Storing Off-Peak Energy

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Cover: Three major technical options for the storage of electric power involve conversion into mechanical or chemical energy and subsequent reconversion into electric energy.

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Storage: Strategic Element in Energy Management

It is now national policy to reduce the consumption of oil in the United States, and electric utilities are working to respond to the challenge. Although new and renewable resources will be used to the extent feasible, the real option today is energy conservation and increased use of coal and nuclear. Energy storage, operating both on electric utility systems and on the customer side of the meter, can be a key element in the strategy for shifting energy consumption from oil to coal and nuclear in the electric utility, space heating, and transportation market segments.

Baseload operation is the least expensive energy available in the utility system, and as described in this month's lead article, it is the availability of this low-cost, off-peak (night) energy that makes the concept of energy storage attractive and economically feasible. Supplying peak loads with stored baseload power will help utilities respond to the national policy of conserving oil in particular and conserving energy in general. Less energy, for example, would be used by a 70% efficient energy storage system charged by an efficient coal plant than would be used by a combustion turbine supplying the same power from coal-derived liquids.

In another efficient alternative to managing energy, electric utilities today are actively pursuing load management by end-use storage to improve system load factors and reduce peak demand growth. This will reduce to some extent the need for peaking and intermediate units. However, our studies show that even extensive implementation of load management and end-use energy storage will not eliminate the need for the type of flexible generating unit best represented by today's pumped hydro and tomorrow's advanced storage technologies. For example, electric utilities even today can plan for incorporation of compressed-air storage or underground pumped hydro (both having more flexible siting possibilities than conventional pumped storage) in their operating systems. The world's first compressed-air storage plant has been in operation in Huntorf, West Germany, since December 1978. Thus sufficient engineering detail is now available to assure us that no insurmountable problems remain for either compressed-air storage or underground pumped storage.

The introduction of more advanced energy storage technologies, such as batteries and systems, will depend greatly on the success of ongoing research, development, and engineering efforts. The next several years should resolve the basic questions regarding the technical and economic potential of several battery concepts for both electric vehicles and utility applications. The commercial feasibility of cool storage systems for reduction of air conditioning loads is currently being explored.

In our optimism for energy storage, it is important to recognize that the value and potential benefits that can be derived from energy storage require the availability of low-cost energy at periods of low demand. Energy storage is not an energy source—it is part of a strategy for managing energy. For energy storage to be successful, utilities must continue to build and operate baseload coal and nuclear generating stations. Further into the future these conventional sources may well be supplemented by solar, breeder reactors, or fusion. Energy storage owned and operated by utilities or operating on the customer side of the meter can assist in the most efficient and economic utilization of these resources.

Thomas R. Schneider
Manager, Energy Storage Program
Energy Management and Utilization Division

Authors and Articles

Utilities have always stored energy as fuels of all kinds in holding tanks, stockpiles, and hydraulic reservoirs and in the delivery networks of railroads and pipelines. They have used those fuels in power generation technologies that can match the daily swings and even minute-by-minute surges of electricity demand. Now, however, the natural gas and (especially) oil supplies for those most adaptable power technologies are drying up.

Putting Baseload to Work on the Night Shift (page 6) explains how electricity can be generated continuously, with some of it converted to other energy forms and then regenerated on demand. Several EPRI- and DOE-sponsored projects are science writer Jack Catron's sources, plus his discussions with Thomas Schneider, who has headed the Energy Storage Program of EPRI's Energy Management and Utilization Division since January 1977. Earlier, Schneider worked four years for New Jersey's Public Service Electric and Gas Co., initiating and directing assessments of energy conversion and storage technologies, including batteries, fission and fusion reactors, and electric vehicles. Schneider graduated from Stevens Institute of Technology; he earned a PhD in physics at the University of Pennsylvania.

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It's one thing for stored energy to fill a gap in power generation when electricity demand surges momentarily upward. It's quite another for entirely new power options to fill the gap when specific fuel shortages preclude former storage means and power technologies.

Time Lag of Energy Innovation (page 14) characterizes in one phrase the major problem that delays new energy resources and technologies. EPRI's R. L. Rudman and C. G. Whipple are the authors, assisted by writer Jack Catron, and they discuss various time-dependent phenomena that prevent our full use of new energy technology as quickly as the need arises.

Rudman came to EPRI in March 1973 as assistant to Chauncey Starr, founding president of the Institute. He organized EPRI's Planning Staff in 1974 and now directs the Policy Planning Division. Rudman is a graduate of the University of California at Los Angeles, with an MS degree in nuclear engineering from the same school. He worked at Los Alamos Scientific Laboratory on gas-cooled reactor design and was later an IBM consultant on engineering computing.

Whipple has been with EPRI since June 1974, involved in a succession of assignments as manager of special studies for the Planning Staff and since September 1978 as a technical manager in the Energy Study Center. Whipple graduated in engineering science from Purdue University; he added MS and PhD degrees at the California Institute of Technology.

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Magnetohydrodynamics is quickly and mercifully abbreviated to MHD, so it's easy to miss what's going on: trading the kinetic energy of a fast-moving, ionized fluid for the dc electric energy it induces in a circuit when passed through a magnetic field. The phenomenon has a twenty-first-century aura, but its first application will likely use coal, a fuel from centuries past, to produce the ionizing heat.

MHD: Direct Channel From Heat to Electricity (page 21) summarizes the twin potentials of high efficiency and pollution freedom when coal combustion gases are used to drive a combination of MHD and steam electric generators. The *Journal*'s Nadine Lihach also writes of the wisdom and the ways of trading early efficiency for early reliability. And she taps the expertise of two project managers who have guided EPRI's selective research in MHD.

Paul Zygielbaum came to EPRI in December 1973, and MHD was his principal project management concern until November 1977, when he went to Portland General Electric Co. on loan for two years in plant startup and operations and in generation planning. MHD now occupies him again, but only as a part of his work with combustion turbines in the Power Generation Program of the Advanced Power Systems Division. Zygielbaum holds a BS in engineering and applied science from the California Institute of Technology; he also earned an MS in mechanical engineering there.

Andrew Lowenstein, now a consultant, was EPRI's project manager for MHD during much of Zygielbaum's absence, from June 1978 until January 1980. He previously worked more than four years in MHD power research at Avco Everett Research Laboratory, Inc. Lowenstein graduated in aeronautics from Rensselaer Polytechnic Institute; he holds MS and PhD degrees in aeronautics and astronautics from Massachusetts Institute of Technology.

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For most of this century, as the U.S. gross national product rose year by year, we were content that this measure of national wealth was an inclusive and therefore satisfactory index of overall well-being. Moreover, for some 50 years, there was a nearly constant relationship between GNP and energy consumption.

Quality of Life: An International Comparison (page 26) suggests the basis of a new index to well-being, or the quality of life, one that uses international comparisons of many factors and, as a consequence, seems to resolve long-evident discontinuities between the U.S. energy-GNP ratio and those of other nations that have high living standards. The article was adapted by Jenny Hopkinson, *Journal* feature writer, from a paper by C. F. Anderson, an EPRI senior economist, and Ben-Chieh Liu of the Midwest Research Institute.

Anderson joined EPRI's Planning Staff in July 1976 and is now in the Special Studies Department of the Policy Planning Division. He was previously with SRI International for 2 years. Anderson also worked in econometric analysis for several firms and lectured at several California universities over a 14-year period. He holds BA and MA degrees in economics from the University of California at Santa Barbara.

Rudman

Whipple

Schneider

Zygielbaum Lowenstein

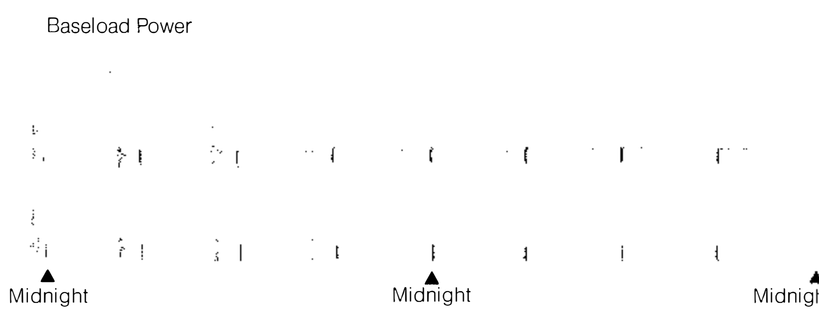
Anderson

Putting Baseload to Work on the Night Shift

Energy storage could open the door to full employment of baseload power, allowing the excess output of nighttime production to be shifted to daytime consumption. This would help utilities and their customers to better manage electric load cycles, shift demand from the scarce fuels to the more plentiful and less costly domestic resources, and assist the gradual integration of solar energy into utility systems. A variety of technologies for both system-load storage and end-use storage are under development.

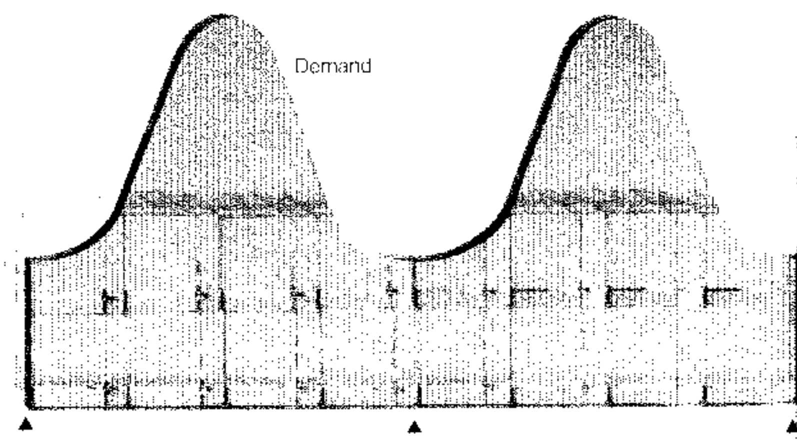
1

All utilities have a certain electric generating capacity that is designed to produce continuous power. This basic block of power—baseload—is typically generated around the clock from large coal and nuclear facilities.



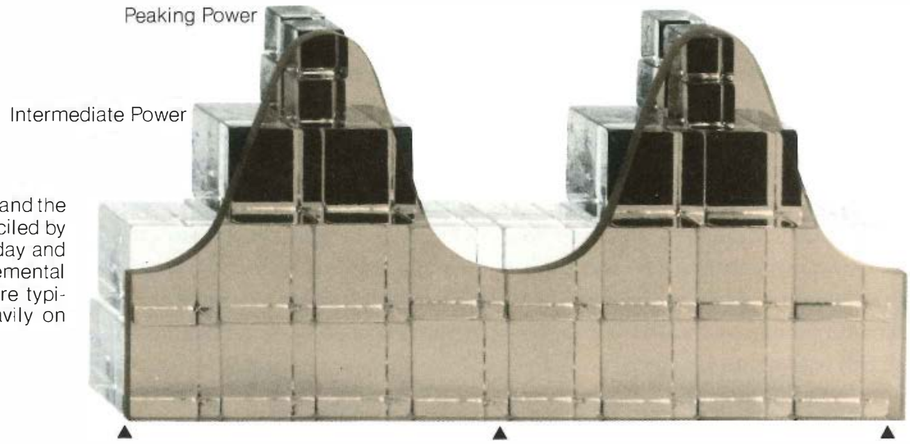
2

All utilities face a cyclical demand for electricity that fluctuates by time of day and season of the year. The demand for power surges above baseload capacity during the working portion of the day, when industry, business, homes, and transportation are simultaneously using large amounts of electricity, and dips below baseload at night.



3

Disparity between the peaks and valleys of demand and the constancy of baseload supply is traditionally reconciled by adding supplemental blocks of power during the day and cutting back on baseload power at night. Supplemental sources—intermediate and peaking generation—are typically more expensive than baseload and rely heavily on such scarce fluid fuels as oil and gas



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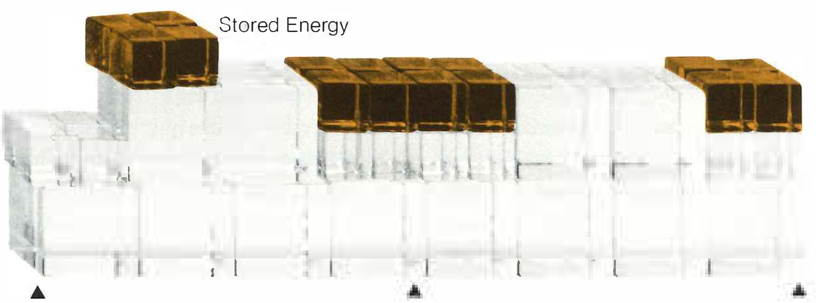
The unused portion of baseload power available at night would, in principle, create a block of reserve energy that could be lifted out and stored to help meet the peak demand of the following day



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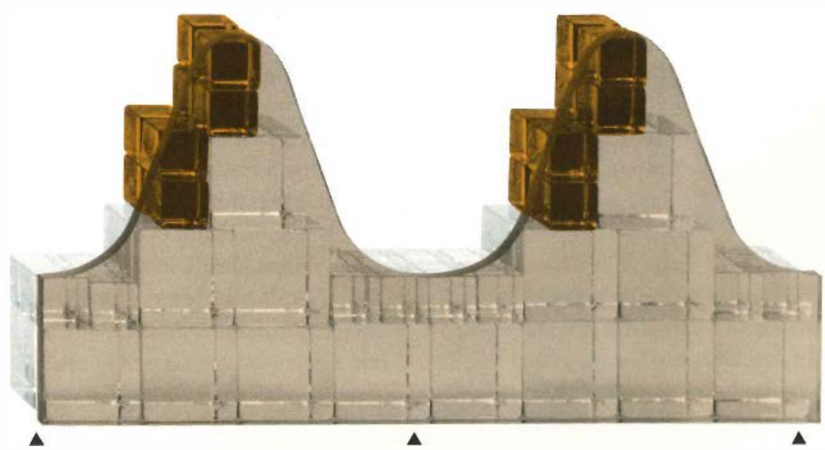
Using some of the relatively inexpensive baseload power that was stored at night to meet daytime demand would reduce costly intermediate and peaking power and oil/gas consumption. It would also make better use of capital investment.



