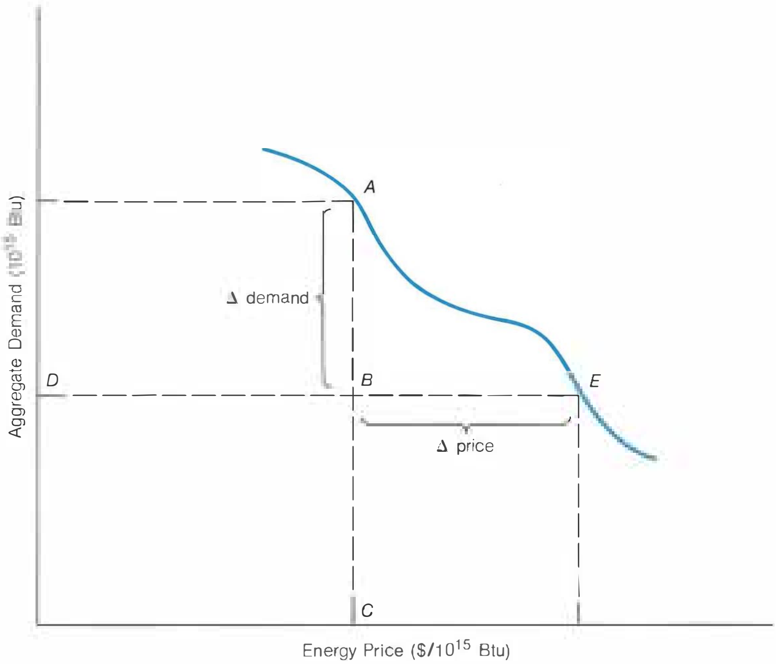
The response of energy demand to changes in energy prices is central to the evaluation of energy policies. To study this response, analysts and modelers have developed many sophisticated models of energy demand. These models, different in structure and degree of detail, are not easily compared in terms of the relationship between demand and price.

Simplified to a single number, the response of demand to changes in price is called elasticity. The aggregate price elasticity of energy demand is equal to the percent reduction in energy demand produced by a 1% increase in energy price, with all else held constant (Figure 1). By convention, aggregate elasticities are positive when price increases lead to a decrease in demand.

Straightforward in concept, properly quantifying the aggregate elasticity of energy demand is difficult in practice. However, this simple, single parameter has appeal as an indicator of important underlying relationships, and there is little doubt that it will continue to be used to describe aggregate changes in future energy demand. If the elasticity is to be used correctly, its definition and measurement must be improved. The fourth EMF study worked toward this end by comparing many energy demand models.

The goal of the study was to describe the aggregate price elasticity of demand implicit in energy demand models. The working group ran experiments with 16 detailed models of the energy sector and developed consistent estimates of the 15-, 25-, and 35-year energy demand elasticities implicit in each model. The comparison of results is descriptive; there was no attempt to produce a single best estimate of the demand elasticity.

Figure 1 Computation of the aggregate price elasticity of demand at point *A*. The percent reduction in demand is given by $(AB \div AC) \times 100$, and the percent increase in price is given by $(BE \div DE) \times 100$. The aggregate price elasticity is the percent decrease in demand caused by 1% increase in price, or $(AB \div AC)/(BE \div DE)$.



Having an aggregate elasticity value or a set of fuel-specific elasticities is critically important for many analyses. The higher the elasticity of demand for energy, the smaller is the impact of a given increase in the cost of imported energy on the gross national product. The higher the elasticity, the lower is the forecasted future energy consumption in high-price situations, the less urgent is the perceived need for new energy supply technologies, and the lower are projected world oil prices.

Energy encompasses a number of heterogenous commodities, each with a separate price, and the prices and quantities of these commodities must be aggregated to calculate a single elasticity. The choice of aggregation rules can influence the resultant estimations. The group examined several aggregation indexes: Paasche, Laspeyres, Tornquist, and Btu-weighted. Also, elasticity can vary by a factor of nearly 2 over different stages from production to consumption. The group used two standardized points of measurement: primary energy (measured immediately before the losses entailed by refining, electricity generation, and synthetic fuel conversion); and secondary energy (measured immediately after conversion and refining losses). Primary-energy prices are generally lower and the quantities higher than the corresponding secondary-energy values; consequently, primary-energy elasticities are generally lower than secondary-energy elasticities.

Total demand for energy can adjust in many ways. The detailed energy demand models focus on different system elements, possibly fixing some demands while calculating others. Some of the models include restrictions that reduce the ability of the economy to adjust to higher prices or that reduce the measured elasticity. Also, the disaggregated elasticities used in the models may be estimated statistically or by engineering or judgmental approaches.

Study results

The working group found that the more comprehensive models (i.e., those that cover all energy-using sectors, incorporate the full range of potential energy-using flexibility, and employ historical data to statistically estimate parameters) were generally characterized by the highest implicit aggregate secondary-energy demand elasticities. Long-run aggregate secondary-energy demand elasticity estimates for these five models ranged from 0.3 to 0.7. Other models produced lower estimates, either because they incorporated lower, subjectively determined component elasticities or because they allowed for only limited energy-use substitutions. Four of the five models in this category produced elasticity estimates from 0.1 to 0.2; the fifth estimate was 0.6.

As shown in Table 2, demand elasticities vary significantly across sectors, among models, and with different policy assumptions. Automobile efficiency standards, for example, may lower the elasticity for gasoline by a factor of 2 to 3.

Aggregate elasticity estimates were not sensitive to the choice of Paasche, Laspeyres, or Tornquist indexes but were different when the Btu-weighted index was used. Because the Btu-weighted index is theoretically less attractive, all elasticities referenced in this summary were computed by the Paasche method.

The aggregate demand changes projected with many models were sensitive to the specific composition of price changes. Because an aggregate analysis may be inadequate or misleading for these models, a method was developed to illustrate the implications of different compositions of price changes.

The study did not examine the adjustment dynamics inherent in the models. However, energy demand adjustments occur slowly because demand is linked to the stock of energy-using equipment. An analysis of post-1973 experience indicated that the conservation actually experienced to date could be consistent with any of the estimated long-run primary-energy elasticities implicit in the models.

There is a range of uncertainty associated with any demand elasticity estimate; the actual elasticity could be greater than or less than any of the estimates presented in the study. (The range of uncertainty is not the same as the range of elasticity estimates.) Several sources of uncertainty exist in each model: measurement error in the data, parameter estimation uncertainty, and model specification errors. However, limitations in the current state of the art either preclude calculation of explicit uncertainty measures or make it extremely costly.

Measurement of prices and quantities at the secondary-energy level was more useful for computing dependable aggregate elasticities than measurement at the primary-energy level. The conditions necessary to ensure the theoretical consistency of aggregate economic indexes are more

Table 2
ESTIMATES OF 25-YEAR SECONDARY-ENERGY DEMAND ELASTICITY

Sector	Statistical Parameter Estimation	Other Estimation Approaches (engineering or judgmental)
All sectors	0.3–0.7	0.1–0.6
Residential	0.5–1.0	0.4
Residential and commercial	0.5–0.8	0.5
Commercial	0.5	0.3–0.4
Commercial and industrial	0.3–0.7	0.1
Industrial	0.2–0.5	0.2–0.7
All transportation	0.2–0.5	0.4
Automobile (gasoline)		
With efficiency standards	0.1–0.2	—
Without efficiency standards	0.1–0.5	..

nearly satisfied at the secondary-energy level. Also, most demand models are structured in terms of delivered energy, which can be adjusted easily to the secondary-energy level; more arbitrary procedures were required to adjust data to the primary-energy level.

The elasticities differ in part because of differences in modeling approaches, techniques, or assumptions. Detailed models often represent some components of energy demand as independent of price, thereby biasing downward the calculated aggregate elasticity. Engineering process models may exclude unrecognized technological options and may underestimate the substitution flexibility of the economy.

Recommendations

On the basis of its findings, the EMF working group made the following recommendations.

- DOE's Energy Information Administration (EIA), working closely with modelers, should develop consistent accounting conventions and standardized data for demand analysis. The working group spent considerable time trying to standardize the data but did not fully succeed.
- Modelers should routinely publish assumptions, error statistics, robustness tests, validity tests, descriptive information, and historical data supporting their models. Agencies funding model development should insist on and support this effort.
- Modelers should make aggregate and fuel-specific elasticities (whether explicit or implicit) a standard component of the documentation of demand models. EIA should publish a set of definitions and computation procedures for calculating these elasticities and the associated adjustment time lags.
- Modelers should develop and then consistently apply techniques for describing the uncertainties in their models. This will require basic methodological research. In recognition of the importance of uncertainty analysis, funding organizations and modelers should budget sufficient funds for this activity.

The working group's report, *Aggregate Elasticity of Energy Demand* (EA-1559), is now available. *Project Manager: Stephen Peck*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

ELECTRIC TRANSPORTATION

Transportation is the energy sector most in need of liquid fuels, most dependent on imported oil, and thus most vulnerable to supply interruptions. It accounts for 50% of U.S. petroleum consumption, an amount roughly equal to petroleum imports. In response to such developments as the 1973 Arab oil embargo and the 1979 Iranian production cutbacks, it has become national policy to reduce petroleum use in this sector by increasing motor vehicle efficiency, increasing supplies of unconventional fuels (e.g., shale oil and coal liquids), and developing such technological options as the electric vehicle (EV). In August 1979 the EPRI Board of Directors instructed the staff to develop research options for accelerating R&D in electric transportation. As a result, the Energy Management and Utilization Division initiated a strategy planning effort to lay the foundation for a program that addresses utility interests and concerns.

There are several electric transportation options: EVs, hybrid vehicles, electric mass transit, electrified railroads, and electrified highways. EPRI's activities focus on the EV because it is considered to have the largest potential for petroleum substitution (light trucks and cars currently consume about 5.5 million barrels of petroleum a day). By using energy produced from coal, uranium, and renewable resources rather than imported oil, EVs would increase the efficiency of primary energy use for transportation; for example, using coal to generate electricity for EVs is much more efficient than using it to produce synthetic fuels for combustion vehicles. Such a resource substitution would also reduce pollution, permit centralized emission control, and reduce traffic noise.

The current state of EV development poses a fundamental commercialization dilemma, however. EVs simply cannot compete in the marketplace with mature conventional internal combustion vehicles, which have high performance levels, unlimited range, relatively low cost (as a result of large production volumes), and an extensive infrastructure to support their distribution and operation. Furthermore, EVs cannot generate a large market demand because they do not perform a unique function or offer sufficiently valuable advantages over combustion vehicles. EV commercialization will require further technology improvement, infrastructure development, and government incentives for market introduction.

Development efforts

Several organizations have been involved in EV development in the past few years. Their efforts have focused on vehicle and component R&D and on small-scale demonstrations of state-of-the-art vehicles. By far, the most extensive program is DOE's, established in response to 1976 legislation that provided $160 million to advance electric and hybrid vehicle technology and to demonstrate commercial feasibility. This program strives for a balance between early commercialization of near-term technology and long-term development of advanced designs and technologies.