Until now, demand for instantaneous energy has been met primarily by the most convenient form of large-scale energy storage: fuel reserves. Oil and gas stand out as the preferred fuels for storage because of their high energy density and their ease of transport and combustion. Utilities, in particular, have come to rely on them to run the power plants that are started up and shut down each day to meet peaks of demand for electricity.

All this is likely to change. During the coming decade, law and circumstances will force both electric utilities and their customers to sharply curtail their use of oil and natural gas. Coal, uranium, and to the extent possible, renewable resources will have to take up the slack, together with conservation and increased efficiency in energy use. Yet none of these major supply options are well adapted to meeting rapid variations in energy demand. Coal and nuclear power plants are better suited for continuous, baseload operation. Solar power is even less suitable because of its own intermittent nature and the vagaries of weather.

So as oil and gas are phased out, other forms of energy storage must be found to accommodate the peaks and fluctuations in daily demand. Development is now proceeding rapidly on a number of alternative storage systems that can take advantage of surplus electricity generated at night by baseload plants. In turn, they can help speed the transition from scarce to plentiful primary resources, improve utility load management, and reduce overall costs for utilities and their customers.

Benefits of energy storage

To grasp fully the prospective benefits of energy storage it is necessary to step back and view this vital link between supply and demand in the broad context of the integrated energy system. Benefits gained by any single part of such a system eventually accrue to the whole.

Starting with the supply side, direct and indirect storage of electricity from coal and nuclear baseload plants can displace the consumption of oil and gas in peaking and intermediate (cycling) power plants. Present estimates are that fully implemented utility storage systems could supply 1.5–2.5% of U.S. electric energy (100–150 TWh) by the year 2000, providing up to 15% of peak load demand from stored coal and nuclear in some regions. For each gigawatt of energy storage plant in operation, 2–3 million barrels a year of petroleum could be saved. The total savings for the United States at the turn of the century could be as high as 150–300 million barrels a year.

On the customer side of the electric meter, energy storage can have a comparable impact. Performing customer load management with energy storage systems, daily variations in demand could be reduced. Given nighttime electricity rates, storage could help the penetration of electricity into water- and space-heating applications. This approach would substitute coal and nuclear energy for heating oil and save 30–50 barrels of oil a year for each electrically heated residence. Thus, every million residences converted from oil to stored off-peak electric heat would save 30–50 million barrels of oil annually; if 30% of new housing units were so equipped, annual oil savings could reach 500 million barrels by the year 2000.

For utilities directly and customers indirectly, energy storage offers additional benefits. The capital costs of storage systems will be lower than trying to meet fluctuating demands by building cycling coal units. Such systems also hold the potential to improve flexibility in power system planning and operation: They can provide efficient load following, reduce the need for reserve generating capacity, and allow deferral of transmission expansion because they can be sited closer to load centers.

The environmental characteristics of both utility and customer energy storage systems are expected to be superior to those of conventional cycling units. Thus, storage provides an opportunity for transferring environmental control requirements from intermediate and peaking units to nuclear and fossil baseload plants. These are either inherently cleaner or can be equipped with more cost-effective emission control technology.

Electric supply storage

In contrast to oil and gas, which are conveniently transported, stored, and converted at the point of use, electricity has been more difficult and expensive to store and is usually generated on demand. Storage of electricity therefore requires conversion to a more readily storable form of energy, and an energy storage system can be considered in terms of three principal elements. The first is a converter, which accepts electric energy and changes it into a form more easily stored. A pump, for example, can be used to raise water to a greater height, converting electricity into mechanical (potential) energy. The second is a reservoir. In the case of pumped water, the reservoir might be a small lake adjacent to the pumping plant. The third, a reconverter (e.g., a water-driven turbine-generator), is used to transform the stored energy back into electricity.

Until recently, the only economic storage option available to electric utilities was the conventional pumped-hydro concept just described. Because the sites appropriate for such systems are quite limited, current R&D seeks to expand the choice of economic options, with emphasis on underground pumped hydro, compressed-air storage, and advanced batteries.

The method of storing energy by transferring water between surface reservoirs has been used in the United States since 1929. About 35 such systems, with a generating capacity of more than 25 GW, are either in operation or being constructed in the United States. The largest of these plants is the Ludington pumped-storage facility on the eastern shore of Lake Michigan, with a storage capacity that can provide 15 GWh. Six reversible pumps raise water an average of 250 ft (76 m) into an artificial lake. As it is discharged, the water produces 2 GW of power.

Such facilities are obviously dependent on availability of suitable topography and they sometimes raise environmental objections. The artificial lake at Ludington, for example, must be contained by an earth-filled dam some 6 miles (9.7 km) long. The size of the upper reservoir can be substantially reduced if the height to which water is raised can be increased. For conventional surface reservoirs this is frequently impractical, but engineers have begun to study the possibility of installing generating equipment and a lower reservoir deep underground.

EPRI and DOE are sponsoring site-specific design studies of such underground pumped-hydro storage systems. The height difference between the upper reservoir at the earth's surface and the lower one underground could be several thousand feet instead of the hundreds of feet common in conventional pumped-hydro installations. The required tunneling techniques, cavern construction methods, and high-lift pumps are essentially in hand, and a commercial underground pumped-hydro plant could be built by 1990. However, the extremely high water pressure involved will still limit the locations where such facilities can be sited because of the need for rock formations of sufficient strength and integrity. More widely adaptable options are therefore needed.

A mechanical storage system with potentially wider application employs air pumped into underground chambers during off-peak hours and later released to generate electricity (*EPRI Journal,* April 1979). Compared with pumped hydro, compressed-air storage has several advantages, including wider choice of suitable geologic formations, greater compactness, and a smaller minimum capacity. On the other hand, estimates of feasibility are less certain because of limited experience with compressed-air storage.

Some of these uncertainties are now being resolved with the world's first commercial compressed-air storage facility at Huntorf, West Germany. This 290-MW plant began operation in December 1978, using two 5-million-ft^3 (140-km^3) salt caverns.

EPRI and DOE are cosponsoring three preliminary engineering studies to provide bases for design and decision by U.S. utilities interested in compressed-air storage. Each focuses on a particular storage medium: salt caverns, rock, and aquifers. The component technologies are largely available, and commercial-size plants (200–500 MW) could be operating in the United States by 1985.

Another advanced technology, batteries, could become the preferred choice for daily cycle energy storage because of their potential for easy siting, operating flexibility, and short installation lead time. They could provide a significant part of daily peak loads and might ultimately represent up to one-half the utility industry's energy storage capacity if battery systems with sufficiently long life and low costs are developed.

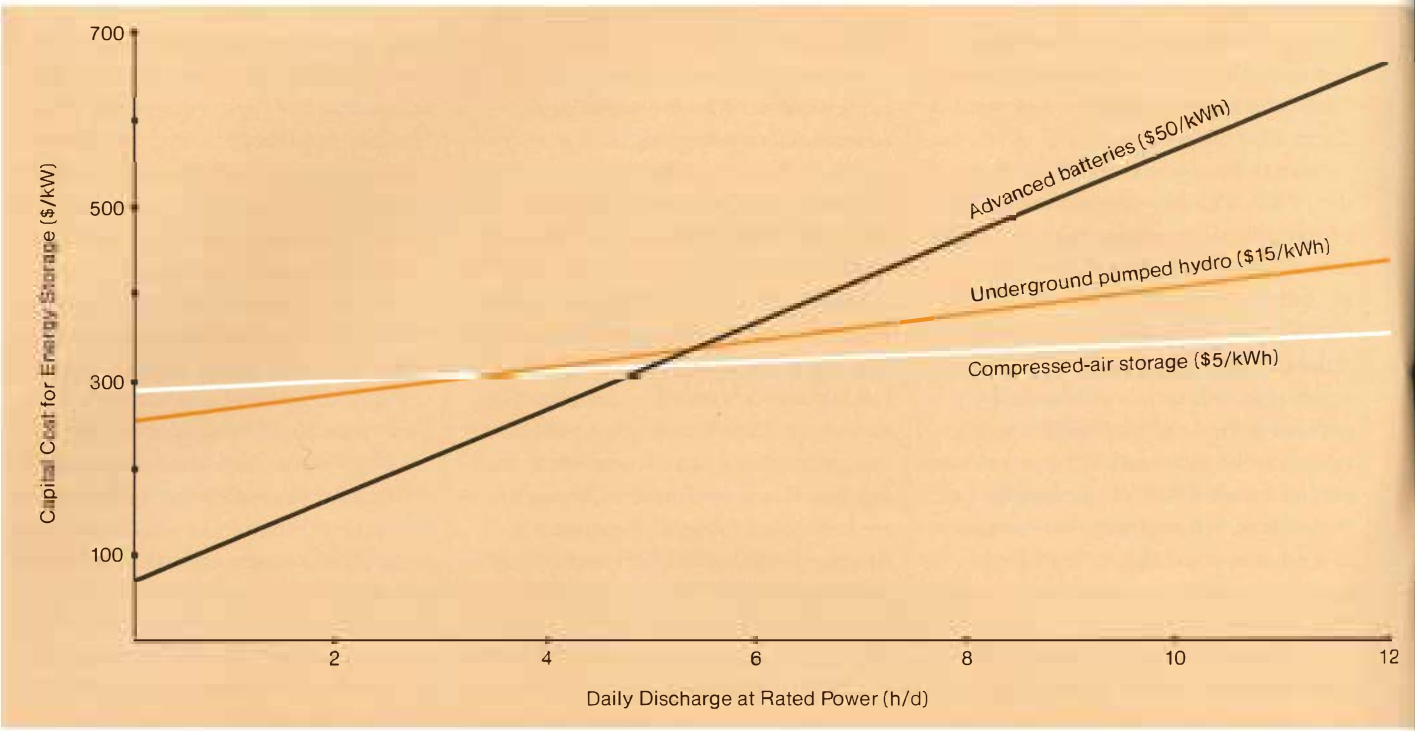
Although batteries were used in several U.S. cities more than 50 years ago to supplement the dc power required by electric streetcars during rush hours, the conventional lead-acid battery is too expensive for large-scale application to modern power systems. A generation of advanced batteries, with potentially lower initial costs and longer service life, are now being developed; if successful, they could again make the large-scale storage of electricity in batteries attractive.

Although some of the systems being developed may eventually last 2000 or more cycles and cost less than $50/kWh of storage capacity, they tend to be more complex than conventional batteries. The sodium-sulfur battery, for example, must be operated at 300–350°C, while the zinc-chlorine battery depends on separate storage of chlorine in a solid, hydrated form. Before commercialization, these advanced batteries must still pass several technical hurdles, including achievement of high efficiency to confirm the durability of battery reactive and containment material, establishment of adequate cell and multicell battery reliability, and development of truly low-cost manufacturing techniques.

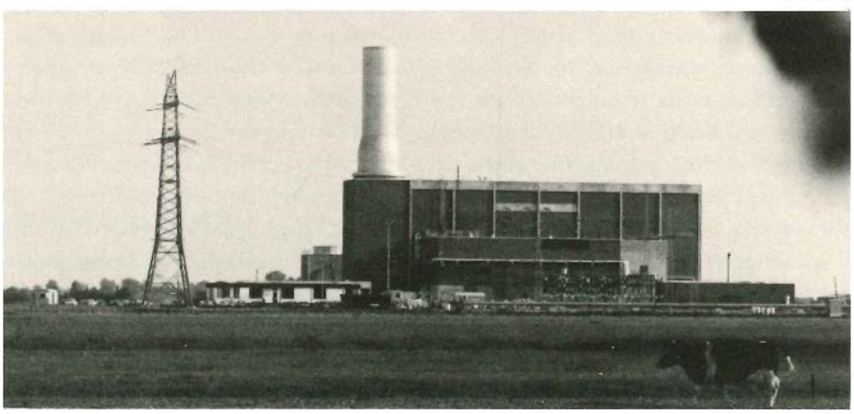
To assess the technical and economic prospects of the most promising advanced batteries under development, EPRI and DOE have established the Battery Energy Storage Test (BEST) Facility. This facility, which is being cofunded and constructed by the Public Service Electric and Gas Co., New Jersey, is expected to begin operation in 1980. It will evaluate battery prototypes with a storage capacity of 5–10 MWh in a utility environment. The first prototype to be tested will probably be the 5-MWh zinc-chlorine battery now being built by Energy Development Associates, a subsidiary of Gulf + Western Industries, Inc. This battery will consist of up to 100 modules, each capable of discharging for five hours at 10 kW. Another prototype, a 5-MWh sodium-sulfur battery, could be ready for testing by 1985.

To help ensure utility familiarity and acceptance of batteries as a practical energy storage option, DOE and the electric power industry have launched the storage battery for electric energy demonstration (SBEED) project. The 1984 goal of this project is to demonstrate the operation of a 30-MWh lead-acid battery storage system connected to the grid of the Wolverine Power Cooperative in northern Michigan. The SBEED plant will be operated by utility personnel and will provide the realistic on-line performance, reliability, and economic data that utilities need to gain sufficient confidence to adopt battery storage on their systems.

Although there are many other ways to store energy that may look attractive in principle, few of them are likely to be developed commercially during this



Seneca



Huntorf

BEST Facility

omparing costs of three utility storage ptions reveals that underground pumped ydro and compressed-air storage are ıcreasingly attractive when long periods of ischarge at full power are sought. Many tilities look for discharge capability of -10 hours or more. For discharge periods ss than 8 hours, battery systems become ıcreasingly attractive.

ecause electricity cannot be stored, it ıust be converted to a storable form of nergy and reconverted to electricity when eeded. Utilities are pursuing several ıethods of system-level storage, notably umped hydro, compressed-air storage, nd advanced batteries.

At Seneca, New York, water is pumped ıto an elevated reservoir at night and eleased to generate power during the day. bout 35 such pumped-hydro systems are ow in operation or under construction in ıe United States. Design studies are under ay to place the lower reservoir deep nderground to increase the head of falling ater and thus reduce the size of the pper reservoir.

At Huntorf, West Germany, the world's st compressed-air storage plant went to operation in 1978. During off-peak eriods, electricity is used to pump ompressed air into underground salt averns. In the United States, salt caverns, ock caverns, and aquifers are being xplored, and commercial-size plants 00–500 MW) could be operating by 1985.

At Hillsborough Township, New Jersey, ıe BEST Facility is nearing completion. unded by DOE and EPRI and operated by ublic Service Electric and Gas Co., the cility will become a major center for sting advanced battery systems. Two omising battery prototypes, the zinc-ılorine being built by Energy Development ssociates and the sodium-sulfur being built General Electric Co., will be among the st to be evaluated.

century at the utility system level. Their large-scale application must await the resolution of major technical and economic uncertainties. For example, various methods have been suggested for directly storing the heat energy of nuclear reactors or of conventional steam plants, but EPRI studies indicate that this type of storage will not become economically competitive in the nearer term. The development of technology for thermal storage is continuing, however, mainly as an adjunct to other energy management applications, including compressed-air storage, cogeneration, and solar power.

Superconducting magnets could be used to store electricity directly, with very little energy wasted. However, useful installations would have to be extremely large, and the need for maintaining the system at cryogenic temperatures raises great uncertainties of cost that have not been fully addressed in current conceptual designs. Flywheels are able to absorb and release energy very quickly, but they appear too expensive for large-scale utility application. Electric energy can be converted to chemical energy, producing a fuel that can be stored, transported, and reconverted to electricity. Hydrogen produced by electrolysis, for example, can be stored and subsequently used to generate electricity efficiently in a fuel cell. However, the energy lost during this sequence of conversion steps and the cumulative cost of the required subsystems are at present too great for near-term consideration of this option on a large scale.

End-use storage

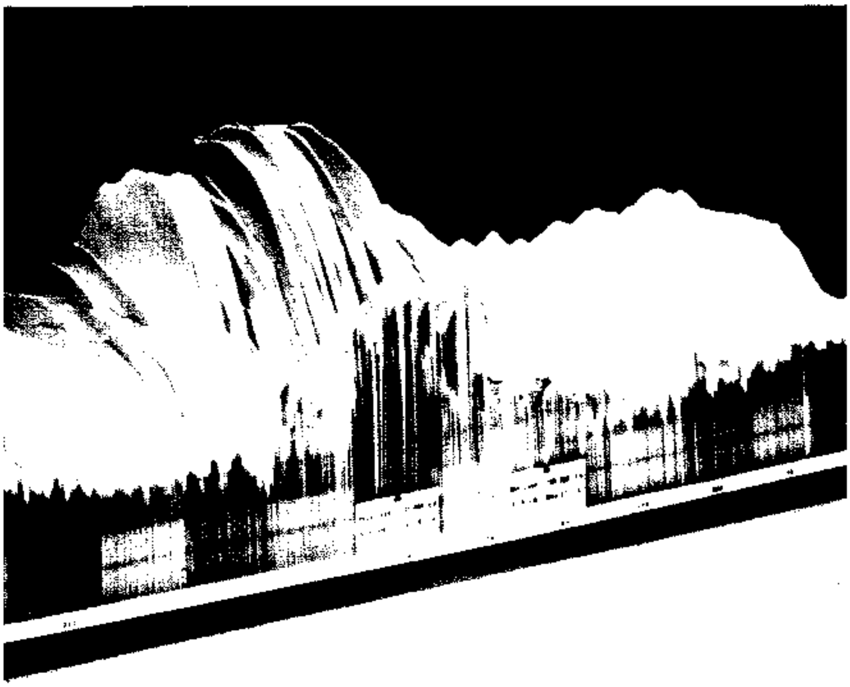
The residential, commercial, and industrial sectors of the national economy account for nearly 80% of U.S. gas consumption and about 37% of U.S. oil consumption. Direct burning to provide space, water, and process heating accounts for most of this fuel use.

If daytime demand for space heating and hot water is to be met increasingly by electricity from baseload coal and nuclear power plants, some of that electric energy must be generated at night and stored. A cost-effective way to store baseload energy for such application could be to install a storage unit on the customer's side of the meter. Because this approach shifts the burden of capital investment from the utility to the customer, the utility must offer a lower, off-peak electricity rate to create an incentive for this investment shift. It must also be able to monitor time-of-use by customers.

Several U.S. utilities have been making off-peak rates available for timer-controlled electric hot water heating, with a positive but somewhat limited impact on their load curves. A substantially larger impact can be expected if space heating is also provided from storage, which has been a growing practice in several European countries for the past 10 years. In some parts of Germany, for example, electric storage heaters represent nearly 25% of the total demand for electricity, and in winter the daily load curve for a utility is almost flat. Various methods, including signals transmitted via radio waves or carried by electric power lines, are being explored as means to provide utilities further control over the load represented by such storage units.

The technical options for storage at the customer's side of the meter are constrained by the requirements of low cost, high reliability, and low maintenance. At present, these requirements are met by electrically heated water tanks, ceramic brick storage units for rooms, and floor slab heaters. All these are commercially available and are being studied as components of ongoing programs to develop economic load management strategies for utilities and their customers.

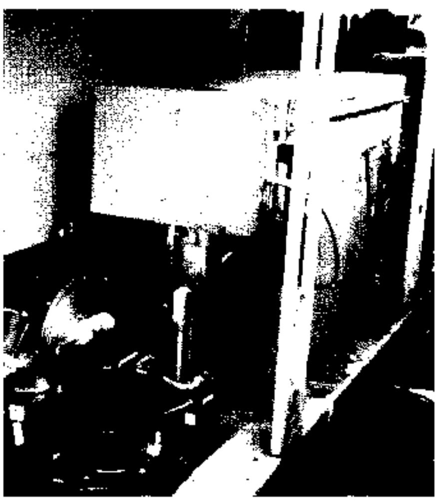
For many U.S. utilities, air conditioning represents a large portion of the load peak for summer days, and it would be very desirable to condition air with coolness produced by baseload power at night. Prototypes of cool storage systems

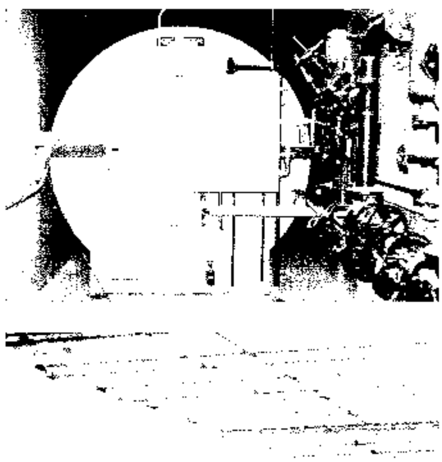


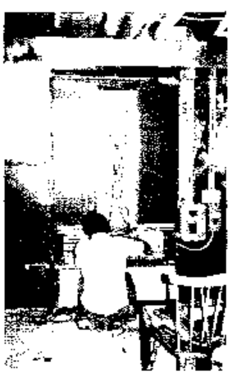
A typical profile of annual electric demand shows that utilities experience seasonal as well as daily cycles in electric load. Most utilities are now summer peaking, but with more than 50% of new homes going to electric resistance heating, a more balanced annual load may take shape.

End-use storage devices that take advantage of off-peak rates will also help to shave peaks and level load. Development is proceeding on both hot and cold storage, as well as electric vehicles. Because air conditioning contributes greatly to summer peaking, cool storage is considered a more pressing need than heat storage, but it is further from commercialization. The basic technical problem is that cool storage devices operate over a narrow temperature range (tens of degrees) whereas heat storage devices operate over a much broader range (hundreds of degrees).

Below: A storage device to cool a typical residence for an entire day; residential/commercial heat storage devices—pressurized water tanks, floor slabs, central brick reservoirs, and room brick reservoirs; battery storage EVs—commercial vans and passenger cars.







based on electric refrigeration to chill water or produce ice are now being tested (*EPRI Journal*, December 1978). Such systems tend to be more bulky and expensive than heat storage, but if these problems can be overcome through more research, the potential benefits would be substantial: Cool storage could reduce summer daytime air conditioning electric demand by up to 50% in some areas of the United States.

Further in the future, electric vehicles (EVs) charged at night for use the next day may eventually represent a significant form of energy storage influencing electric power load curves. From the technical side, the key to success will be the development of efficient, compact batteries for EVs (*EPRI Journal*, November 1979). But social and economic changes will be needed as well; again, favorable off-peak utility rates could provide a strong incentive to use EVs. The potential payoff is large. For urban driving, EVs promise to be at least 50% more efficient than conventional cars in using coal as a transportation fuel, and they represent the only approach to using uranium as a transportation energy source.

Storage of solar energy

Solar energy—now being tapped for hot water and residential heating, eventually also for electric power generation —provides an excellent example of how utility and customer storage can complement one another. On-site storage of low-grade, solar-derived thermal energy for buildings has an advantage over system-level thermal storage because of the difficulty and cost of transporting low-temperature heat by water or other media. On the other hand, with solar electricity generation (by thermal or photovoltaic or wind energy conversion approaches), system-level storage permits better use of capital investment and makes available the economies of scale that result in lower cost per unit of storage capacity.

In both cases, provision for backup energy supply will be vital to the eventual large-scale adoption of solar power. Storage can provide the needed backup, coupling the inherently intermittent supply of solar energy to the fluctuating pattern of energy demand. In practice, if only a small fraction of a utility's generating capacity is supplied by solar energy, storage would not normally be required because other components of the system could provide backup power. However, as solar electricity approaches 10% and more of a system's total capacity, storage is needed to prevent more frequent and serious mismatches between supply and demand.

Utility storage systems will likely be commercialized before solar-electric generation, or possibly concurrently, and their presence will help utilities accommodate an extensive penetration of solar electricity without drastic system-level changes. Wide acceptance of hot water storage by energy users will likewise help acceptance of solar space-heating units.

Outlook

Facing the need to find substitutes for oil and gas to meet peak electric loads, most utilities will eventually have to adopt an integrated energy management system that incorporates both system-level and end-use storage. System-level storage (which includes all storage units connected to the power grid, regardless of geographic location) appears to be the most cost-effective means for storing electric energy. End-use storage (which includes storage units dedicated exclusively to a particular point of consumption) appears to be the most cost-effective means for storing low-grade thermal energy. Yet the two categories of storage clearly interact. The problem is to determine what blend of system-level storage and dedicated storage will work best to level utility loads, help bring oil-displacing energy resources on-line, and provide service at the lowest possible cost to the consumer. The preferred storage system mix will depend on the specific generating and energy resources available to a given utility and the economic, climatic, and meteorological characteristics of the region that help shape the profile of energy demand.

Technologically, energy storage development is proceeding swiftly. Within five years several U.S. utilities are expected to announce plans to build underground pumped-hydro or compressed-air storage systems. Utility-level battery storage systems could come on-line by the late 1980s. Equipment to provide storage for residential and commercial water and space heating is already commercially available and is in widespread use abroad. Developing systems that can benefit both utilities and their customers will depend on more than an economic analysis of the technical options.

Regulatory strategies will also strongly affect the role that energy storage will play. Pricing and tax policies aimed at reducing the use of natural gas and oil will increase the attractiveness and importance of energy storage, as will restrictions and priorities in fuel allocations. Tax credits and other financial incentives could promote the use of oil-displacing energy storage applications. Wider use of off-peak rates will encourage customer energy storage, but such rates must be carefully designed to avoid shifting peaks from day to night.