Automobile manufacturers, component suppliers, and vehicle fleet operators have also initiated EV programs. For example, General Motors Corp. is conducting an electric van development and production program and has established a project center to design and engineer a small, battery-powered passenger automobile for introduction in the mid-1980s. Gulf+Western Industries, Inc., has developed a high-performance, long-range, long-cycle-life zinc-chloride energy storage system it calls the Electric Engine. A pilot manufacturing plant has been opened, and the company is planning limited production by 1983. In a demonstration program conducted by the U.S. Postal Service, 350 EVs are being used on specifically designed short routes involving low-speed, stop-and-go driving. The postal service expects to place 3000–5000 EVs in service in this decade.

Although these RD&D programs have been successful in raising the level of public interest in EVs as a petroleum conservation option and in demonstrating their potential in commercial applications, EVs are still far from ready for large-scale commercialization. State-of-the-art EVs continue to exhibit limited range (25–50 miles), low performance, and high costs (the initial cost is 25–40% greater than that of a conventional vehicle, and short battery life increases operating costs). EV commercialization is further hampered because energy supply and vehicle support requirements are not clearly understood.

The utility industry has a crucial role to play in developing the infrastructure to supply energy for EVs. It must ensure that EV systems are designed to interface with the established electric power distribution network and EV loads are properly managed to benefit the utility and the consumer. Widespread commercialization will also require the utility industry's close cooperation with the automobile industry (to design and manufacture vehicles) and the government (to provide incentives for introducing EVs into the market).

EPRI can support the utility industry by conducting projects to acquire vehicle performance and utility impact data, organizing and managing utility-based demonstrations to give utilities direct experience with EVs, and integrating EV development and commercialization programs with automobile industry and government programs. EPRI's strategic planning activities over the past year have focused on defining an R&D program to provide this necessary support. The resulting research plan is divided into four areas: the testing, evaluation, and demonstration of EV technology; the evaluation and improvement of critical EV components; the effects of electric transportation on electric energy and power systems; and the introduction of EVs by utilities.

EV testing, evaluation, and demonstration

Although a number of EVs have been manufactured and demonstrated in the United States and abroad, there is no reliable data base on their performance characteristics and their impact on utilities. EPRI is sponsoring a pilot demonstration program to help fill this void by developing data on the performance characteristics, economics, and support requirements of EVs used in utility fleet operations (RP1136-5). The data base will be used to measure EV performance, total vehicle efficiency, and subsystem efficiency (i.e., battery, battery charger, and power train). It will also be used to clarify the effect of subsystem failures on performance efficiency and to guide future R&D.

TVA was selected in March 1978 as the demonstration host and contractor. By providing funds for technical personnel and facilities for the program, TVA has made a major commitment to EV demonstration. It has established a team of 15 engineers and technicians to plan, manage, and support the project. TVA has also developed detailed acceptance testing, maintenance, and operating procedures; designed and equipped an EV battery acceptance testing laboratory; and built a dedicated maintenance and parking garage for the EVs.

Past EV demonstration projects by the government and others have been compromised by a variety of technical deficiencies in the vehicles used. To avoid this, EPRI decided to select vehicles for its demonstration program on the basis of thorough preliminary testing in real-life road situations. Thus, in March 1978 it initiated testing at Southern California Edison Co. (SCE) to define performance and use characteristics of state-of-the-art EVs (RP1136-1).

This testing, now in its third phase, evaluates the range, acceleration, and reliability of vehicles in fleet use under actual driving conditions on city streets and highways. Each EV is driven more than 1000 miles along designated test routes to determine the effects of payload, terrain, and traffic conditions in the city (one to four stops per mile) and on the freeway. Vehicle performance and reliability data are collected, and subjective assessments are made by the SCE fleet drivers.

SCE evaluated four EVs in the first test phase (March 1978–January 1979) and four in the second (June 1979–February 1980). The results on range, acceleration, and energy consumption are summarized in Table 1. The vehicles tested in Phase 2 showed improved reliability over the Phase 1 vehicles, which experienced numerous motor and drive train failures. In Phase 2 there were only minor problems, such as low specific gravity of battery cells, fuse failures, and sticking fuel gages and accelerator pedals.

To further broaden the data base on available EVs, a third test phase began in May 1980 with evaluation of the Jet Electra-Van 600 and a Volkswagen Rabbit converted by South Coast Technology Corp. Testing is now being transferred to TVA, and the first vehicle that will be tested is a Volkswagen pickup truck also converted by South Coast Technology.

The Phase 1 testing at SCE (reported in EM-1245) resulted in the selection of the Volkswagen Type 2 Electro-Transporter for use in the TVA demonstration. It was chosen on the basis of reliability, manufacturing support, maturity of commercial design, and performance (range and acceleration) suitability to TVA missions.

In January 1979 TVA issued a purchase order to Volkswagen for 10 EVs (five vans and five microbuses). The vehicles were manufactured in Wolfsburg, West Germany, and delivered to TVA in December 1979 after successful on-site factory acceptance testing by the TVA staff. The EVs have been tested while being used in actual van pooling and delivery missions. According to preliminary findings, each EV is being driven 17–28 mi/d (27–45 km/d); energy consumption averages 0.8 kWh/mi (0.5 kWh/km). The purpose of testing is to verify the operating performance of the vehicle subsystems and the performance of the data acquisition systems designed, built, and installed by TVA.

To meet the major challenge of data acquisition, TVA developed two hardware systems—a primary and a secondary. The primary system is a microprocessor-based system with up to 32 analog and 16 pulsed electric inputs; it has been designed to have an overall accuracy within 1.5%. The system is connected to sensors and transducers located in the EV subsystem and component circuits (battery charger, controller, battery, and motor). Sensor data are conditioned and digitized by the system and then stored on cassette tapes, which are later removed from the vehicle and taken to a central computer for data analysis. The primary system is used on selected vehicles for a specified period of time. The secondary system, which is a simplified version for record-

Table 1
EV TEST RESULTS

	Phase 1	Phase 2	
	All Vehicles	Jets	Lucas-Bedford
Useful range, city streets (mi)	15–30	15–30	60
Maximum range, freeway (mi)	36	24–53	74
Top speed (mph)	42–45	55–64	54
Acceleration 0–30 mph (s)	11–14	9–15	11–16
Ac energy consumption (kWh/mi)	0.6–2.0	0.6–2.3	0.7–1.3

Note: The vehicles tested by Southern California Edison Co. in Phase 1 were a Battronic Minivan, a Jet Electra-Van 500, a Volkswagen Type 2 Electro-Transporter, and a Volkswagen Type GM2 with Daug drive. The vehicles tested in Phase 2 were a Jet 007, a Jet 1400, a Jet 750, and a Lucas-Bedford van.

ing five performance parameters, will be installed in every test vehicle in the fleet.

The 1981 plans for the TVA demonstration include adding 5–10 passenger or commercial vehicles to the EV fleet. An EV battery-testing program is also being planned to evaluate the performance of advanced batteries (e.g., lead-acid, zinc-nickel, zinc-chlorine, and nickel-iron); the performance data collected on the Volkswagen EVs will be used as a baseline for comparison.

In addition to the work at TVA, EPRI plans to support other utility demonstrations. Data from the SCE and TVA programs, along with the planning, testing, and data acquisition experience gained, will be transferred to other utilities interested in EV development.

Component evaluation and improvement

The objectives of efforts in this area are to evaluate battery chargers and other interface equipment in terms of their compatibility with utility systems and battery requirements and to develop improved designs. Battery charger efficiency, the harmonic content of line current, reactive power content, electromagnetic interference, and radio frequency interference are factors that will have important implications for utilities. Poorly designed chargers could cause severe harmonic injection, communication interference, and power factor problems and thus prevent the development of the EV as a load management option. As an initial effort in this area, Purdue Research Foundation is testing commercially available battery chargers to establish their performance characteristics and is examining their potential impacts on utility grids (RP1523-1). This work will form the basis for setting battery charger standards and determining design requirements for improved chargers.

Projects will be initiated to advance the development of batteries and related components when it appears that a modest EPRI effort could make a significant contribution. For example, EPRI is funding a project with Gesellschaft für Elektrischen Strassenverkehr mbH in West Germany to develop a range-metering device for lead-acid batteries (RP1136-4). Other work will include selected evaluation of battery-recharging requirements to validate advances in battery designs. Proof-of-concept testing of new battery systems developed for EV application will also be conducted to identify promising candidates. Improvements in the energy density, power density, life cycle, and production cost of batteries will be monitored.

Effects on energy and power systems

The objective of this research area is to develop methodologies and analytic tools to help utilities understand their role as energy supplier. An evaluation of national EV development and commercialization programs has been undertaken as a basis for establishing projects to meet this objective (RP1524-1). This evaluation, cofunded by DOE and conducted by Purdue University, is intended to identify options for cooperative EPRI and DOE projects and to characterize the opportunities and risks associated with these options. The project has brought together representatives from major automobile manufacturers, component suppliers, national research and consulting firms, utilities, DOE, and EPRI in a series of workshops on specific EV development issues. Preliminary results include the reorientation of DOE's EV commercialization approach (to allow utility and auto industry planning input) and the development of an EV market information project to be steered by a committee of marketing representatives from automobile manufacturers and component suppliers.

Utilities will be called on to supply power for EVs, but the extent of the impact of EVs on utilities is uncertain. EPRI contracted Systems Control, Inc., to identify areas in which the impact could be significant (RP1524-2). This scoping study has defined the following research topics as critical to the utility industry: EV load location, magnitude, duration, and shape; battery charger technology; distribution system impact; regulatory agency perspectives; financial impact; infrastructure requirements; and EV technology assessment. As a result of this project, an EV recharging, generation, distribution, and cost model is being developed. A model developed by General Research Corp. that calculates EV recharge energy use and utility capacity to provide this energy has been adapted to the calculated cost of the EV load. Preliminary efforts have been under way with two West Coast utilities to confirm the applicability of this approach. (RP1524-3).

As EV technology evolves, it will be necessary to revise predictions of EV penetration and impact. EPRI's initial effort in this area—an assessment of the expected effect of electric passenger cars on utility system loads in 1985–2000 (EA-623)—and other penetration predictions will be reviewed by the Demand and Conservation Program in the Energy Analysis and Environment Division. This effort, like the projects discussed above, is aimed at providing an analytic basis for utility planning and policy in support of EV transportation.

Utility introduction of EVs

The objectives of efforts in this area are to identify opportunities for EV use by utilities and to develop feasible approaches that could lead to the widespread use of EVs. Utilities need direct experience with EVs to understand their benefits, limitations, and utility impact. Because utilities will be called upon to provide electricity and charging infrastructure for EV users in their service areas, they must become familiar with EV performance characteristics, especially those components, such as the battery charger, that directly affect the utility grid. Furthermore, utilities have an opportunity to take the lead in the early demonstration of the appropriateness of EVs for prescribed-distance applications and to obtain valuable experience in developing energy supply and vehicle service infrastructure. In addition to developing EV demonstration planning and operating procedures, EPRI plans to produce instrumentation packages to support utilities in establishing demonstrations and in testing specific utility infrastructure concepts, such as battery charger installation and service, vehicle maintenance and repair, and consumer information service.

The current practice of placing small unit orders for EVs (10–20 vehicles) has done little to encourage the development of a reliable EV manufacturing capability. There is a significant risk that the vehicles purchased will be inadequate, and costly acceptance testing is required, with little opportunity for technology transfer back to the manufacturer. EPRI has established a utility working group to develop ways of increasing utility EV purchases; the group is currently considering the feasibility of a joint purchase of 1000 or more EVs by a group of utilities.