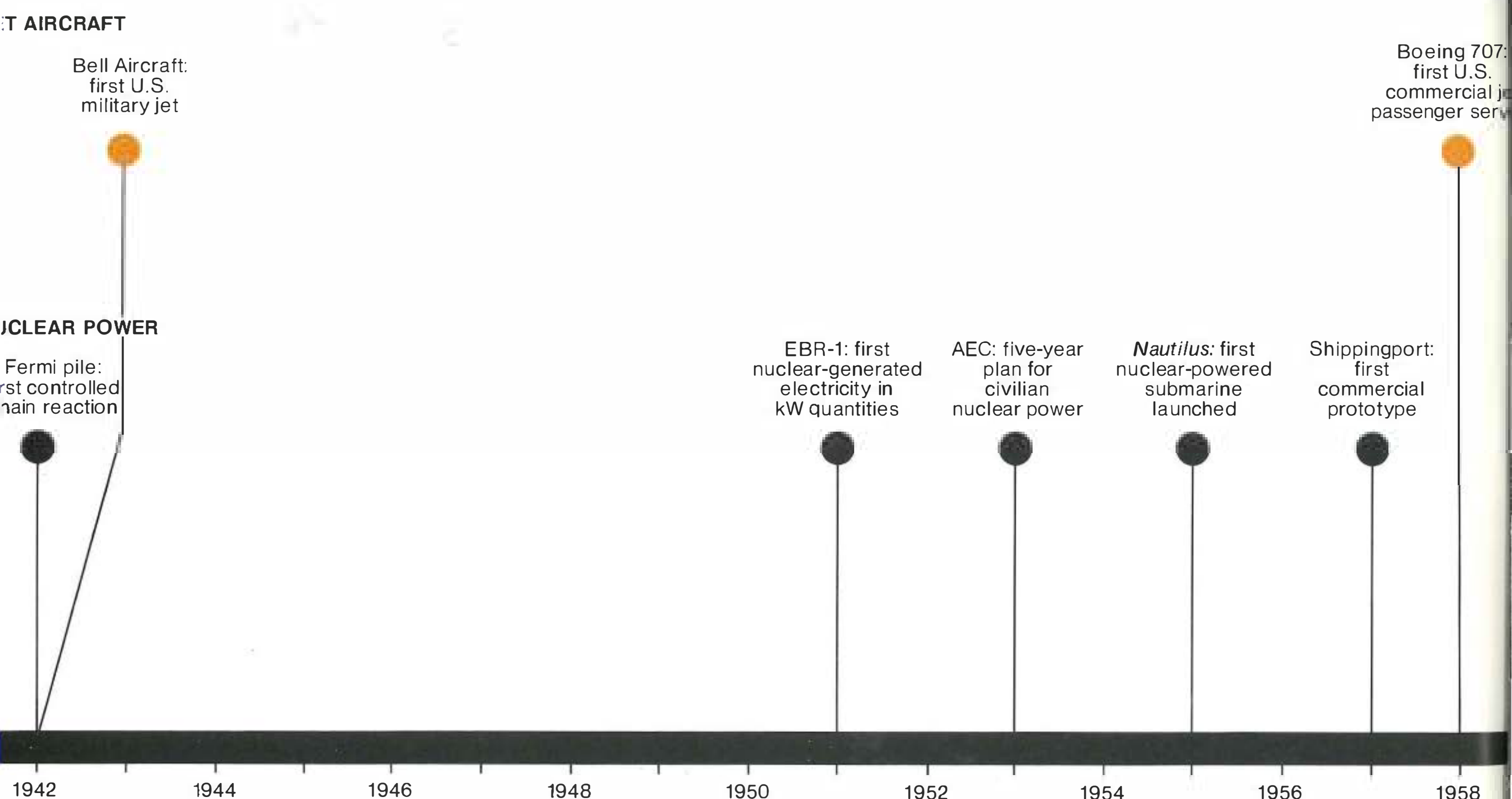
Despite the considerable uncertainty associated with our national energy scene, the breadth of applications, potential benefits, and technological potential of energy storage appear sufficiently established to ensure an important role for storage in the energy systems of the future. ■

Time Lag of Energy Innovation

Providing alternative energy sources for the future requires more than just good ideas. New technologies take time to mature.

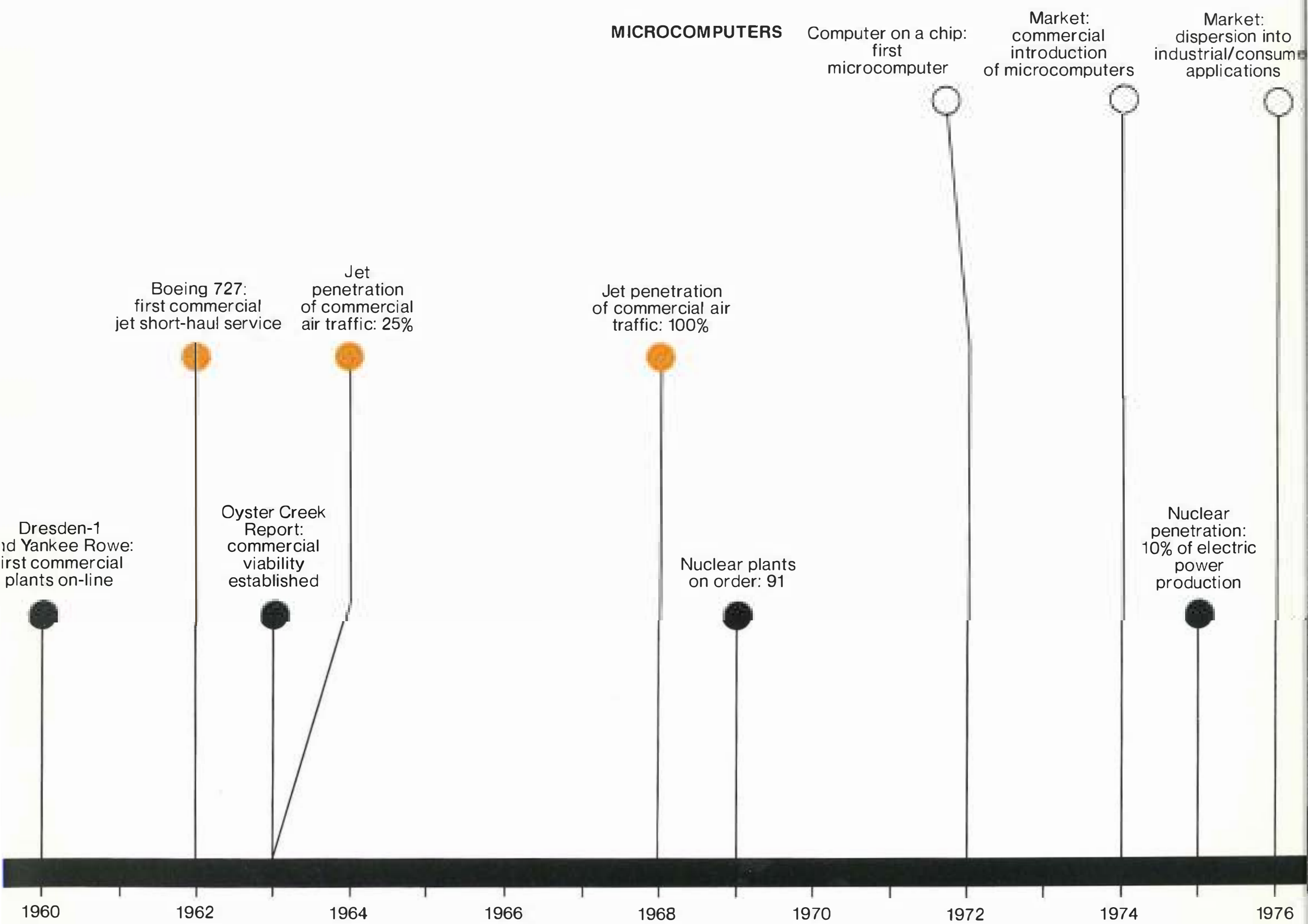
by R. L. Rudman and C. G. Whipple

The time it takes for a new idea to emerge from the laboratory and dominate a commercial market depends on the type of technology involved, the size of devices to be manufactured, the complexity of the manufacturing system that must be set up, and the type of market to be penetrated. In the electronics field, change is swift because the technological base developed quickly, the devices are small and simple to manufacture, and new markets are rapidly evolving. In jet aircraft, once the transition had been made from military to commercial manufacturing, market penetration was rapid and complete—approximately 10 years. Nuclear power, despite favorable conditions, took over 30 years to achieve a substantial penetration (10%) of the large and complex electric utility system.



It took just 10 years after Thomas Edison patented the incandescent lamp for the electric generation and distribution system he had developed to spread throughout the industrialized world. During the next decade, the fledgling electric power industry went through another revolution—the shift from Edison's low-voltage, direct-current system to the complex high-voltage, alternating-current network we know today. Why, then, do experts warn that the emerging electric power technologies can have only marginal impact before the turn of the century?

This question is being raised with increasing frequency by a wide variety of groups, each hoping to speed the innovation process to meet its own set of priorities. "Push conservation; the technology is already in hand," says one group. "What energy growth is needed could be supplied with simple solar technology," adds another group. "No, no," replies a third, "only coal and nuclear energy will be sufficient to supply American needs well into the next century."



The controversy is familiar, but the role that time must play in resolving it is not. Even if a scientific breakthrough should suddenly occur—say, the development of extremely inexpensive photovoltaic cells—incorporating the new technology into the mainstream of electric power generation would remain a time-consuming and expensive process. The main reason, of course, is that the electric utility industry has become so large that sheer scale precludes the speed of change that was possible in Edison's day. But other factors are important as well.

The way of change

Generally speaking, a new technological idea must pass through four stages of development from the laboratory to widespread commercial use. Each stage is significantly more expensive than the one before, and insurmountable obstacles can appear unexpectedly at any point during the process. The cost of failure rises with each succeeding step, so that taking shortcuts can be an extremely hazardous approach.

The first stage is to prove a concept's scientific feasibility—that is, whether the concept can be demonstrated in a laboratory environment. This stage usually gets the most publicity because of the exciting possibility of achieving a sudden breakthrough. Yet even at this stage, the development process can become painfully tedious. For example, nearly 40 years passed from the time Einstein showed theoretically that energy might be obtained from the breakdown of matter until the first experimental evidence of nuclear fission.

The next stage—to demonstrate engineering feasibility—actually involves several intermediate steps of constructing progressively larger devices, translating the concept into practical application. First, a pilot plant is built that is just large enough to incorporate key subsystems and to check their performance. Next, the subsystems are individually scaled up to commercial size and incorporated into a medium-to-large demonstration plant to make sure that they can operate together. Finally, the first fully commercial-size plant (sometimes called the pioneer plant) is built and tested to see whether total cost, performance, and reliability are acceptable.

If the first two stages have been successful, the new technology enters the third stage—commercialization—during which private investors begin to place orders for equipment. For mature industries like electric power utilities, the rate at which a new technology gains widespread application is usually very slow. Even if all new orders for equipment are suddenly shifted in favor of the new devices, market penetration lags because new plants take a long time to build and old ones take even longer to wear out. If the new technology involves fundamentally different methods of operation and maintenance, development of vital support systems requires another major commitment of time and expense.

Before a new technology gains significant use, it must overcome one last barrier. It must prove to be more economically attractive than the competing alternatives. Here, in this fourth stage, even the best ideas may meet crushing defeat. Industrialists often speak of a market window for any given technology, a period during which it may appear so attractive that it is swept into significant use relatively smoothly and rapidly. But when enthusiasts bring a new idea to market before all its problems have been worked out or when development is delayed too long, competing technologies may sweep it aside. The window may close forever.

Recent experience shows that the time required for a new technology to achieve significant use in the electric power industry is now roughly 30–40 years, significantly longer than the decade or so common when the industry was young. Planning for alternative energy sources to generate electricity in the future makes it vital to account for this time lag. Even under the best circumstances, development and adoption of new power sources will be extremely time consuming and expensive.

The nuclear example

Nuclear power offers an excellent example of how a new energy source can be expeditiously developed to generate electricity and of how delays can nevertheless arise along the way. Born of wartime urgency, developed through government subsidization, and commercialized during a period of rapid economic growth, minimum regulatory delays, and unabashed optimism, nuclear reactors still required 30 years to achieve a 10% penetration of the market in 1975.

Nuclear power's four developmental stages were more complex than most people realize. Demonstrating scientific feasibility, in particular, was a tedious process; some reputable scientists predicted that it would never be accomplished. Einstein propounded his theory in 1902; fission of individual nuclei occurred in 1939; and the first simple reactor (literally a pile of graphite bricks and uranium fuel) began operation in 1942. During the next two years, five separate reactor concepts were introduced as possible candidates for further development.

The milestone in demonstrating engineering feasibility—the first kW generation of electricity from atomic power—did not come until 1951. The nine years since the operation of Enrico Fermi's first simple reactor had been filled with feverish activity. Parallel development of several promising reactor designs was facilitated by unlimited government financing and managed by the dynamic Hyman G. Rickover.

At this point, the priorities of utility designers diverged from those of engineers developing reactors for nuclear submarines. Although old hands still argue about the wisdom of choosing the pressurized water reactor designed for submarines as a model for building the first commercial-size nuclear power plant, a 60-MW pioneer plant began operation in 1957. By 1963 commercialization was considered established when utilities began to place orders for major nuclear installations on the basis of their experience with the early prototypes.