Large automobile manufacturers (especially General Motors) are planning to mass-produce electric passenger cars by the mid-1980s, but they have not yet focused on field test and market issues. Furthermore, existing demonstration projects are an inadequate test of the extent to which EVs can penetrate markets; they are too small in scale to examine utility system impact and to convince the general public that EVs are a viable alternative transportation mode. Large-scale purchase and demonstration projects are required to promote improvements in technology and develop marketing and infrastructure support concepts required for widespread EV acceptance.

By helping to establish such large-scale demonstration projects, the utility industry can be a catalyst in moving EVs toward commercialization. A communitywide demonstration of thousands of vehicles, for example, planned in cooperation with automobile and battery manufacturers, could contribute to the establishment of the commercial potential of EVs and to ensuring that energy supply interface, recharging, and load management requirements are taken into account in EV design and operation. *Project Manager: G. H. Mader*

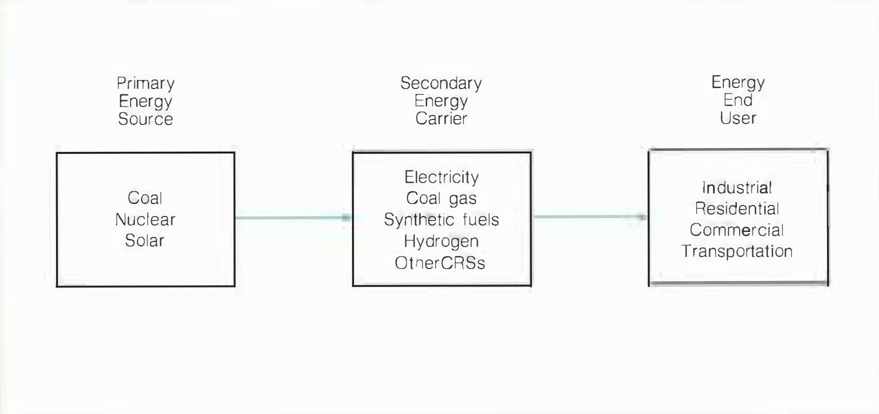


Figure 1 Conceptual scheme for coupling large, central, and remote primary energy sources with users in population centers via secondary energy carriers. Various energy conversion devices, such as turbines, boilers, fuel cells, or synfuel plants, could be used to produce secondary energy carriers for delivering end-use energy in the most efficient and convenient manner.

CHEMICAL ENERGY CONVERSION

*The chemical energy conversion (CEC) subprogram is investigating chemical reaction systems (CRSs) that have the potential to deliver energy from a variety of primary sources to end-use sectors efficiently, economically, and in an environmentally acceptable manner. The production of hydrogen from water and energy and its reconversion to useful energy forms (electric or thermal) constitute the most familiar CRS. Other CRSs that have been studied are benzene-cyclohexane, methane–carbon monoxide–hydrogen, sulfuric acid–water, and sulfur trioxide–sulfur dioxide. Current subprogram efforts are focused on identifying hydrogen generation and application concepts that offer near- to intermediate-term benefits to utilities and developing the appropriate technologies for these concepts. Development of advanced hydrogen production hardware and its demonstration in utility system operations are to be accomplished in the next two or three years. Technoeconomic assessments of hydrogen production by water electrolysis and by thermochemical processes, as well as comparative evaluations of CRSs, have been discussed in previous R&D status reports (*EPRI Journal, *December 1978, p. 44, and December 1979, p. 39).*

Nonrenewable liquid and gaseous hydrocarbon fuels are the only primary energy sources that also serve as convenient energy carriers. Coal and such domestic nonhydrocarbon energy sources as nuclear and solar require delivery systems based on secondary forms of energy to couple them to remote users. To date, electricity is the only secondary energy form that can be derived from such sources as coal, oil, gas, uranium, and falling water and can be used as a universal energy carrier. As hydrocarbon fuels are being depleted, important questions arise: Which energy carrier or combination of carriers might best link future primary energy sources with the ultimate industrial, residential, and commercial consumers to satisfy their needs for heat, electricity, and convenient transportation fuels? And how can electric utilities take advantage of new energy carriers in serving energy users with the highest efficiency and at the lowest cost?

A CRS is a chemical system that can be converted from a low- to a high-energy state in an energy-charging (endothermic) step and returned to the original state with the release of energy in an exothermic step. In systems of practical interest, the energy-rich state is sufficiently stable to allow energy to be transported over long distances and stored for long periods of time. The chemically bound energy is then delivered at the desired location when it is required. Thus, CRSs are potentially capable of coupling large, remote primary energy sources (coal, nuclear, solar) with population centers to provide end-use energy in the most convenient and efficient form—heat, electricity, chemical energy (Figure 1).

Results of past research

The purpose of the CEC subprogram is to explore the potential usefulness and utility applicability of CRSs. Several conceptual and technoeconomic analysis projects were conducted in the 1975–1980 period. The major conclusions of these projects are as follows.

▫ At present, hydrogen production from water and energy appears to be the only CRS that has reasonable potential as an energy carrier. Other CRSs currently under investigation—such as EVA–ADAM (a methane–carbon monoxide–hydrogen system being developed in West Germany to transfer heat from a gas-cooled, pebble-bed nuclear reactor to a district heating network) and the benzene-cyclohexane system—seem too inefficient and capital-intensive (TPS76-658, RP1086-1).

▫ On the basis of both cost and efficiency, hydrogen production by advanced water electrolysis will be competitive with the far more complex and technically risky thermochemical concepts (RP1086-2, RP1086-3).

▫ Hydrogen produced from fossil fuels will be less costly than that produced by water electrolysis in quantities of more than 100×10^6 (standard) ft^3/yr (2.6×10^6 [normal] m^3/yr). For smaller quantities distribution costs become a major factor, and on-site hydrogen production can be cost-effective (RP1086-4).

▫ Hydrogen produced by on-site electrolyzers could offer utilities a considerable cost saving over merchant hydrogen for generator cooling (RP1086-4).

▫ There are a significant number of other specialty applications (presently served by merchant hydrogen) for which hydrogen produced by on-site electrolyzers may become economic (RP320-1, RP1086-4).

Current hydrogen R&D activities

On the basis of the above conclusions, the CEC subprogram has evolved a strategy to develop advanced electrolyzer technology and introduce it to electric utilities in the near term for applications in generator cooling. This will allow the industry to obtain experience with electrolysis equipment and, if appropriate, expand the technology to other specialty markets in the intermediate term. This strategy also puts the industry in a position to identify, accelerate, and take advantage of a larger role for hydrogen as an energy carrier in the longer term.

Small, reliable electrolysis units for on-site utility service are not currently available. If advanced electrolyzers are successfully developed and demonstrated on-site, they could supply hydrogen not only for generator cooling during normal operation but also for the purging of turbine casing during startup. The cost of this hydrogen is likely to be lower than that of merchant hydrogen by a factor of two or three.

Under EPRI contract, work is proceeding on two promising water electrolysis technologies. One, being developed by General Electric Co., is based on a solid polymer electrolyte (RP1086-5); the other, being developed by Teledyne Energy Systems, is based on an alkaline water electrolyzer (RP1086-6).

Electrolyzer specifications and utility requirements for an on-site hydrogen supply system have been defined on the basis of a survey of some 30 generating stations and recommendations from a utility advisory group. Primary requirements for utility on-site hydrogen supply systems are reliability, ease of operation and maintenance, and cost-effectiveness in relation to merchant hydrogen. Electrolyzer efficiency is considered less important for such small specialty applications. General Electric and Teledyne have completed preliminary system designs and definitions of critical components. The preliminary design specifications for both systems are as follows.

- Production capacity range: 100–500 (standard) ft^3/h (2.6–13.0 [normal] m^3/h) of dry hydrogen
- Hydrogen delivery pressure: minimum 100 psig (689 kPa)
- Hydrogen purity: minimum 99.95% by volume
- Operation: unattended and automatically monitored from central control room
- Maintenance: once a year for one week; forced outage rate of less than 2% annual operating time
- Safety: fail-safe operation with continuous monitoring of safety-related variables
- Construction: factory-assembled, truck-transportable modules; compliance with all applicable codes and standards

An on-site demonstration of General Electric's electrolyzer to validate prototype performance and to confirm utility specifications has been planned for the Sewaren station (790 MW) of Public Service Electric and Gas Co. (New Jersey). To ensure reliability, the prototype electrolyzer will be thoroughly tested for six months at the factory before being delivered to the plant in September 1981. The unit will be operated and maintained by plant personnel for two years to produce hydrogen for generator cooling (RP1086-7). During this period, operating and maintenance data will be logged and evaluated. A similar program is being planned for the Teledyne unit with Allegheny Power System, Inc.

New CEC concepts

Although no new projects have been initiated in this area since the December 1979 R&D status report, in-house evaluation of CEC concepts is continuing. The focus of this work is innovative CEC concepts that could substitute coal- and nuclear-derived electricity for liquid and gaseous hydrocarbons. The potential for introducing energy-efficient electrochemical concepts in the metal and chemical industries—2 of the 10 most energy-intensive industries—will be assessed. For example, electroorganic synthesis technologies might offer opportunities for conserving scarce petroleum resources, while representing a new market for the efficient utilization of electricity. Typically such processes would offer favorable and perhaps controllable load patterns.

The longer-term viability of electricity-producing photochemical concepts will be assessed. The conversion of solar energy into storable chemicals that can be converted into electricity as required is potentially attractive. For example, some aqueous chemical and electrochemical reaction systems might be found that can efficiently and economically absorb visible light and catalytically decompose water to generate hydrogen and oxygen or, alternatively, reduce carbon dioxide to methanol. *Project Manager: B. R. Mehta*

R&D Status Report
NUCLEAR POWER DIVISION

SECOND-GENERATION PSMS

*The power shape monitoring system (PSMS) was conceived in 1975 as an engineering tool for monitoring and predicting both core power distribution and fuel performance in BWRs (*EPRI Journal, *May 1979, p. 47, and December 1979, p. 26). The rationale for the development of the first-generation PSMS was to improve plant load-maneuvering capability, while minimizing fuel failures from pellet-cladding interaction (RP895). As the work progressed, however, it was agreed that significant additional benefits could be gained by extending the capabilities of PSMS to the monitoring and prediction of power-related margins. Thus RP1442 was initiated to develop a more operationally oriented second-generation version of the system. This version, called the hybrid PSMS, uses both neutronics models and in-core measurements for greater monitoring and prediction accuracy and greater anomaly detection sensitivity.*

When in the monitoring mode, PSMS automatically performs on-line calculation of core power distribution and assessment of margin to operating limits. The reactor engineer can then evaluate the state of the core and determine the performance of the model by reviewing the corresponding output files. When in the predictive mode, the PSMS can analyze past or future reactor states, as specified by the user, by a variety of analytic options.

The second-generation hybrid PSMS offers the following important advantages over the original PSMS and existing interpretive systems (which estimate local power from measurements).

▫ Improvements to the basic neutronics models, resulting in more accurate and quicker determination of local power

▫ Characterization of the differences between predicted and actual in-core detector readings (which allows for correction of small model deficiencies, identification of measurement errors, and location of anomalies as they develop over time)

As a result of these features, the accuracy with which the hybrid PSMS can monitor and predict local power or power-related margins is greatly improved (Figure 1). The system is not as susceptible to individual measurement problems as the interpretive systems and is able to reflect actual core conditions more precisely than predictions based solely on the first-generation PSMS model.

In October 1980 EPRI, General Public Utilities Corp., and Jersey Central Power & Light Co. sponsored a meeting for utilities

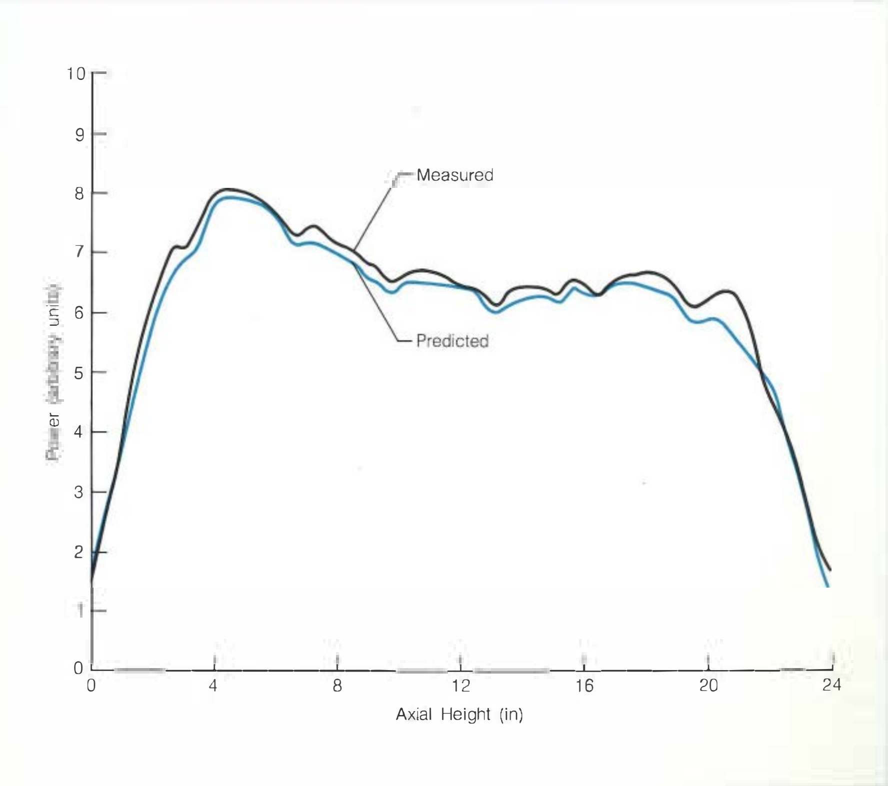


Figure 1 Close agreement between measured axial power distribution and predictions made with the hybrid PSMS at Oyster Creek demonstrates the system's modeling capabilities.

operating BWRs to discuss the transfer of the hybrid PSMS technology; 14 utilities representing 71% of the BWRs in operation attended. Contractor and EPRI staff members outlined the capabilities of the second-generation system, with emphasis on benchmarked results from the Quad Cities and Oyster Creek reactors. Utility representatives discussed how the system compared with other systems, as well as issues related to software transportability, post-TMI requirements (NUREG 0696), and reload licensing.

Key reasons cited by the meeting attendees for interest in the hybrid PSMS were the system's benchmarked technical capabilities and its nonproprietary nature. The use of the system for monitoring operating limits may be restricted until utilities independently develop reload licensing submittals. However, many participants felt the system was justified simply on the basis of its superior core monitoring, predictive capability, and anomaly-detection capability.

The formation of a hybrid PSMS working group that would specify operational improvements and provide benchmarking was strongly endorsed at the meeting, as was the formation of a users group to facilitate technology transfer. Organizational efforts are under way for both groups. Also, preliminary agreements have been reached with Commonwealth Edison Co., General Public Utilities, Jersey Central Power & Light, Tennessee Valley Authority, and Washington Public Power Supply System to perform off-line benchmarking and on-line operational monitoring and to investigate transportability.

The BWR hybrid PSMS will continue to be refined (RP1442), and system software and documentation will be available through the Electric Power Software Center in the spring of 1981. Plans are also being made to develop and transfer the technology to PWRs (RP1582). *Project Managers: A. B. Long and Floyd Gelhaus*

NATIONAL DATA SYSTEM ON POWER PLANT PERFORMANCE AND AVAILABILITY

Utility managers face an increasing number of difficult decisions. Among these are decisions about the need for new generating units and decisions about methods for improving the reliability and productivity of existing and planned facilities. Decisions about new plants depend not only on projections of load demand but also on projections of the future performance of a mix of generating units. Improving existing facilities may involve modifications to problem equipment, maintenance planning, outage scheduling, parts stocking, and personnel training. For new facilities, managers must select design concepts, system configurations, and equipment that best balance plant costs and plant productivity. All these decisions require the systematic analysis of past experience with similar equipment.

EPRI is developing a central national data system (NDS) on power plant (all types) and component performance that will support utilities in making decisions on generation planning and reliability/productivity improvements. This information will also be useful to government agencies, architect-engineers, research organizations, and equipment vendors. NDS will be based on the Generating Availability Data System (GADS), a system designed and managed by the National Electric Reliability Council (NERC). Through the addition of an analytic capability, a comprehensive data management capability, and an interface capability with utility-based systems, GADS can be transformed into the desired national system. EPRI's NDS program is developing these capabilities and supporting their implementation.

Need for NDS

An interagency task force led by the Federal Energy Administration (FEA) recommended in March 1975 that the utility industry initiate a coordinated effort for managing power plant performance and reliability data. From this impetus, the concept of NDS evolved through a series of studies by EPRI and a survey conducted by the American National Standards Institute's (ANSI) steering committee on power plant data systems. The ANSI committee was formed in May 1976 with representatives from several industry and government organizations, including EEI, NRC, ANSI, EPRI, FEA (now part of DOE), and the Federal Power Commission (also now part of DOE). The committee's objective was to obtain a national consensus on data needs, the shortcomings of existing systems, and recommended changes. This objective was accomplished through a series of five meetings with representatives of various federal agencies and industry groups, including utilities, consulting firms, architect-engineers, steam system suppliers, turbine generator manufacturers, and major auxiliary equipment manufacturers.

Later in 1976 EPRI was formally requested by EEI to develop an NDS. The first EPRI study began in September 1976 and entailed (1) a series of in-depth interviews with more than 150 people representing power plant data users from all segments of the utility industry and from government agencies; (2) a survey questionnaire mailed to an even larger cross section of the utility industry; (3) an examination of existing data systems, including some used by other industries; and (4) participation in the ANSI steering committee's meetings (RP826). This study identified how existing data systems were being used by the industry and what needs the systems were not satisfying. A follow-on study presented recommendations for making power plant data systems more responsive to the identified needs of the industry.

The utility industry stated its position on an NDS development program in the ANSI steering committee's report, which was published in February 1977. The report cited an urgent need for a unified, central data system because existing utility industry data systems were found to be inadequate to meet the many needs of industry and government. For example, they lack the capability for early-alert reporting of generic equipment problems and do not provide for communication between utilities, equipment manufacturers and suppliers, regulatory bodies, and government agencies. Further, they involve a duplication of effort and thus increase the reporting burden on utilities. A central NDS could eliminate these problems and serve as a valuable resource in utility decision making. EPRI has undertaken the development of such a system but does not plan to operate or manage it. This effort has the support and encouragement of the utility industry and the federal government.

Program objectives and plan

Five of the ANSI steering committee's recommendations were identified by EPRI as the major objectives of its NDS development program (RP1391).

- Develop a unified, central information system on power plant performance and reliability
- Support programs to improve existing industry data systems to increase their usefulness
- Establish an early-alert reporting system for generic equipment problems that have a high probability of causing unit unavailability
- Support implementation of availability engineering methods in the design, construction, operation, and maintenance of power plants

- Reduce the utility reporting burden to the lowest practical level

A review of previous efforts in the area of availability engineering data systems was useful for recommending improvements in methods and systems. Preliminary work under RP1391 established the basic structure and functions of NDS, supported the development of GADS by NERC, and identified specific applications of NDS data in power plant availability engineering (NP-1520). The next steps in the development program are to design, specify, and support the implementation of the functional capabilities required to transform GADS into NDS. There are three areas in which capabilities must be developed and implemented: data analysis and decision processes, data system results evaluation and performance analysis, and interfacing with decentralized data systems (DDSs).

Functional capability in the area of data analysis will be achieved through the development and application of methods in availability and reliability engineering and decision analysis. These efforts will result in tested, operational hardware and software for implementation in NDS.

Functional capability in the area of results evaluation and performance analysis will be developed and applied by establishing the baseline for data systems in terms of availability and reliability engineering, evaluating the effectiveness of R&D results in the data system program, and evaluating data system performance. These efforts will result in tested, operational methodologies that can be used both in existing data systems and in NDS.

The last area, interfacing, involves selecting DDSs to be included in NDS and developing the functional capability for electronic communication and data transfer between these systems and NDS. These efforts will result in tested, operational hardware and software designs that will permit the interfacing of remote computer systems through a standard network architecture or bulk processing mode on a national scale.

Milestones for the development of NDS and its functional support projects are given in Figure 2. The major functional capabilities will be developed concurrently to ensure orderly implementation of manageable segments. This plan is consistent with a modular design that maximizes flexibility in implementing system functions. As each capability is developed through NDS projects, NERC will implement it in GADS with EPRI advice and support. This step-by-step approach will allow for timely evaluation to ensure proper implementation and operation.

NDS scope

NDS will collect power plant performance statistics, data on unit outages, and data on component failures. This scope, defined on the basis of EPRI studies and experience gained in working with existing data systems, reflects both current reporting practices and the analytic needs of decision makers.

Performance Performance statistics, which describe such parameters as energy generation, service hours, and capacity factor, represent a general measure of a unit's productivity and reliability. Existing data systems, such as the NRC Grey Book and GADS, have been collecting this type of data for some time with few problems. One major improvement offered by NDS, then, will simply be a reduction in the reporting burden on utilities.

The other major improvement in this area will be standardization of terms. The problems that do exist in the reporting of performance statistics primarily result from inconsistent definitions. An example can be seen in the calculation of capacity factor, a common parameter reported by all generating units. Capacity factor is the ratio of the electric energy actually generated during a given period to the potential generation at full capacity. On the surface this appears straightforward, but in practice there are several ways to interpret the terms that go into the calculation; for example, generated electric energy can be either gross or net, and full capacity can be maximum depend-

Expansion of GADS for Development of NDS	Data Analysis and Decision Processes	Evaluation of Data System Performance and R&D Resources	Interfacing With Other Data Systems
Develop hardware and software specifications to support expansion of GADS into NDS (September 1981)	Specify analytic methods and decision processes for NDS (June 1981)	Assess value of DDSs for availability and reliability engineering (June 1981)	Select DDSs for interfacing with NDS (June 1981)
Select hardware and develop software for expanded GADS (March 1982)	Develop data systems management plan (June 1982)	Report on implementation of R&D recommendations in DDSs and NDS (June 1982)	Specify interface hardware and software (June 1982)
Complete testing and demonstration of NDS (March 1983)	Complete development of analytic methods and decision processes (June 1983)	Report on data system performance and assess value of R&D projects in the NDS effort (March 1983)	Complete analysis and decision technology transfer between DDSs and NDS (June 1983)
Perform evaluation and final upgrading of NDS (December 1983)	Complete results evaluation of operations, using analysis and decision processes (December 1983)	Report on areas requiring further R&D efforts (June 1984)	Produce final report and accomplish technology transfer of engineering design (June 1984)
Complete development of a fully operational NDS (June 1984)	Produce final report and accomplish technology transfer (June 1984)		

Figure 2 Development plan for major NDS functional capabilities.

able capacity (which itself can be calculated in several ways), design capacity, or turbine or generator nameplate rating.