For the next 10 years, market penetration was rapid. By the end of 1972, 160 power reactors had been ordered. Although new orders for nuclear plants have now fallen off, it would be hard to imagine faster development of this technology from laboratory experiments to significant commercial use.

Some of the reasons for the current retrenchment of nuclear power are, of course, unique to that technology. However, many of the economic, regulatory, and political constraints that now affect reactors will also slow the development of other alternative energy technologies. They will have to compete in a time of reduced economic growth, slower turnover of generating capacity, and diminishing natural resources. Instead of sharing the postwar enthusiasm for technological development, the public demonstrates only a vague perception of the energy crisis. Perhaps most important, the tremendous growth of regulatory and licensing requirements for new power plants of any kind—environmental impact assessment, land use planning, and regulatory commission hearings—will slow the introduction of even the most attractive new alternatives. No future electric power option is likely to exceed the nuclear power speed record.

Rising constraints

Since the early days of the atomic age, both technology and society have become more complicated. Scientific breakthroughs still occur, but the distance between bench models and commercial plants is rapidly increasing. Specifically, the side effects of any new technology must be more carefully monitored because the potential environmental damage in an increasingly industrial society has also grown. Despite growing public concern over energy shortages, total social commitment to any one technological alternative is unlikely; neither political power nor popular opinion is as coherent as it was during the introduction of the nuclear power option.

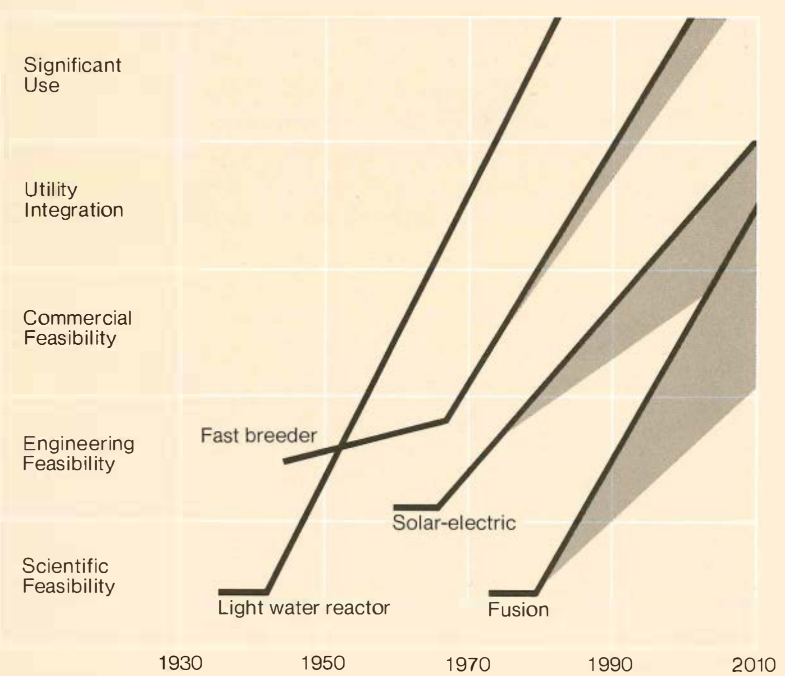
Just changing the fuel base for power generation would require a long lead time, even if present technologies were used. And in general, the more complex a technology, the longer is its development. Fusion energy will almost certainly take much longer to develop (if, indeed, it can be developed) than did fission reactors. The fundamental reason is clear: There is no simple fusion equivalent to the first atomic reactor. To demonstrate the scientific feasibility of nuclear reactors, Enrico Fermi and his coworkers were able to construct a relatively inexpensive model, by hand, underneath a football stadium. However, fusion can only occur under extreme temperature and pressure conditions, so large, expensive machines are required to support even the smallest fusion reaction. Thus, fusion energy's scientific feasibility has yet to be demonstrated, although recent progress has been very encouraging.

The increasing complexity of energy technology requires sophisticated auxiliary equipment and trained personnel. Both take time to develop. If, by some miracle, practical fusion devices could be demonstrated this year, a new set of industries would still be required to build them and a new generation of technicians trained to operate and maintain them. But fusion represents an extreme example.

The Industrial Fuel Use Act of 1978 prohibits the building of any new oil- or gas-fired power plants (with a few exceptions) and calls for phasing out entirely the use of natural gas for power generation by 1990. To accommodate a shift away from petroleum and gas will send a shudder through the energy production establishment—from the demand for freight cars to transport coal to the increase of incentives for developing synthetic fuels.

The case of coal also illustrates how tighter environmental regulation has increased the time required to install new energy sources, even for a mature technology. About half of the 8–10 years required to bring a new coal-fired power plant into operation is spent obtaining the necessary government approvals. About 60% of the cost of a new coal station going on-line in the mid-1980s will be spent on environmental controls, which significantly adds to construction time. If the use of coal is increased as expected, even more delays must be expected because of the provisions of the

Development Phases for Future Power Technologies



Bringing a new electric power technology from the laboratory to the point of commercial penetration in the electric utility industry takes roughly 35–45 years. The scale, complexity, and cost of hardware development increase significantly with each stage in the development process: $1–$10 million for scientific feasibility, $10–$100 million for engineering development, $100 million–$1 billion for engineering demonstration, and $1–$10 billion for the first commercial plant.

The pace of development for future power options is based on the example of nuclear light water reactor development between 1945 and 1970. The principal barrier to fusion is technological; to solar-electric, economic; and to the fast breeder, institutional. Given today's climate of constraint, these projections may be optimistic.

Resource Conservation and Recovery Act and the Clean Water Act.

Thus, the old adage time is money takes on new meaning for time-consuming constraints on technological development. Even if all the other technical and social barriers to rapid development of new energy sources can be accommodated, demand for painfully limited capital will still remain. One-third of the U.S. consumption of primary energy resources now goes to generate electricity, and by the year 2000 that figure is expected to be one-half. Just to meet that schedule will tax capital supply because electric utilities represent about one-sixth of total annual business investment. Any substantial effort to shift the energy base to new technologies could only come at the expense of other industrial investment, for they tend to be more capital-intensive than conventional power sources.

As a result of these and other constraints, EPRI scientists have developed a hypothetical scenario that provides a ceiling estimate of the rate at which any new power generation technology might be integrated into the existing system. In this scenario it is assumed that scientific feasibility has already been demonstrated, that a large demonstration plant could be completed in 1985, that utility orders for the technology grow rapidly, and that new plant construction time is eight years. Under these assumptions the new technology might provide 8.2% of the nation's electricity in the year 2000. However, if longer construction times are required or if generating capacity does not grow as rapidly as expected, market penetration by century's end will be far less.

Against this background, the optimism sometimes expressed regarding quick development of various alternative technologies begins to fade.

The new options

Promising ideas abound. Solar energy has captured the public fancy; the federal government has launched a massive synthetic fuels program; fusion power's scientific feasibility may be demonstrated by the present generation of experimental devices; and new ways of tapping geothermal resources are being developed. Yet, before any of these options can have more than a marginal effect on the total U.S. energy balance, many time-consuming experiments must be conducted.

Geothermal energy has been used since the time of the Romans, who exploited it to heat their famous baths. Some 500 MW of relatively inexpensive electricity is now being generated in the United States, using commercially available technology. However, if this generating capacity is to be expanded significantly, new technologies must be developed because the easily tapped dry steam being used represents only about 0.5% of the total U.S. geothermal energy reserves.

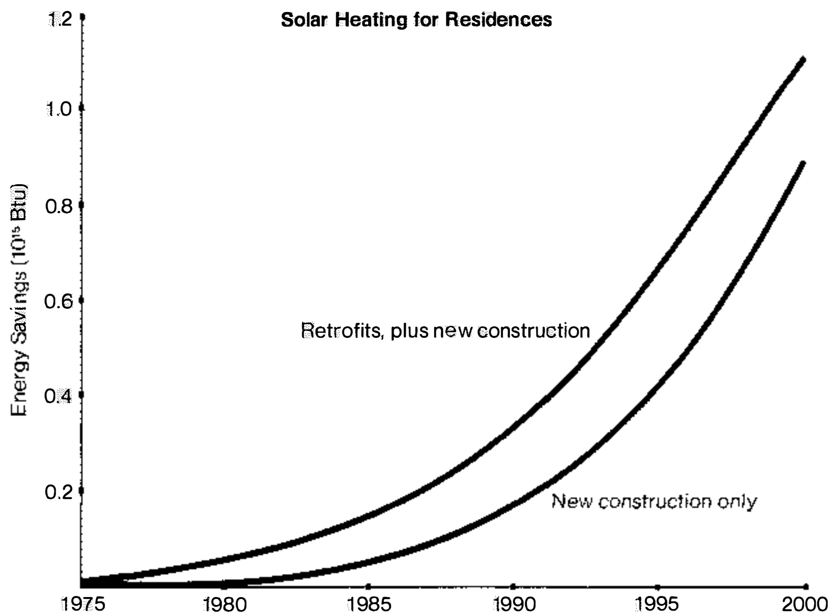
The time that will be required to tap additional geothermal resources varies according to the type of heat available. Hydrothermal (hot water) resources make up about 10% of the recoverable electricity-grade geothermal energy, but water temperatures differ considerably, as do mineral content and the presence of noxious gases. EPRI is sponsoring development of a binary-cycle technology that can use a variety of hydrothermal sources, but no commercial-size plant has yet been built. Tapping the geopressurized reservoirs that lie in deep sedimentary strata or the heat of rocks that lie just above magma from the earth's molten interior will take much longer.

Hydrothermal is the only geothermal resource that can make a noticeable contribution to U.S. energy needs during the balance of this century. By using this resource, total geothermal capacity could be expanded by a factor of 40 during the next 20 years (to 20,000 MW). Although this contribution would be important to the energy needs of the Southwest, it would only represent about 2% of the nation's total anticipated capacity in the year 2000.

Synthetic fuel, in the form of coal gas, has also been commercially available for more than a century. To enable it to compete in today's market, however, new ways must be developed to convert coal into oil or gas or to extract a useful product from oil shale. Most of the technologies in question have only reached the pilot plant stage of development, although one (gasification–combined cycle) is considered ready for commercial demonstration. But even if the relatively ambitious goals set for the new government synfuels program could be met (which many experts doubt), total production capacity in the next one or two decades would still be less than 10% of today's demand for oil.

Solar energy must be understood as involving two different groups of technologies, each involving a different set of delays. On one hand, solar units for residential hot water and space heating are already commercially available, but barriers to their wider use are related to the shift of energy investment from utilities to homeowners. On the other hand, solar technology for utility-scale production of electricity is not yet here; it is just now entering the demonstration plant phase of development.

The economic and social problems facing expansion of the home solar heating market are typical for dispersed energy systems. As long as electricity or other forms of energy for consumers are delivered from central generating or distributing facilities, the burden of capital investment falls on utilities and other industries. So also do the responsibilities for providing reliable service and meeting government regulations. But when the facilities are consumer-owned, other considerations emerge. For example, the interest rate for consumer investment in energy equipment is much higher than that for utility systems, although tax credits and programs for consumer financing are being developed. Further, only a handful of the nation's 10,000 or more municipal building codes provide for solar equipment installation or solar access rights, and the infrastructure



Solar energy devices for heating homes are now reaching the stage of commercialization, but significant market penetration will depend on the rate of growth and turnover of housing stock. If 22% of the new houses built in the next two decades incorporate solar heating, total residential heating demand from conventional sources would be reduced by 7% by the year 2000 (lower curve). This corresponds to 9.5 million solar-heated homes in 2000. If, in addition, 5% of the housing stock existing in 1985 is retrofitted with solar heating, heating demand would be reduced by 9% (upper curve). This corresponds to 13.2 million solar-heated homes in 2000.

needed to produce, market, finance, install, and maintain solar units has not yet matured.

Several years will likely be required to provide the economic and regulatory incentives that can assure homeowners of recouping their solar investment. Even then, the relatively slow turnover of the housing stock will further delay the significant impact of solar heating on total energy demand. If 20–25% of the new residences constructed between now and the year 2000 are installed with solar space heating and an additional 3.5 million homes are retrofitted, the savings would amount to roughly 9% of residential heating demand, or 1% of total U.S. energy requirements.

The eventual success of solar-generated electricity will depend on the results of tests and experiments just now being conducted. A 10-MW solar-thermal demonstration plant is under construction, and if technical and economic uncertainties related to this technology can be resolved, such systems may be commercialized by the early 1990s. As a result, solar electricity is likely to make only a marginal contribution to total supply by the turn of the century. Once solar power does provide a significant fraction of a utility's generating capacity, a new set of considerations arise, including the need for storage facilities to compensate for irregularities of supply.

As would be expected of a technology in the earliest stages of development, scientists are not yet sure which potential fusion power reactors look the most promising or how they might best be used. Scientific feasibility of the fusion concept (obtaining more energy from a reaction than is required to ignite it) will probably be demonstrated first in a magnetic confinement device of the tokamak type. But there is intense disagreement over whether other magnetic confinement designs or fusion induced by laser beams may eventually provide the best model for scaling up to commercial size. Even after this decision is made, other critical uncertainties will remain, such as the choice of fuel and whether to use fusion devices to breed fuel for nuclear reactors. In any case, the first fusion reactor to produce useful power will probably not be built until after the year 2000.

Money and time

If time is so precious, how much could the introduction of a new energy technology be speeded up by throwing money at it? Not much. The main advantage of massive funding, as in the case of nuclear energy, is to promote the development of several design options, thus allowing more freedom of choice and increasing the chances for ultimate success. Many young technologies can be tested on the pilot plant scale at the same cost as building a full demonstration facility for a single technology. Once the most promising candidates for further development have been selected from early experiments, progressively larger models must be built to prepare the technology for commercialization. Each step is far more expensive than the one before, and taking shortcuts can lead to rude surprises.

The American heat pump experience offers an example of what can happen when a technology is marketed prematurely. Introduced commercially in the 1950s, heat pumps were touted as a more efficient (and eventually a more economical) way of residential heating and cooling, although they initially cost more than conventional units. But because not all the bugs had been worked out by thorough testing and the development of maintenance experience, many of the early devices were plagued by problems. Sales rapidly declined, and the experience soured the market for a basically attractive technology for about two decades. Now, however, improved heat pumps are again being offered for sale and may eventually make a sizable contribution to energy conservation.

Undue haste could be particularly detrimental to the development of solar technology. If the home units now being marketed prove unreliable because of installation and maintenance problems, potential buyers may become disillusioned, as in the case of heat pumps. Although solar energy offers long-term potential for displacing scarce fuels, initially the construction of solar devices requires a substantial fuel investment. The energy required to build solar systems represents about 30% of the total energy they eventually produce, so that trying to rapidly accelerate the introduction of solar equipment could actually result in a substantial short-term increase in demand for conventional power.

If massive funding is not carefully controlled, flexibility may suffer. Out of several promising new technology options, one may be pushed ahead simply because it is available, and thus it may capture a significant market share before other options are given a chance to compete. A crash program to develop synthetic fuels also runs this risk. If substantial production capacity is expected to be operating in a decade, the only way to meet this goal will be to build plants of a type already commercially available. But the only fully developed synfuels technology—the Lurgi process—is already obsolete. Far more efficient and environmentally benign processes will soon be available, but not in time to meet massive production goals by 1990.

Even conservation—the only available short-term option—faces some inherent time constraints that mere money would be powerless to remove. Energy-efficient new buildings, for example, can easily be constructed, but the turnover rate is so low that it will take years for this effort to have noticeable effect. Again, some retrofitting is possible, but just adding insulation and double windows to a home requires substantial investment, and legislation to provide incentives to make such a commitment has been slow in coming. Such energy-conserving technologies as cogeneration and urban waste conversion will take even longer to introduce.

The importance of conservation and the inevitability of delay were emphasized in a report prepared by the Committee on Nuclear and Alternative Energy Systems of the National Research Council.

"In the very near future, substantial savings can be made by relatively simple changes in the ways we manage energy use and by making investments in retrofits of existing capital stock and consumer durables to render them more energy efficient.

"The most substantial conservation opportunities, however, will be fully achievable only over the course of two or more decades, as existing capital stock and consumer durables are replaced. There are economically attractive opportunities for such improvements in appliances, automobiles, buildings, and industrial processes at today's prices for energy, and as prices rise these opportunities will multiply."

Time to plan

The implication of the inevitable time lag associated with adoption of any new technology is sobering: Energy decisions must be made far in advance if a crisis is to be averted. This conclusion is especially true for electric utilities, whose complexity makes them prone to particularly long technological lead times. If the benefits of new technologies are to be harvested in the twenty-first century, the necessary research and development must be conducted now.

Advanced electricity options, such as solar electric and geothermal, will provide a small fraction of our energy needs in the next 20 years. Their contribution could be very important, but by themselves they are unlikely to swing the energy balance in favor of adequate supplies. Even with extensive conservation and the orderly introduction of new technologies, demand for electricity is expected to at least double by the year 2000, and based on abundant domestic energy resources of coal and uranium, present power generation technologies must be responsible for most of this growth.

MHD: Direct Channel From Heat to Electricity

Team a conventional steam-electric power plant with an unconventional new technology and you get the promise of better efficiencies—but bigger engineering problems as well. The new technology now under development is magnetohydrodynamics, or MHD.

In this new power plant's MHD topping cycle, terrifically hot, pressurized combustion gases would rush through a duct and through the field of a superconducting magnet. The 4600°F (2200°C) heat of these gases would be far above the temperatures used in conventional turbines, but this heat and the judicious addition of an ionizing material would boost the gases' electrical conductivity. The flow of the ionized gases through the magnetic field would produce a direct electric current across the duct. The current would be amassed by hundreds of electrodes, converted to alternating current, and sent on its way.

The exhaust gases, their conductivity reduced and now at 3600°F (1650°C), would then be routed through a bottoming cycle, where a special heat recovery boiler would raise the steam to run a conventional turbine unit. The steam portion of the plant would generate an amount of electricity roughly equal to that generated in the MHD portion.

With possible efficiencies of up to 50%, a power plant that combines conventional steam-electric generation with unconventional magnetohydrodynamics would seem a compelling choice. But MHD still has much technical ground to cover and plenty of competition before it can reach the electric utility market.

Promise—and problems

The fifty-fifty combination of MHD topping cycle and steam-electric bottoming cycle could permit a power plant to achieve power conversion efficiencies of 45–50% from direct coal firing, compared with the 35% efficiencies of steam-electric generation alone. Because of these higher efficiencies, less coal would be needed to produce the same amount of power, thereby reducing fuel costs and thermal pollution. The new system also offers the possibility of internal sulfur oxide control: The potassium carbonate seed used to ionize the combustion gases could recombine with the sulfur in those gases, and the sulfur would then be trapped as potassium sulfate. Precombustion sulfur removal or postcombustion scrubbing would thereby be eliminated.

But whether MHD power plants will be a part of the nation's energy future is a tough question to answer. MHD technology is "high-risk, high-cost, long-term," according to Paul Zygielbaum, a project manager in EPRI's Power Generation Program, which includes MHD research. Although most of the plant systems will be conventional—fuel storage, steam turbines, boilers, and the like—the critical MHD system is made up of many subsystems that are new to utilities, in need of much development, or destined to operate in a hostile environment.

A high-temperature combustor; MHD generating channel; appropriate dc-to-ac power inverters; superconducting magnet with cryogenic support system; and seed injection, recovery, and reprocessing systems are some of the major prerequisites for an MHD power plant. Some have to be developed from the ground up; others have counterparts in other industries and need adaptation before being used on a utility system.

Many of these subsystems will be subject to MHD's greatly elevated temperatures and to damage from slag, potassium seed, and electrochemical erosion. Plainly, the task of developing MHD is not a small one. "MHD has sizable engineering problems, but there appear to be no insurmountable problems," says Andrew Lowenstein, a former EPRI MHD project manager who now has his own consulting firm specializing in MHD power engineering. "What's needed is a lot of building, trying, learning, and redesigning."

In recent years, MHD's engineering problems have been vigorously tackled with both federal and utility monies. Although funding for this complex technology flagged in the mid-1960s when it appeared that the engineering hurdles were too formidable to merit large investment, the dollars picked up again in the early 1970s when fuel shortages loomed. Since 1971 DOE and its predecessor agencies have invested some $250 million in utility-oriented MHD research; EPRI has contributed about $6 million in utility funds. Although the EPRI investment is modest compared with the federal outlay, both Zygielbaum and Lowenstein agree that the returns on that money have been considerable. Through projects concentrated on critical research items, EPRI has been able to explore for itself the MHD option, identifying important R&D needs, performance requirements, preferred applications, and plant configurations for MHD's ultimate buyer—the utility industry.

These combined federal and EPRI investments have already produced significant results in the development of major MHD subsystems. In 1978 a 500-hour cycling test of an MHD generator was accomplished by Avco Everett Research Laboratory, Inc. DOE sponsored the test, performed under simulated coal-fired conditions at Avco's 20-MW (th) Mark VI test facility in Massachusetts. An MHD channel must endure punishing treatment, notably electrochemical erosion and corrosion by slag and potassium seed. Although the goal for generator wall life is one year (about 7000 hours), the jump from only minutes of operation in the 1960s, to a duration record of 95 hours in 1976, and from there to the present 500 hours is a significant achievement.

Another important development was the 1977 milestone testing of a 5-tesla (50,000-gauss) superconducting magnet on the 20-MW (th) bypass loop of the USSR's U-25 MHD pilot facility near Moscow. The 40-ton magnet, built by Argonne National Laboratory for DOE, is the largest superconducting magnet ever built of the type suitable for MHD applications. The magnet has been extremely reliable in its more than two years of operation.

In still another MHD advance, a 250-kW inverter developed by Avco Everett for EPRI has converted the dc output of the Mark VI facility to ac power for 12 hours. This test was the result of a joint EPRI–DOE effort to research power-conditioning and control circuitry. During testing, the inverter started, adjusted load, and shut down without significant operation problems. Power was actually delivered to a local utility grid.

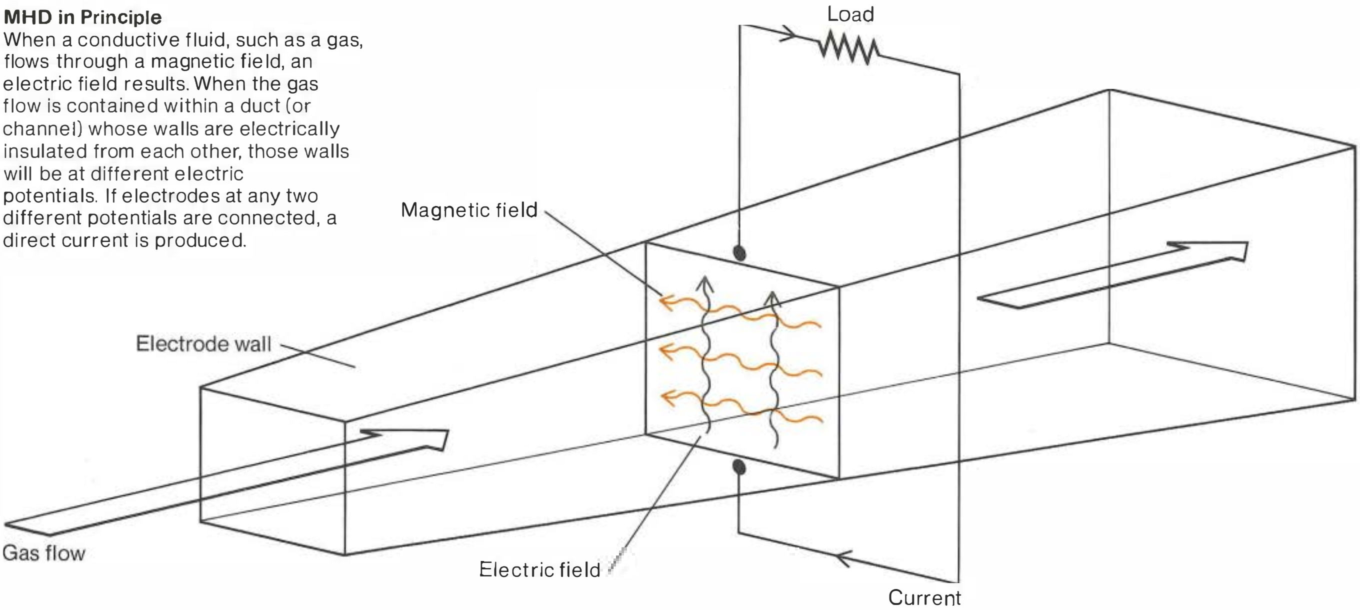
The next big stage in the development of MHD is startup of a 40–50 MW (th) component development and integration facility (CDIF) in Butte, Montana. The plant, commissioned by DOE, is scheduled to begin operation in late 1980. During testing, CDIF will deliver power to the grid of The Montana Power Co.

Although there are numerous MHD test facilities in the United States, CDIF will be the first integrated coal-fired plant for testing MHD components on a fairly large scale and under realistic operating conditions. The 20-MW (th) Mark VI MHD generator test facility, for example, lacks coal-firing capability and tests only channel and inverter components; DOE's 20-MW (th) coal-fired flow facility, under construction near Tullahoma, Tennessee, will test downstream components, such as heat exchangers and seed recovery equipment, but will be equipped with a generator smaller than CDIF's. And although the USSR's U-25 is an integrated, functioning 250-MW (th) pilot plant, it runs strictly on natural gas; coal-fired MHD plants require considerably more engineering.