If data reporters and users do not apply the same terms for performance calculations, significant misrepresentation and inaccuracy can result. In response to this problem, an industry ad hoc committee was formed in 1977 to write a standard on power plant productivity definitions. This work is nearing completion, and NDS will incorporate the definitions contained in the final standard (ANSI/IEEE Standard 762).

Outage Probably the most important kind of data NDS will collect is on unit outage. Existing data systems have collected generating unit outage data for some time. NDS will continue this effort, but with some important modifications.

NDS will emphasize the reporting of outage causes and will include a definitive narrative description of an outage, as well as coded information. This practice will solve several problems with existing systems that result from inconsistent classification or incomplete reporting. Different plants often code similar outages differently; by having the analyst code the data, more consistency in classification will be achieved. Also, the narratives will help the analyst more clearly understand complicated outage progressions, such as the occurrence of several partial outages in conjunction with a full outage, and will thus promote consistency in recording these parallel outages. All narrative description data will be stored in the computer and will be available for examining individual outages in some depth. This method is used in GADS and has been successfully tested. It is one of the reasons GADS was chosen as the base system for the NDS development program.

Component Failures Not all component failures in a generating unit are now routinely reported. The nuclear plant reliability data system (NPRDS) is designed to collect component failure data only for safety-class equipment in nuclear plants. GADS collects data on the failure of other equipment only when it causes or contributes to unit outage time. The problem is that there are so many different components in a power plant (an average of 10,000 components per unit) that it has beem impractical to collect the data on a continuing basis. For component data to have maximum usefulness, reports of individual failures must be accompanied by some descriptive data on the population of components in which the failures are occurring. Until recently, any attempt to collect this much information would have placed an unacceptable burden on power plants.

In the past few years, however, some large utilities have decided that they need such information for use in designing and maintaining their own units. Computers now allow these utilities to store and retrieve information on most components in their units and on all the failures that occur in these components. In some plants the mechanism for collecting data on failure events is available in their maintenance work order systems. If the maintenance work order forms are properly formatted, the data can be taken directly from them and entered into the computer.

This trend toward utility development of in-house computer data systems is what will make it possible for a central national system to collect extensive component failure data. One of the problems being addressed in NDS development is interfacing with these utility systems, which are not uniform. NDS will have to have a means, such as automatic transposers, for taking data from different systems and standardizing them in format and terminology.

NDS application

The analytic methods and decision processes NDS will incorporate are based on recent wide-ranging work on availability engineering (RP1391, RP1446). This work has produced a definitive statement on the practical application of availability engineering concepts (NP-81-2-LD). It examined basic availability engineering techniques and equations, effective use of plant betterment funds, analytic and planning methods, and specific applications involving power plant problems. The work also developed major strategies for implementing deterministic and probabilistic methodologies.

In February 1981 EPRI began a series of workshops on generation and component data use in availability engineering. This is the first step in the process of technology transfer, which must accompany NDS development. The most important purpose of NDS is to support decision making to improve power plant productivity. The success of the system depends on providing the industry with the analytic tools that will enable the data reporter to become a data user. *Project Manager: J. M. Huzdovich*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP475-9	Central Receiver Open-Cycle Gas Turbine Solar Power Plant—Analysis of Thermal and Mechanical Stresses	2 months	43.7	AiResearch Manufacturing Co. of California *J. Bigger*
RP779-30	New Catalytic Materials: A Perspective for R&D	1 year	12.0	Catalytica Associates, Inc. *Ron Wolk*
RP1348-9	Wind Turbine Dynamic Impact on Interconnected Utility Systems	3 months	23.9	Zaininger Engineering Co. *F. Goodman*
RP1348-10	Review of Economics for Solar Studies	4 months	3.5	Zaininger Engineering Co. *J. Bigger*
RP1509-2	Solar-Thermal Conversion, Full System Experiment (Lead Utility)	28 months	24.2	Public Service Co. of New Mexico *J. Bigger*
RP1525-1	Scale Control for Geothermal Heat Exchange Operation	8 months	55.0	Sierra Pacific Power Co. *E. Hughes*
RP1525-2	Scale Control by Crystallization	7 months	85.2	Bechtel National, Inc. *E. Hughes*
RP1654-4	Exploratory Gasification Systems Studies: Analysis of Refractory Design of Slagging Gasifier	7 months	90.2	Babcock & Wilcox Co. *W. Bakker*
RP1654-7	Characterization of Thermal Decomposition of Coal in Experimental Reactors	11 months	57.5	Advanced Fuel Research, Inc. *G. Quentin*
RP1671-2	Hybrid Power Plants for Geopressured Resources	4 months	32.7	United Technologies Corp. *M. Angwin*
RP1696-2	Occurrence and Role of Organometallics in Coal Liquefaction	4 months	20.0	Virginia Polytechnic Institute and State University *L. Atherton*
RP1799-1	Gasification Tests With U.S. Coal in 150-t/d Texaco Gasifier	3 months	982.7	Ruhrchemie Aktiengesellschaft *J. McDaniel*
RP1800-1	Guide: Methods for Forecasting the Reliability of GCC Power Plants	8 months	148.2	ARINC Research Corp. *J. Weiss*
RP1802-1	Investigation and Research of Specific Combustion Turbine and Combined-Cycle Field Problems	3 months	21.7	Coe Associates *R. Duncan*
RP1898-1	Evaluation of Synthetic Fuel Character Effects on Rich/Lean Stationary Gas Turbine Combustion Systems	1 year	500.0	United Technologies Corp. *L. Angello*
RP1900-1	Heber Binary-Cycle Geothermal Demonstration Plant	7 years	11,000.0	San Diego Gas & Electric Co. *V. Roberts*
RP1900-2	Reliability and Availability Analysis of Projected Heber Geothermal Demonstration Plant	6 months	82.3	ARINC Research Corp. *J. Weiss*
Coal Combustion Systems				
RP536-6	Chiyoda Laboratory Tests With Adipic Acid	7 months	49.0	Radian Corp. *T. Morasky*
RP982-25	FGD Report Reviews	15 months	40.0	Radian Corp. *R. Rhudy*
RP1031-4	Flue Gas Desulfurization Chemistry Studies	14 months	165.0	Radian Corp. *D. Stewart*
RP1255-3	Technology Assessment: Municipal Solid Waste as a Utility Fuel	5 months	44.0	Ebasco Services, Inc. *C. McGowin*
RP1263-5	Portable Field Instrument for PCB Measurement	1 year	87.0	Union Carbide Corp. *R. Komai*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1689-3	Inlet-End Corrosion Problems in Steam Surface Condensers	23 months	177.2	Ocean City Research Corp. *B. Syrett*
RP1689-7	Electrochemical Measurement of Corrosion Rates in Cathodically Protected Systems	6 months	11.0	SRI International *B. Syrett*
RP1721-2	Evaluation of Regeneration of Spent Absorbents, Aqueous Carbonate Demonstration Plant	3 months	49.5	Rockwell International Corp. *R. Rhudy*
RP1836-1	Evaluation of Tangential Fired Low-NO_x Burner	8 months	390.3	Mitsubishi International Corp. *M. McElroy*
RP1870-1	Spray Dryer Pilot Plant Procurement, Construction Management, and Startup	8 months	1369.8	Stearns-Rogers, Inc. *R. Rhudy*
RP1870-2	Characterization of Spray-Drying Wastes	11 months	80.2	Radian Corp. *R. Rhudy*
RP1872-1	Component Failure Data System for FGD	8 months	42.5	Aptech Engineering Services *C. Dene*
RP1895-1	Coal-Water Slurry as a Utility Boiler Fuel	8 months	150.0	Atlantic Research Corp. *R. Manfred*
Energy Analysis and Environment				
RP434-45	Rate Design Study: Consultation	8 months	19.8	Interlink *J. Malko*
RP434-46	Workshop: Rate Design Study—Costs and Rates	2 months	14.8	Ebasco Business Consulting Co. *N. Hassig*
RP434-48	Workshop: Rate Design Study—Costs and Rates	7 months	94.4	ICF, Inc. *N. Hassig*
RP434-49	Workshop: Rate Design Study—Costs and Rates	5 months	8.9	National Economic Research Associates, Inc. *N. Hassig*
RP576-2	User's Guide: MRI Appliance Ownership and Usage Data	1 month	13.9	Cambridge Systematics, Inc. *S. Braithwait*
RP1057-2	Cofunding of Fifth International Symposium on PAHs	6 months	7.5	Battelle, Columbus Laboratories *J. Guertin*
RP1109-13	Workshop: Acid Precipitation	3 months	21.2	Sigma Research, Inc. *R. Goldstein*
RP1430-4	Integration and Evaluation of EPRI's Coal and Electricity Supply Models	5 months	26.0	ICF, Inc. *D. Hu*
RP1484-5	Energy Policy Analysis Review	3 months	10.0	TEC Research Associates, Inc. *R. Richels*
RP1613-5	Rate Design Study: Topic Paper 6	2 months	12.4	Decision Focus, Inc. *E. Niemeyer*
RP1617-1	Measurement of Chemical Emissions From Coal Gasification Facility	18 months	1848.1	Radian Corp. *J. Guertin* *G. Quentin*
RP1785-1	Estimating Differential Lead Times for Power Plants	3 months	21.1	Applied Decision Analysis, Inc. *S. Chapel*
RP1785-2	Estimating Differential Lead Times for Power Plants	3 months	15.0	International Energy Systems Corp. *S. Chapel*
RP1812-1	Effects of Acid Precipitation on Agricultural Crops of the Northeast	34 months	357.2	Boyce Thompson Institute for Plant Research *J. Huckabee*
RP1813-1	Acid Rain Effects on Forest Ecosystem Nutrients	3 years	586.6	Union Carbide Corp. *J. Huckabee*
RP1815-1	Utility Load-Forecasting Handbook	17 months	144.7	Applied Forecasting & Analysis, Inc. *E. Beardsworth*
RP1820-1	Load Data Transferability	16 months	139.5	ICF Incorporated *E. Beardsworth*
RP1824-3	Data Analysis: Electric Wiring Configuration and Childhood Cancer	5 months	14.9	H. Daniel Roth Associates, Inc. *B. Kavet*
RP1904-1	Response of Agricultural Soils in Acid Deposition	9 months	68.6	Battelle, Columbus Laboratories *J. Huckabee*
RP1909-1	Legionnaires' Disease Bacteria in Power Plant Cooling Systems	35 months	500.0	Union Carbide Corp. *I. Muraka*
RP1910-1	Acid Rain Effects on Aquatic Processes, Methodology Development	40 months	914.5	Lawrence Berkeley Laboratory *R. Brocksen*
RP1922-1	Weather Normalization of Electricity Sales	15 months	199.5	Cambridge Systematics, Inc. *A. Faruqui*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Electrical Systems				
RP1291-3	Application of Light-Triggered Thyristors to a HVDC Valve System	28 months	619.3	General Electric Co. *G. Addis*
RP1426-2	Microprocessor Control for Real and Reactive Power Modulation	23 months	277.9	General Electric Co. *J. Reeve*
RP1492-1	Compact Transmission Line Flashover Determination	17 months	498.1	Power Technologies Inc. *R. Kennon*
RP1494-2	Transmission Grounding	20 months	165.4	Georgia Institute of Technology *J. Dunlap*
RP1494-3	Transmission Grounding	11 months	115.9	Ohio State University *J. Dunlap*
RP1497-2	Remote-Controlled Maintenance Device	7 months	46.0	Westinghouse Electric Corp. *J. Dunlap*
RP1717-5A	Transmission Line Mechanical Research Facility	10 years	1134.2	Adelphon-TLMRF, Inc. *F. Vinson*
RP1717-5B	Transmission Line Mechanical Research Facility	15 months	5923.7	Adelphon-TLMRF, Inc. Ebasco Services, Inc. *F. Vinson*
RP1718-1	Improved Cellulose Insulation for Distribution and Power Transformers	3 years	813.8	McGraw-Edison Co. *B. Bernstein* *N. Hingorani*
RP1738-1	Evaluation of Electric Interference to the Induction Watthour Meter	1 year	115.2	Honeywell, Inc. *W. Blair*
RP1763-1	Improved Motors for Utility Applications	10 months	241.7	General Electric Co. *D. Sharma*
RP1764-2	Power Flow Computer: Word Length/Precision Studies	20 months	49.9	University of Pittsburgh *J. Lamont*
RP1945-1	Application of Induction Generators in Power Systems	6 months	90.8	Power Technologies Inc. *J White*
RP7879-1	Basic Breakdown Study of HPOF and Extruded Dielectric Cables	31 months	1710.0	Underground Systems, Inc. *J. Shimshock*
RP7880-1	Paper-Film Laminate for 138–550-kV Pipe-Type Cables	52 months	888.4	Phelps Dodge Cable & Wire Co. *S. Kozak*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Energy Management and Utilization				
RP1041-7	Effects of Alternative Fuels on the Performance Economics of Dispersed Fuel Cells	3 months	50.0	Westinghouse Electric Corp. *E. Gillis*
RP1087-3	Assessment of Practical Potential for Heat Recovery and Load Leveling on Refrigeration Systems	15 months	209.6	Applied Energy Systems, Inc. *L. Harry*
RP1199-12	Hydroelectric R&D	5 months	77.1	Charles T. Main, Inc. *A. Ferreira*
RP1200-9	Studies on Adsorption of Synthetic Acid Anions on Fuel Cell Catalysts	1 year	40.0	Texas A. & M. Research Foundation *J. Appleby*
RP1201-15	Field Performance Monitoring of Split Air-Air Multizone Heat Pump System	18 months	87.1	International Energy Systems Corp. *J. Brushwood*
RP1464-1	Advanced Two-Bridge Power Conditioner for Batteries, Fuel Cells, and Alternative Applications	39 months	1293.9	United Technologies Corp. *R. Ferraro*
RP1495-1	Assessment of Performance, Advanced Air Source Heat Pumps	27 months	107.1	General Electric Co. *B. Mauro*
RP1524-4	Techniques for Transferring EV Test Methods and Technology Assessment Information	4 months	19.6	O. M. Bevilacqua & Associates *J. Mader*
RP1670-1	Preferred System Controls for Optimizing Performance of SHAC and Heat- and Cool-Storage Installations	17 months	183.7	Research Institute of Colorado *J. Brushwood*
RP1670-2	Residential Heating and Cooling Monitoring Instrumentation Methodology	18 months	99.4	Berkeley Solar Group *J. Brushwood*
RP1791-1	Void Fraction Measurement	3 months	5.0	National Nuclear Corp. *R. Schainker*
Nuclear Power				
RP506-7	Uranium Enrichment, Using Tailored Chemical Species	19 months	150.0	Northwestern University *M. Lapides*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1445-5	High-Temperature Filtration	5 months	131.3	Commonwealth Research Corp. *M. Naughton*
RP1580-4	Cost of Fuel-Related Maneuvering Restrictions	10 months	60.3	Science Applications, Inc. *D. Franklin*
RP1611-2	Water Level Indicator	5 months	70.0	Science Applications, Inc. *P. Bailey*
RP1611-3	Calculation Support for Level Detection, Using Excore Neutron Detectors	5 months	37.0	Technology for Energy Corp. *P. Bailey*
RP1627-2	Assessment and Application of Transient Fuel Behavior Computer Codes	3 months	11.9	Babcock & Wilcox Co. *R. Oehlberg*
RP1704-11	Review of Large LMFBR Design: Thermal Stripping Evaluation	16 months	228.7	Rockwell International Corp. *J. Matte*
RP1704-14	Special Concretes for LMFBR Applications	10 months	24.0	Northwestern University *J. Matte*
RP1704-18	LMFBR (Pool Type) Study	2 months	39.4	NUS Corporation *R. Winkleblack*
RP1733-2	Jet Impingement Phenomena	8 months	22.0	General Electric Co. *A. Singh*
RP1741-2	Study of Efficient Numerical and Physics Modeling Methods for the Analysis of LWR Transients, Part 2	11 months	39.9	University of Pittsburgh *G. Srikantiah*
RP1749-2	Application of COMMIX-1A for Thermal Mixing Analyses of PWR Downcomer and Lower Plenum	10 months	100.0	Argonne National Laboratory *J. Kim*
RP1784-3	Cobalt Alloy Replacement for PWR	9 months	96.7	Westinghouse Electric Corp. *J. Magaw*
RP1843-1	Fire-Retardant Fluids for Turbine Generator Lubrication Systems	9 months	201.5	Westinghouse Electric Corp. *R. Swanson*
RP1905-1	Analysis of Eddy-Current Signals From Zircaloy Tubing	10 months	79.5	Adaptronics, Inc. *H. Ocken*
RP1929-3	Residual Stresses in LP Turbine Disks	11 months	58.4	Southwest Research Institute *M. Kolar*