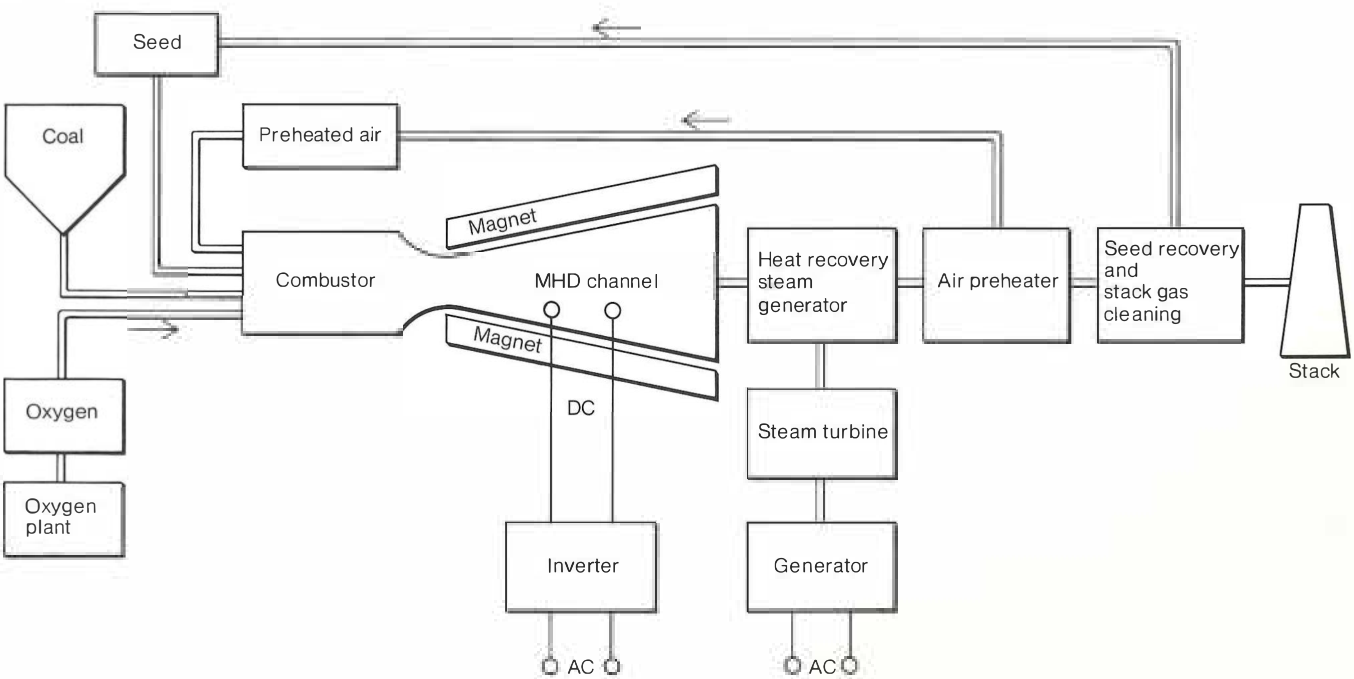
When suitable MHD components have been developed at CDIF, DOE may engineer those components up to 250–500-MW (th) scale for an engineering test facility that would go on-line around 1990. The next step could be a commercial-size facility.

Meanwhile, EPRI continues its MHD research, whose main objectives have been the development of design data for MHD generators, the development of power-conditioning equipment, and the design and analysis of first-generation MHD plants. EPRI-sponsored work at Avco Everett and at Stanford University has made key contributions to generator development in the areas of slag behavior, electric current transport, electrochemical reactions in the generator, and diagnostic instrumentation. Stanford is providing data on generator operation to support the development of power-conditioning equipment. Having completed development of the 250-kW Avco Everett inverter, EPRI now has Westinghouse Electric Corp. under contract to provide a 3.5-MW inverter for DOE's CDIF, according to Robert Schainker, project manager. Through this major MHD subsystem effort, EPRI staff will have an opportunity to work closely with federal

MHD in Principle
When a conductive fluid, such as a gas, flows through a magnetic field, an electric field results. When the gas flow is contained within a duct (or channel) whose walls are electrically insulated from each other, those walls will be at different electric potentials. If electrodes at any two different potentials are connected, a direct current is produced.



Inside the MHD Power Plant
In an MHD power plant, power is produced through a combination of magnetohydrodynamics and steam generation. Coal and oxygen-enriched, preheated air are fired in a combustor, resulting in 4600°F (2200°C) combustion gases. The conductivity of those gases is enhanced by the addition of potassium carbonate seed material. The pressurized gases rush through an MHD channel surrounded by a superconducting magnet. The flow of the ionized gases through the magnetic field produces a direct electric current across the channel. This current is collected by electrodes in the channel walls and converted to ac power in an inverter. Meanwhile, the sulfur in the burning coal combines with the potassium carbonate seed material and is trapped as potassium sulfate. The 3600°F (1650°C) exhaust gas then passes through a steam generator; the resulting steam spins a turbine, which in turn powers a conventional ac generator. The ionizing seed in the exhaust gases is later regenerated. Advanced plants might make more extensive use of exhaust gases to preheat combustion air, thereby eliminating the need for oxygen enrichment.



researchers at this key facility. EPRI's three major design and analysis studies—two by Westinghouse and one by STD Research Corp.—are now largely completed, but EPRI may well continue with further design and analysis efforts. Future funding depends largely on MHD progress at CDIF and in other projects. The federal government, on its part, is expected to continue to pursue its sizable development program.

Stiff competition

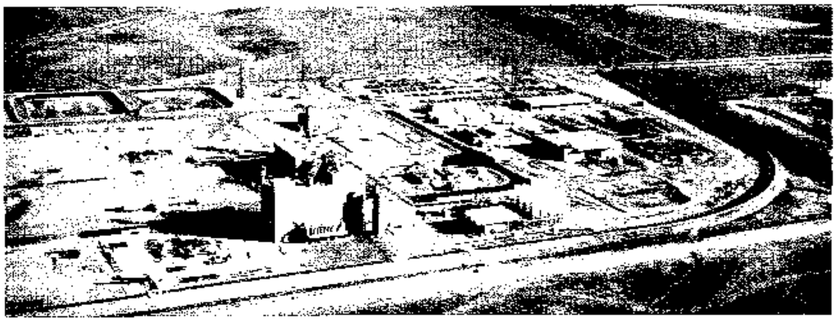
These many recent advances have improved MHD's prospects, yet hardware advances alone are not enough to put MHD plants into commission by 2000, the year first-generation units might be expected to enter utility service. Ultimately, hardware must go to market, where the competition among advanced power systems is rough. For the long term, MHD, advanced gasification–combined cycles, molten carbonate fuel cells with gasifiers, and other technologies are all competing for the baseload power generation market. Many of these technologies may require less engineering development than does MHD, and some have comparable attractions. Many have the added push of vendor support, something that MHD, with its special development problems, lacks.

But there may be a way to keep MHD in the running. "The utility industry sees the reliability problem as paramount," reasons Zygielbaum. So instead of concentrating R&D efforts on reaching the highest possible efficiencies, researchers could plan a two-stage development program whose first stage stresses the reliability necessary for MHD to get that all-important foothold in the utility market.

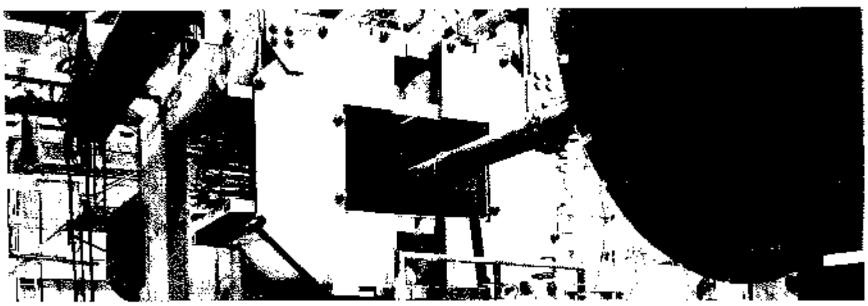
Thus first-generation MHD plants could be built with relatively modest efficiencies of about 38–39%. These efficiencies would certainly not be the highest MHD is capable of, but they might be a sufficient incentive for some utilities to invest in first-generation

MHD Hardware in Place

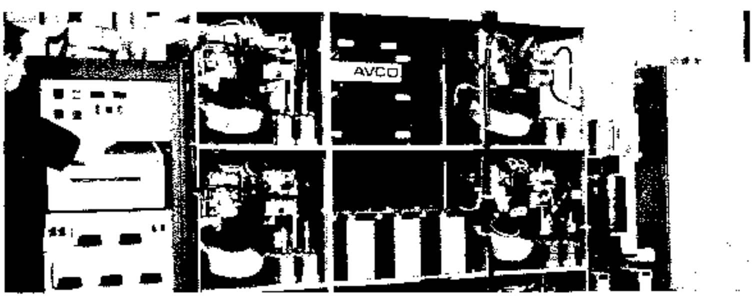
DOE's 40-50-MW (th) Component Development and Integration Facility in Butte, Montana; startup is scheduled for late 1980.
Photo courtesy MERDI.



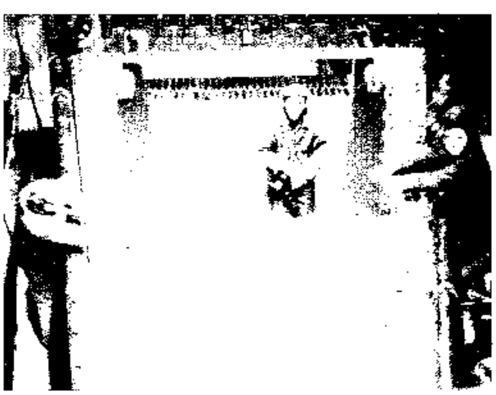
Iron-core magnet at CDIF; a superconducting magnet will be installed later.
Photo courtesy MERDI.



The 250-kW inverter developed by Avco Everett Research Laboratory, Inc., for EPRI.



Maintenance work on a channel of the USSR's U-25 MHD pilot facility near Moscow.



MHD plants. At the same time, such a plant might have reduced technical risks; thus demonstration of reliable operation might be more easily attained and utility confidence won. Second-generation MHD plants with high efficiencies could then evolve to compete with the advanced technologies beyond the year 2000.

Operation and system analyses contracted by EPRI have indicated a first-generation MHD plant design that incorporates more conventional technologies in key subsystems for improved reliability. One important part of such a design concerns the method used to help boost combustor temperatures to the 4600°F (2200°C) necessary for proper conductivity.

The researchers originally thought that heat from MHD exhaust gases could be used to preheat combustion air to temperatures of 2500–3000°F (1050–1500°C), thereby elevating plant efficiencies. However, the practicality of such a design seemed questionable after thorough EPRI analysis. An advanced MHD plant with such a direct-fired preheater might attain efficiencies approaching 50%. Nevertheless, the high-temperature, potassium- and slag-laden gas would wreak havoc on downstream heat exchangers, ducts, and valves.

Both the number of components involved in this design and the harsh environment would result in poor reliability. An MHD plant with a separately fired preheater was another possibility. The fuel for this preheater would come from a small coal gasification plant. This design could result in an MHD plant with 40–42% efficiencies; again, however, the number of components required would constitute a reliability risk.

Recent EPRI research has shown that oxygen enrichment of the combustion air might be the best approach for first-generation plants. Granted, oxygen enrichment would use less of the available exhaust heat than would the other approaches, would entail operation of an on-site oxygen plant, and would permit efficiencies of only 38–39%. However, oxygen production and oxygen enrichment are tried-and-true technologies that require little additional R&D to be pressed into service at an MHD plant. And recent work sponsored by NASA indicates that advanced MHD plants using oxygen enrichment might achieve efficiencies of up to 42%.

Similarly, a first-generation MHD plant might rely on conventional scrubbers instead of internal controls to clean the sulfur oxides from flue gases. Internal SO_x control, where potassium carbonate seed traps SO_x as potassium sulfate, would save utilities the price of a scrubber. However, chemical regeneration would be required to retrieve the potassium carbonate seed from the potassium sulfate and an applicable system has yet to be developed. Accordingly, EPRI research suggests standard scrubbers in first-generation MHD plants to eliminate the need for seed regeneration. Potassium sulfate, instead of potassium carbonate, would be used for seeding. The potassium sulfate seed recovered from the flow could then be recycled directly to the combustor.

Low slag carryover from the combustor to the rest of the system might be another desirable characteristic for a first-generation MHD plant. Although a thin layer of molten slag can reduce heat loss to the walls of the channel and may even protect channel electrodes from erosion to some degree, cleaner combustion gases would reduce wear and tear on downstream components. A combustor that rejects about 90% of the coal ash as liquid slag might be used to improve reliability over a combustor that does not remove slag from MHD gases.

Unit sizes no larger than 500 MW (e) were also suggested to help first-generation plants along. Such smaller-scale units would probably be easier and less expensive to develop than larger units and could have better operating availability.

MHD outlook

These first-generation designs, however, will simply help put MHD in the race for a demonstration facility. To firmly establish MHD's niche in the utility grid, this demonstration facility will have to prove that the technology is economically competitive.

The economics of MHD are hard to quantify just now, according to Zygielbaum. There are too many variables and unknowns that still need to be dealt with. Generator electrode life must be brought up to a span of one year, with suitable reliability and cost. An MHD combustor must be developed that can attain the right temperature, pressure, slag removal, and other requirements under difficult electrical isolation conditions. Seed recovery and reprocessing need work. Even internal emission controls may not be good enough to meet future standards. For instance, MHD's high operating temperatures are expected to produce correspondingly high nitrogen oxide levels. Although internal combustion control can possibly bring these NO_x emissions down to today's EPA standards, additional controls may have to be developed for the tighter standards projected for the mid-1980s. Once discrete hardware systems and overall plant configurations for MHD have been more accurately established, more reliable cost estimates for MHD can be attempted.