New Technical Reports

Each issue of the *Journal* includes summaries of EPRI's recently published reports.

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ADVANCED POWER SYSTEMS

Phase Equilibrium in Coal Liquefaction Processes

AP-1593 Final Report (RP367-2); $7.25

This report presents a study of vapor-liquid equilibrium in mixtures of light gases and heavy hydrocarbons under conditions encountered in coal liquefaction processes. A specially designed experimental flow apparatus was used to collect coal-related solubility and vapor pressure data at high temperatures and pressures. The correlation of these data with the Soave and Boublik-Alder-Chen-Kreglewski equations of state and with solubility parameters is discussed. The contractor is Purdue University. *EPRI Project Manager: L. F. Atherton*

High-Reliability Gas Turbine–Combined-Cycle Development Program: Phase 1

AP-1598 Final Report (RP1187-2); $12.50

The results of developmental work on high-reliability gas turbine combined cycles are documented. The six tasks reported here involved (1) baseline data analysis and methodology development, (2) reliability design trade-off studies, (3) conceptual designs for the high-reliability combustion turbine unit and the combined-cycle plant, (4) a development plan for key technologies, (5) analyses of the conceptual designs to determine what modifications the use of coal-derived fuels would require, and (6) analyses of installed and current-design plants. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. L. Duncan*

High-Reliability Gas Turbine–Combined-Cycle Development Program: Phase 1

AP-1599 Interim Report (RP1187-1); Vol. 1, $19.00; Vol. 2, $5.75

Volume 1 presents results from the first phase of a program to develop a high-reliability gas turbine for baseload combined-cycle application starting in the mid-1980s. This phase involved conceptual design studies of both the gas turbine and the full plant, with emphasis on reliability. Recommendations for the Phase 2 preliminary design are detailed. Volume 2 contains four appendixes that describe the procedures and assumptions used to estimate the cost of electricity in the trade-off studies; the models used to calculate availability; the procedures and results of a Monte Carlo analysis; and the reliability characteristics for the plant. The contractor is United Technologies Corp. *EPRI Project Manager: R. L. Duncan*

Guide for Assessment of the Reliability of Gasification–Combined-Cycle Power Plants

AP-1610 Interim Report (RP1461); $7.25

This report describes a methodology for performing the reliability portion of a formal reliability and availability analysis of a gasification–combined-cycle power plant design. The methodology uses the concepts of system states and state capability with a matrix of state-transition probabilities to produce a time-varying estimate of plant effectiveness. The report also presents a failure-rate data base at the major component level and a documented computer program. The contractor is ARINC Research Corp. *EPRI Project Manager: Jerome Weiss*

Wind Power Generation Dynamic Impacts on Electric Utility Systems

AP-1614 Final Report (TPS79-775); $4.50

This technical planning study is an initial assessment of potential dynamic impacts on electric utility systems of wind power generation via large wind turbines. Three classes of dynamic problems—short-term transient stability, system frequency excursions, and minute-to-minute unit ramping limitations—were examined in case studies based on the Hawaiian Electric Co. system. The contractor is Zaininger Engineering Co. *EPRI Project Manager: F. R. Goodman, Jr.*

Gas Turbine Combustor Performance on Synthetic Fuels

AP-1623 Final Report, Vol. 1 (RP989-1); $4.50

This volume presents a summary of a project to determine the effects of burning currently available coal-derived and shale-derived synthetic liquid fuels in state-of-the-art gas turbine combustors. It describes the fuels tested, the effects of NO_x emission and of smoke formation and reduction, and a comparison of surrogate and synthetic fuels. The project concluded that a number of selected coal and shale oil fuels can be used in current turbines as soon as these fuels become available. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Arthur Cohn*

Economic Evaluations of Energy Recovery Options for Oxygen- and Enriched-Air-Blown Texaco GCC Power Plants

AP-1624 Final Report (RP239-2); $12.00

The results of a comprehensive engineering and economic evaluation of seven integrated Texaco-based gasification–combined-cycle (GCC) power plant systems are presented. Two types of coal oxidants and four gas-cooling options were used in the system configurations. The cost of electricity generated by oxygen-blown GCC systems employing current-technology combustion turbines (2000°F) was compared with that of electricity produced by a coal-fired steam plant with limestone slurry scrubbers, and the impact of the gas-cooling options on electricity costs was studied. The contractor is Fluor Engineers and Constructors, Inc. *EPRI Project Managers: E. L. Force and M. J. Gluckman*

Investigation of the Liquefaction of Partially Dried and Oxidized Coals

AP-1625 Final Report (RP779-25); $7.25

Tests were conducted to determine how the predrying and partial oxidation of subbituminous coal affect its liquefaction behavior. Samples of Belle Ayr subbituminous and Powhatan bituminous coals were dried in various gases at three equipment scales (micro-, laboratory-, and bench-scale) and were then used in liquefaction studies. A literature survey on the coal drying-oxidation-aging process, the effects of coal oxidation on liquefaction, and safety considerations in drying powdered coal was also conducted. The contractor is Gulf Research & Development Co. *EPRI Project Manager: L. F. Atherton*

High-Reliability Gas Turbine–Combined-Cycle Development Program: Advanced Compressor Design Study

AP-1628 Final Report (RP1187-2); $3.50

This report describes conceptual design work on a 13-stage compressor that uses low-aspect blading and other technology developed in advanced aircraft compressor projects. This work resulted in the selection of stage parameters for an optimal compressor configuration to meet reliability and performance requirements for a high-reliability industrial combustion turbine. The report also includes a literature survey, primarily of advanced aircraft projects. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. L. Duncan*

Characterization of Mineral Matter in Coals and Coal Liquefaction Residues

AP-1634 Final Report (RP366-1, RP779-19); $6.50

A study of organic and mineral matter in coals and coal liquefaction residues was conducted to determine relationships between the composition and properties of this matter and the behavior of specific coals during liquefaction. This report discusses the efficiency of a process to solubilize specific coals; retrogressive reactions; types and physical nature of the minerals present; associations between various components; and formation of inorganic precipitates during liquefaction of low-rank coals. The contractor is Pennsylvania State University. *EPRI Project Managers: L. F. Atherton and W. C. Rovesti*

COAL COMBUSTION SYSTEMS

Electrostatic Precipitator Plate Rapping and Reliability

FP-1006 Final Report, Vol. 3, Part 1 (RP1180-10); $4.50

This report describes an effort to acquire empirical data on the dynamic response of electrostatic precipitator collecting surfaces to mechanical in-plane rapping. Response to varying in-plane rapping intensities was measured in the in-plane and out-of-plane directions. Dynamic response was obtained as a function of time, location, and rapper and plate configuration. These data were obtained on full-scale plates. In addition, laboratory-scale experiments were conducted to determine the effect of dust on surface response. The contractor is Joy Industrial Equipment Co. *EPRI Project Manager: O. J. Tassicker*

Materials for Generator Retaining Rings: State-of-the-Art Review

CS-1578-SR Special Report; $3.50

This report is a comprehensive state-of-the-art review of generator retaining-ring materials. It discusses industry experience with retaining-ring failures, material property requirements for retaining rings (physical properties, mechanical properties, and environmental considerations), available data on currently used materials, and recent developmental work on alternative materials. *EPRI Project Manager: Ramaswamy Viswanathan*

Evaluation of Chiyoda Thoroughbred-121 FGD Process and Gypsum Stacking

CS-1579 Final Report, Vol. 3 (RP536-3); $6.50

This volume presents the results of geotechnical laboratory testing of gypsum produced in the Chiyoda Thoroughbred-121 flue gas desulfurization (FGD) process. It also discusses the basic concepts governing the design and management of gypsum stacks in the phosphate industry and describes the construction and nine-month operation of a half-acre, 12-ft-high prototype gypsum stack at the Scholz power plant. The contractor is Ardaman & Associates, Inc. *EPRI Project Manager: T. M. Morasky*

User's Manual for WDCSIM–II Wet-Dry Cooling Computer Program

CS-1594 Final Report (RP1182-1); $5.25

This guide describes the power plant and cooling-system performance models incorporated into the WDCSIM—II program, the structure of the program, and the required input data. It also describes the WDCSIM—II computer model (including program units), the significant active variables associated with each program unit, and program modifications for alternative applications. The contractor is Dynatech R/D Co. *EPRI Project Manager: J. A. Bartz*

Laboratory Testing of Resox Process

CS-1602 Final Report, Vol. 1 (RP1257-1); $8.25

This volume describes pilot-scale work on the Resox process. It identifies the advantages and disadvantages of the process for the utility engineer, details the flexibility demonstrated by the system in combination with three different front-end processes, specifies the criteria for selecting a coal to be used as a reductant, and defines some of the parameters that must be addressed before engineering a specific system. The contractor is Foster Wheeler Energy Corp. *EPRI Project Managers: T. M. Morasky and S. M. Dalton*

Detection of Water Induction in Steam Turbines

CS-1604 Final Report (RP637-1); $3.50

Passive and active ultrasonic sensing systems were compared with thermocouple and pressure systems in terms of their ability to detect the presence of water in steam pipes. This report describes the test apparatus, methods, and results for both the static and steam-water flow loop tests. While all sensing methods were responsive to all types of steam-water induction, the ultrasonic instrumentation showed advantages because of its rapid response and nonintrusive nature. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: J. B. Parkes*

Control of NO_x Emissions at a 220-MW Combined-Cycle Power Plant

CS-1608 Final Report (RP782-1); $5.25

This report addresses the impact of NO_x emissions from repowered conventional gas- or oil-fired reheat steam boilers, an important consideration in converting to combined-cycle operation. Field tests conducted on a 220-MW natural-gas-fired combined-cycle unit indicate that simultaneous control of turbine and boiler NO_x emissions via fuel-rich staged combustion is feasible. The contractors are Babcock & Wilcox Co. and KVB, Inc. *EPRI Project Manager: M. W. McElroy*

Engineering Evaluation of Magma Cooling-Tower Demonstration at Nevada Power Co.'s Sunrise Station

CS-1626 Final Report (RP1260-10); $8.25

This report describes pilot-scale testing of the Magma cooling-tower process, which uses a falling-film heat exchanger integrated into an induced-draft cooling tower to evaporate waste water. The pilot unit at Nevada Power Co.'s Sunrise station extracted heat from the power plant cooling system to evaporate cooling-tower blowdown. Two water-treatment methods were tested: makeup-sidestream softening and fluidized-bed crystallization. The report presents the test results, along with recommendations for system application at the station and a comparison of alternative zero-discharge technologies. The contractor is CH2M-Hill. *EPRI Project Manager: Winston Chow*

Biofouling Control With Ozone at the Bergen Generating Station

CS-1629 Interim Report (RP733-1); $6.50

Tests were conducted to evaluate the effectiveness of ozone as an alternative to chlorine for condenser biofouling control in a once-through cooling system. A pilot-scale test facility with three model condensers simulated condenser operation and conditions at the Bergen station. Both ozone and chlorine were tested. The minimum effective level of each was determined by daily measurements of heat transfer coefficients across model condenser tubes and/or water-side pressure drop. Final evaluation was based on biofouling material mass on the tube walls. The contractor is Public Service Electric and Gas Co. *EPRI Project Manager: R. W. Kosage*

Lime FGD System and Sludge Disposal Case Study

CS-1631 Final Report (RP982-18); $6.50

EPRI has published two design guideline manuals for use in selecting optimal flue gas desulfurization (FGD) scrubber and sludge disposal systems: *Lime FGD Systems Data Book* and *FGD Sludge Disposal Manual*. This report is a case study that illustrates how to apply the methods and information presented in those manuals. The study describes design decisions, from system selection through equipment installation and startup, for a hypothetical lime FGD and sludge disposal system for a new 500-MW coal-fired power plant. Alternative FGD and sludge disposal systems are also examined. The contractor is Black & Veatch Consulting Engineers. *EPRI Project Managers: D. A. Stewart and C. E. Dene*

Seminar Proceedings: Municipal Solid Waste as a Utility Fuel

WS-79-225 Seminar Proceedings; $12.50

The papers in this report, which were originally presented at an EPRI-sponsored utility seminar in January 1980, focus on utility participation in projects involving the recovery of energy and raw materials from municipal solid waste. Key issues discussed are refuse-derived fuel versus 100% refuse firing, the technical and economic feasibility of supplemental refuse firing, nontechnical and institutional issues of utility participation in resource recovery projects, and burning refuse directly rather than purchasing refuse-generated steam or electricity. *EPRI Project Manager: C. R. McGowin*

ELECTRICAL SYSTEMS

Real-Time Digital Data Acquisition System for Determining Load Characteristics: Overview and Summary

EL-851 Final Report, Vol. 1 (RP849-2); $4.50

This volume summarizes the design and construction of a real-time digital data acquisition system to be used in power system substations for on-site recording and preprocessing of data on load response to variations in frequency and voltage. Information on the installation, operation, capabilities, and maintenance of the system is presented, as well as summaries of papers on field-test planning and execution, real-time data acquisition systems, and determination of load characteristics. The contractor is Institut de Recherche de l'Hydro-Québec. *EPRI Project Manager: D. F. Koenig*

Digital Revenue-Metering Algorithm: Development, Analysis, Implementation, Testing, and Evaluation

EL-1601 Final Report (RP1359-3); $11.25

This report describes the development of a simple algorithm suitable for accurate measurement of active and reactive power from digital samples of current and voltage inputs integrated over time.

The algorithm uses time-discrete Walsh functions. It was implemented in a test system with two 8-bit microprocessors in order to evaluate its sensitivity to additive noise, frequency variations, and harmonic content of the inputs. The contractor is Ohio University. *EPRI Project Manager: S. L. Nilsson*

Electronic Current Transducer for EHV Circuits

EL-1611 Final Report (RP560-1); $6.50

A digital electronic current transducer that could provide significant cost and reliability improvements has been developed. This report describes the transducer design and specifications, the test program, and installation experiences. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: S. L. Nilsson*

Study of Distribution System Surge and Harmonic Characteristics

EL-1627 Final Report (RP1024-1); $10.50

A study was undertaken to determine how harmonics and electrical noise generated by power converters affect distribution systems and to evaluate methods of reducing harmonics. The effects of current and voltage surges on converter equipment and distribution systems were also investigated. In field tests on two distribution systems, measurements were made of harmonic voltage and current magnitude, capacitor-switching transients, and impulsive electromagnetic noise (3–300 kHz). Test methodology and instrumentation are described, as well as a computer program developed to aid in analyzing distribution system response to harmonics. The contractors are McGraw-Edison Co., United Technologies Corp., and Systems Control, Inc. *EPRI Project Manager: W. E. Blair*

ENERGY ANALYSIS AND ENVIRONMENT

Stochastic Sensitivity Analysis of U.S. Input-Output Model

EA-518 Final Report (RP628); $4.50

Input-output tables were used in a wide variety of energy analyses to examine the economic impacts of changes in demand due to changes in the cost and availability of energy. This report describes a simulation used to measure the propagation of uncertainty through input-output calculations. Measures of uncertainty and probability distributions for published input values were developed. A Monte Carlo simulation was used to develop the distributions of sector outputs for 30-, 90-, and 101-sector tables. The contractor is Energy Research Group, University of Illinois at Urbana-Champaign. *EPRI Project Manager: R. E. Riley*

Dynamic Adjustment Models of Industrial Energy Demand: Empirical Analysis for U.S. Manufacturing, 1947–1974

EA-1613 Final Report (RP683-1); $7.25

This report describes a pioneering study to develop and estimate a fully dynamic model of demand for industrial factors of production, with emphasis on the demand for energy. Short- and long-run price and output elasticities of demand are characterized, and the structural stability and predictive performance of the dynamic model are described. The dynamic model outperformed the two static models also estimated in this project in predicting both the level and the growth rate of energy demand. The contractor is Economics Research Group, Ltd. *EPRI Project Manager: S. D. Braithwait*

Integration Methodology for Energy Supplies and Demands

EA-1633 Final Report (RP1149-3); $4.50

A methodology for integrating separate models of energy supplies and demands into a market equilibrium system is described. Model descriptions are presented, along with details on endogenous and exogenous variables, the experimental design, and equation estimation procedures. Several solutions of the integrated supply and demand system are computed to illustrate the potential uses of the methodology, and possible extensions and improvements of the methodology are summarized. The contractor is Research for Growth & Transfer, Inc. *EPRI Project Manager: A. N. Halter*

Cost Uncertainty in Programming Models of Electricity Supply

EA-1636 Final Report (RP1220-4); $4.50

The literature on risk programming as an analytic approach to cost uncertainty was reviewed, and the feasibility of this approach for models of electricity supply was examined. This report discusses cost uncertainty in programming models and applicable examples of numerical problems; uncertainty issues in planning generating capacity and the respective scopes of capital budgeting and risk programming methods; heat rate variation and its effect on capacity choice; and startup and stoppage cost problems. The contractor is A. L. Fletcher & Associates. *EPRI Project Manager: A. N. Halter*

Protocol for Plume Model Validation

EA-1638 Final Report (RP1616); $2.75

This report describes a procedure to evaluate the performance of dispersion models used for predicting the short-term air quality impact of buoyant, elevated plumes. The performance measures, the statistical methodology, the selection of models used in the study, and procedures for selecting events for model validation are summarized. The contractor is TRC–Environmental Consultants, Inc. *EPRI Project Manager: G. R. Hilst*

ENERGY MANAGEMENT AND UTILIZATION

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

EM-1506 Final Report (RP553-2);
Vol. 2, $5.75; Vol. 3, $4.50

Volume 2 describes various types of solar domestic hot water systems and discusses common installation problems, installation costs, and service area impact analyses. System design parameters—various collector sizing methods, collector orientation, storage capacity, and heat loss from pipes and tanks—are also discussed. The approach used for the utility economic impact analysis and the results obtained are presented in detail. Volume 3 describes customer load management–solar heating and cooling systems, which feature off-peak storage and control at the residences. The performance of these systems is discussed, and detailed analyses of their impacts on utility operations and on utility and customer economics are presented. The contractor is The Aerospace Corp. *EPRI Project Managers: J. W. Beck and F. W. Keith, Jr.*

Battery Energy Storage Test (BEST) Facility: Second Progress Report

EM-1514 Interim Report (RP255-2); $4.50

This report describes work on the BEST Facility, a national center for testing and evaluating advanced battery energy storage systems now under development for utility applications. The report, which covers the period from July 1978 to December 1979, includes details on the construction of the facility, the procurement of major items of operating equipment, and the development of plans for battery testing. The contractor is Public Service Electric and Gas Co. *EPRI Project Manager: W. C. Spindler*

NUCLEAR POWER

PWR FLECHT SEASET 21-Rod Bundle Flow Blockage Task

NP-1382 Interim Report (RP959-1); $14.25

This report presents test plans for the 21-rod bundle flow blockage task of the full-length emergency cooling heat transfer–separate-effects and systems-effects test (FLECHT SEASET). The data requirements, instrumentation plan, test facility, test matrix, and data reduction and analysis plans are described. Appendixes provide details on the COBRA code, COFARR program, bundle instrumentation plan, and blockage sleeves. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: K. H. Sun*

Thermal-Hydraulic Analysis of the Combustion Engineering System 80 Steam Generator

NP-1546 Final Report (S130-1); $6.50

THIRST—a three-dimensional, steady-state, incompressible, homogeneous two-phase flow computer code—was used to make a thermal-hydraulic analysis of the Combustion Engineering System 80 recirculating steam generator. This report includes detailed printouts of calculated values of overall heat transfer, circulation ratio, hot side–cold side flow split, and inlet temperature, as well as computer-generated plots of quality, velocity, and mass-flux distributions. The contractor is Atomic Energy of Canada Ltd. *EPRI Project Manager: D. A. Steininger*

Characterization of Irradiated Zircaloys: Susceptibility to Stress Corrosion Cracking

NP-1557 Final Report (RP1027); $5.25

Irradiated Zircaloy cladding specimens were exposed to iodine to examine their susceptibility to stress corrosion cracking (SCC). Cladding response was determined by various methods, including tube burst tests, uniaxial tensile tests, and scanning electron microscopy. Also, an analytic model was developed to predict the iodine-induced SCC behavior of Zircaloy. The contractor is Argonne National Laboratory. *EPRI Project Manager: Howard Ocken*

Human Factors Review of Power Plant Maintainability

NP-1567-SY Summary Report (RP1126); $3.50

This report presents a study of the potential application of human factors principles and considerations to power plant maintenance activities. Evaluation methods included a checklist-guided observation system, interviews with maintenance personnel, analyses of historical records of maintenance errors, task studies, physical measures of the plant, and studies of critical incident techniques. The contractor is Lockheed Missiles & Space Co., Inc. *EPRI Project Manager: H. L. Parris*

NDE Characteristics of Pipe Weld Defects

NP-1590-SR Special Report; $5.25

This report provides comparative imagery data for use by personnel involved in the nondestructive examination (NDE) of nuclear power plant piping. It is intended as an interpretive aid. Pictures of weld-defect geometry are compared with the corresponding radiographic and ultrasonic NDE results for circumferential butt welds of 10-in schedule-80 piping made of type-304 stainless steel. The weld defects were deliberately introduced. *EPRI Project Manager: M. E. Lapides*

Water Quality in Boiling Water Reactors

NP-1603 Final Report (RP1563-1); $8.75

Reactor water conditions at 20 domestic BWRs from startup to mid-1979 were studied to determine the frequency and magnitude of abnormal reactor water chemistry events. Reactor water transients were defined and documented. Resin intrusions, condenser tube leakage, and unavailability of reactor cleanup systems were identified as the most common causes of these transients. A data base was established for use in later related research on BWR alloy stress corrosion cracking. The contractor is Radiological and Chemical Technology, Inc. *EPRI Project Manager: M. D. Naughton*

Method of Reducing Carry-Over and Reducing Pressure Drop Through Steam Separators

NP-1607 Final Report (RPS122-1); $12.50

This report is a comprehensive review of the state of the art of steam-water primary separators. It covers separator size and configurations (including two-stage separation), separator hydraulics, steam generator–separator interactions, and dryer design and performance characteristics. An extensive literature survey was conducted, and a systematic test program for the qualification of advanced separator designs was defined. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: D. A. Steininger*

Two-Dimensional Water-Impact Tests of Flexible Cylinders

NP-1612 Final Report (RP817); $8.25

A test program measured the two-dimensional response of flexible (thin-wall) cylinders impacted onto a water surface. These tests were conducted to examine the nature of hydrodynamic impact and fluid-structure interaction for cylindrical structures in pressure suppression systems and other nuclear plant systems. Extensive loading and structural response data were recorded for impact velocities from 5.3 to 16.9 ft/s (1.6–5.2 m/s), which gave deformations ranging from elastic to severely inelastic. Because of deformation of the flexible cylinder, peak average pressures were about half the value measured for rigid cylinders. The contractor is Developmental Sciences, Inc. *EPRI Project Manager: George Sliter*

Core Restraint and Seismic Analysis of a Large Heterogeneous Free-Flowering Core Design

NP-1615 Final Report (RP620-25); $6.50

A free-flowering core restraint system and the seismic performance of a heterogeneous core in an LMFBR plant were studied. The core restraint design was analyzed with the NUBOW-3D code over the first two cycles of operation; predicted forces, impacts, displacements, and reactivity effects were assessed. The SCRAP code was used to analyze the time-history seismic response of the core. The key features of the core restraint system (e.g., stiff reflector assemblies and load pad properties) were specified. The contractor is Argonne National Laboratory. *EPRI Project Manager: R. K. Winkleblack*

Hardware Concepts for a Large Low-Energetics LMFBR Core

NP-1617 Final Report (RP620-25); $2.75

This report presents practical design concepts for a large low-energetics LMFBR core. Drawings are included for fuel, blanket, reflector-shield, and control rod subassemblies. A cross-section drawing details the arrangement of the subassemblies in the total core-blanket assembly. The contractor is Argonne National Laboratory. *EPRI Project Manager: R. K. Winkleblack*

Prediction of Critical Heat Flux for Annular Flow in Vertical Pipes

NP-1619 Final Report (RP1380-1); $2.75

A previously developed semiempirical model for adiabatic two-phase annular flow was extended to enable the prediction of critical heat flux in vertical pipes. Model predictions were compared with test data and an empirical correlation; results compare favorably with experimental data when previously reported empirical coefficients of mass transfer as a function of pressure are employed. The contractor is S. Levy, Inc. *EPRI Project Manager: K. H. Sun*

Multifrequency Eddy-Current System for Inspection of Steam Generator Tubing

NP-1621 Final Report (RP403-2); $4.50

This report describes the results of tests undertaken to detect and characterize steam generator tubing defects and failures. The study evaluated (1) the maximum advantage of the multifrequency eddy-current method of tubing inspection; (2) a simplified system-operating procedure and improvements in the presentation of multifrequency data; and (3) multifrequency methods of inspecting for such newly encountered types of anomalies as circumferential cracks, inside-diameter flaws, and flaws in dented regions. A field-usable test system with four test frequencies was also developed. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: H. G. Shugars*

Categorization of Cable Flammability: Detection of Smoldering and Flaming Cable Fires

NP-1630 Interim Report (RP1165-1); $4.50

This report describes work to develop detection requirements for cable fires in utility plants. The effects of forced ventilation and temperature stratification on the detection of flaming and smoldering fires were investigated for a simple corridor geometry common in nuclear reactors. Criteria for specifying the spacing of smoke detectors in rooms with flat and beamed ceilings and in corridors were determined. The contractor is Factory Mutual Research Corp. *EPRI Project Manager: R. E. Swanson*

Sensitivity of Nuclear Fuel-Cycle Cost to Uncertainties in Nuclear Data

NP-1632 Final Report (RP975-4); $4.50

Various alternative fuel cycles—including the extended-burnup (18-month) LWR cycle, the mixed-oxide (plutonium) cycle, the uranium-thorium and denatured uranium-thorium cycles, and the CANDU-type reactor cycle—were examined to determine how uncertainties in nuclear data affect their costs. It was found that uncertainties in data involving thermal capture and fission cross sections of ^{239}Pu have especially important fuel-cycle cost implications. The contractor is Rensselaer Polytechnic Institute. *EPRI Project Manager: Odelli Ozer*

Improvement of the SAM–CE Criticality Capability and Analysis of Thermal Reactor Benchmarks

NP-1635 Final Report (RP972-1-3); $2.75

The criticality capability of the SAM–CE Monte Carlo system was expanded to enable validation of ENDF/B-V cross sections. Details are provided on the minimum-variance eigenvalue estimator; special code modules developed to address the specific characteristics of typical reactivity calculations; benchmark analyses; and SAMRIN, an input preprocessor program developed to simplify the description of reactor lattice for input to SAM–CE. The contractor is Mathematical Applications Group, Inc. *EPRI Project Manager: Odelli Ozer*

High-Efficiency DC Electromagnetic Pumps and Flow Couplers for LMFBRs

NP-1656 Final Report (TPS79-774); $3.50

High-efficiency dc electromagnetic pumps and flow couplers were evaluated for use in pool-type LMFBRs. The basic operation, model, program inputs and outputs, and parametric studies are described for the flow coupler, an innovation that has proved more attractive than the conventional dc pump. Several flow coupler concepts are presented, including the radial current–azimuthal field concept and the radial field–azimuthal current concept. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. K. Winkleblack*

Summary and Evaluation of Scoping and Feasibility Studies for Disturbance Analysis and Surveillance Systems (DASS)

NP-1684 Topical Report (RP891-3); $4.50

Two design and feasibility studies of disturbance analysis and surveillance systems (DASS) are presented, along with background information on disturbance analysis. A technical advisory group guided and evaluated the studies and appraised the results with respect to key design factors. On the basis of its conclusions, the group arrived at an endorsement of the next phase of DASS development. *EPRI Project Manager: A. B. Long*

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