Beyond this coal-fired MHD development program, MHD technology has a longer-term potential. Because MHD can be used to stretch the efficiencies of any high-temperature process, this new technology may well reappear in conjunction with such twenty-first-century technologies as fusion reactors and extremely high-temperature nuclear reactors. The high temperatures these heat sources are expected to generate will make it advantageous to couple them with high-temperature power-generating equipment, and MHD may turn out to be an ideal complement. ■

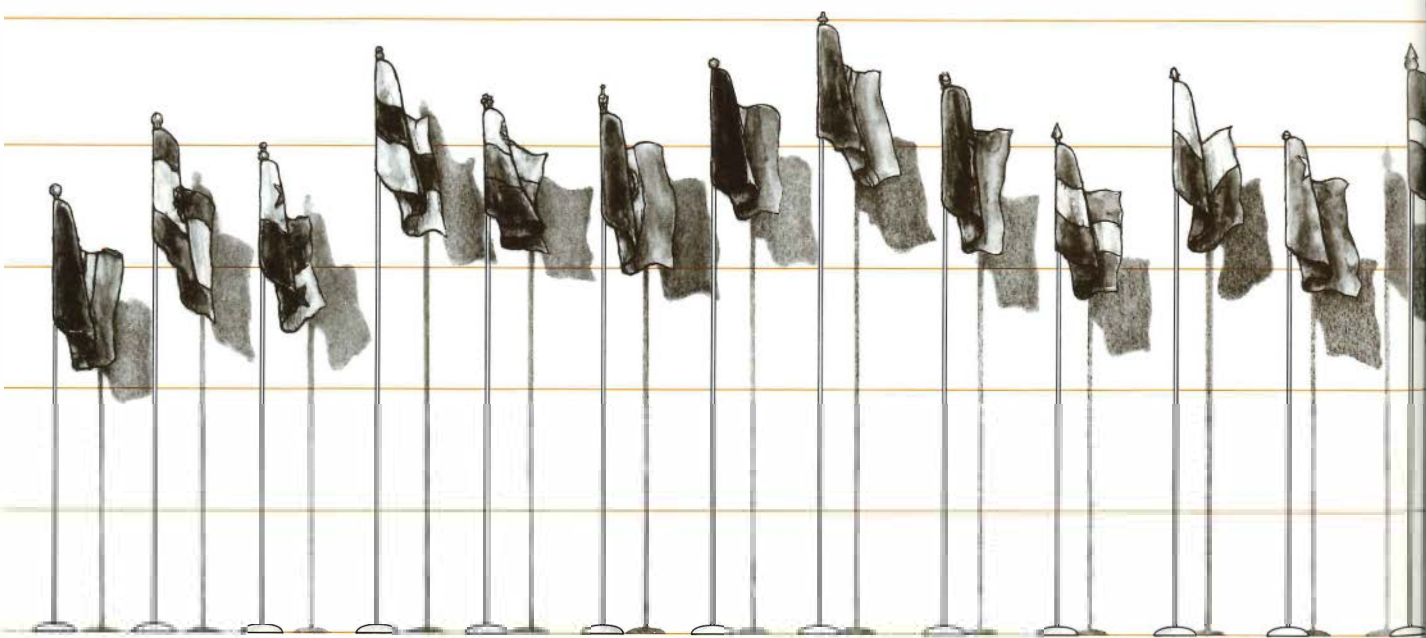
When we think of advanced societies, we picture skyscrapers, power plants, factories, and a vibrant economy that produces myriad goods and services for the benefit of its citizens. The image is one of a society that is advanced not only in terms of industry and commerce but also in the social benefits it can offer: opportunities for personal wealth, health, education, leisure, freedom, and satisfaction. Lately, we have tended to include energy in this picture because energy helps to provide more goods and services and, directly and indirectly, social benefits. The question for the future is whether limiting energy will alter the well-being of a society.

Up to now, the generally accepted indicator of national economic wealth, gross national product (GNP), has served to measure the so-called well-being of a society. But there has been a growing dissatisfaction with such national accounting measures as GNP because they do not and cannot fully reflect prevailing social and environmental conditions.

GNP counts the number and value of goods and services—food, clothing, medicine, for example. But it does not account for pollution costs or the disadvantages of urban living, such as commuting to work along crowded roads. Correspondingly, GNP does not include such amenities as parks or the increased number of leisure hours. Thus, there are negative and positive values not included in GNP. What is desired is a measure that incorporates these values to quantify the quality of life (QOL).

In a sense, QOL is a new name for an old concept. It is a subjective term for the well-being of people that takes into account the environment in which they live. For an individual, QOL expresses a set of economic and noneconomic factors that when taken together, make the individual happy or satisfied. But human wants rarely stand still or reach a state of complete satisfaction. As one want is satisfied, another crops up to take its place. As a result of this fundamental

The quality of life may or may not keep improving along with a continued increase in per capita GNP. But gre



Quality of Life: An Inte

human trait, the concept of QOL varies from person to person and from place to place.

Measures other than GNP are needed to describe life quality, aspirations, goals, and satisfactions. Various branches of the federal government have recognized this need for a more adequate expression of human living conditions and impact of surroundings and have begun to delineate approaches such as social accounting and social indicators. The United Nations and the Organization for Economic Cooperation and Development have initiated similar investigations, realizing the absolute necessity of measures other than economic to determine real development in the Third World.

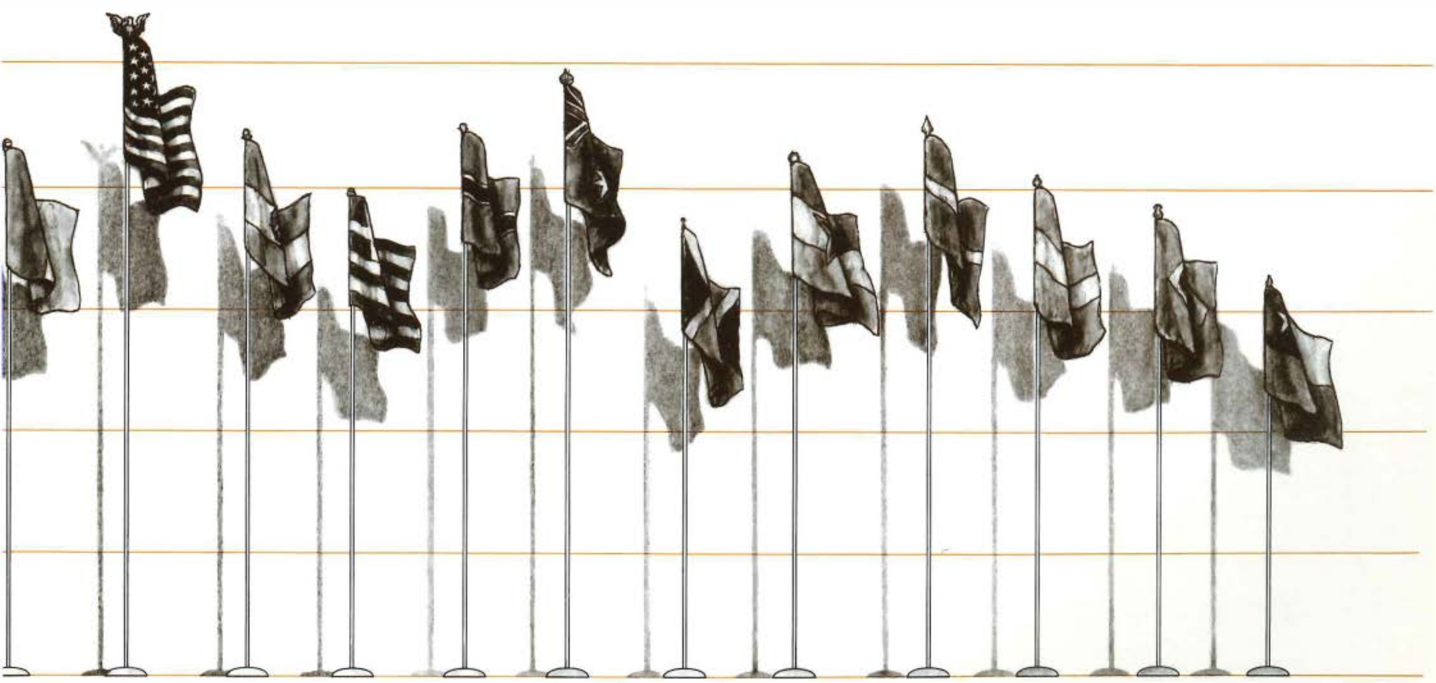
If QOL could be conveniently measured, it would be possible to examine the relationship of energy to QOL. But the task is not an easy one. As pointed out by Raymond Bauer in a study of social indicators, some social statistics are missing or inadequate, and there is still no accepted method of selecting statistics with which to measure QOL. In international QOL comparisons, each society may have its own QOL goals and particular measures. Despite these difficulties, statistics do exist from which QOL status may be inferred, for example, measures of individual and societal wealth, health, or education.

With such measures available, we can ask the following questions. Are energy production and consumption vital to maintain our quality of life? If electric power production and electricity consumption are reduced, how will QOL be affected? If energy production and consumption are accelerated, will the QOL improve? How important is GNP per capita or energy consumption per capita in determining a society's overall QOL? Is one more important than the other?

Measuring QOL

Seeking a way to answer these questions, Claude F. Anderson, senior economist at EPRI, and Ben-Chieh Liu, principal econ-

nergy consumption and a better life do seem to go hand in hand, according to this study.



national Comparison

Energy, GNP, and the Quality of Life

INPUT

To help measure the quality of life in 50 countries, selected variables were divided into 5 categories and 12 subcategories. The weights assigned to the 5 main categories were derived from opinion surveys to find out the most significant concerns of people in four countries—United States, West Germany, Yugoslavia, and Poland. The subcategories were weighted according to estimates of their importance developed by Anderson and Liu. The plus and minus signs for variables indicate positive and negative effects of those variables on QOL.

QUALITY OF LIFE MODEL
Weighted Categories and Subcategories of Variables

Social (24.0)

Satisfaction of basic human needs: standard of living (1.2)

- \+ Index of food consumption per capita
- \+ Steel consumption per capita (kg)
- \+ Cotton yarn production per capita (ton)
- \+ Motor vehicles in use per 1000 population
- \+ Rail traffic, passenger kilometers per capita
- − Relative living-cost index

Informed citizenry with modern conveniences (0.78)

- \+ Television sets per 1000 population
- \+ Radio sets per 1000 population
- \+ Telephone sets per 1000 population
- \+ Newspaper circulation, copies per 1000 population
- \+ Pieces of domestic mail sent per 1000 population

Welfare and independent status (1.02)

- \+ Ratings of social security and insurance system
- \+ Average annual rate of growth in private consumption, 1970-1976
- \+ Ratio of economically active to economically inactive population
- − Adult illiteracy rate
- − Total fertility rate from desired fertility rate, absolute values

Economic (20.0)

Individual economic well-being: flow and stock measures (1.27)

- \+ GNP per capita (1976 $US), adjusted by cost-of-living index
- \+ Motor vehicles per 1000 population
- \+ Television sets per 1000 population
- − Average annual rate of inflation, 1970-1976

Economics, structure and productivity (0.73)

- \+ Cement production per 1000 economically active population (ton)
- \+ Cotton yarn production per 1000 economically active population (ton)
- \+ Acres of arable land per 1000 agricultural workers
- \+ Change in agricultural productivity per worker
- \+ Percentage of labor force employed by manufacturing industries
- − Ratio of armed persons to economically active population
- \+ Average annual growth rate of gross domestic investment, 1970-1976

Health and education (22.0)

Individual health status (1.32)

- \+ Life expectancy at birth, 1975
- − Infant mortality rate per 1000, 1975
- − Crude death rate per 1000 population, 1975
- \+ Per capita food consumption index, 1974

Community health conditions (0.86)

- − Population (1000) per physician, 1974
- − Population (1000) per nurse, 1974
- \+ Percentage of population with access to safe (or piped) water, 1975
- − Population per hospital bed

Educational attainment (0.82)

- − Adult illiteracy rate, 1974
- \+ Numbers enrolled as percentage of age group, 1975: in primary school; in secondary school
- \+ Numbers enrolled as percentage of age group 20-24 in higher education, 1975
- \+ Percentage of GNP spent on education, 1975

Environmental (15.0)

Natural environment and utilization (1.16)

- \+ Arable land, acres per capita
- − Average annual rate of total population growth, 1970-1975
- − Rate of urbanization and urban growth, 1970-1975

Man-made environmental problems (0.84)

- − Population density (population per km^2)
- − Number of motor vehicles in use per km^2
- − Percentage of labor force employed by manufacturing industries
- − Percentage of population in urban areas

National vitality and security (19.0)

National carrying capacity (1.16)

Human capital

- \+ Percentage of economically active population
- \+ Average annual rate of labor force growth, 1970-1975

National and capital resources

- \+ Acres of available land per capita
- \+ Average annual growth rate of gross domestic investment, 1970-1976

Technology

- \+ Percentage of exports in manufactured products
- \+ Steel consumption per capita

Market stability and price mechanism

- − Index of relative living cost
- − Average annual rate of inflation

International security and independence (1.0)

Economic and financial considerations

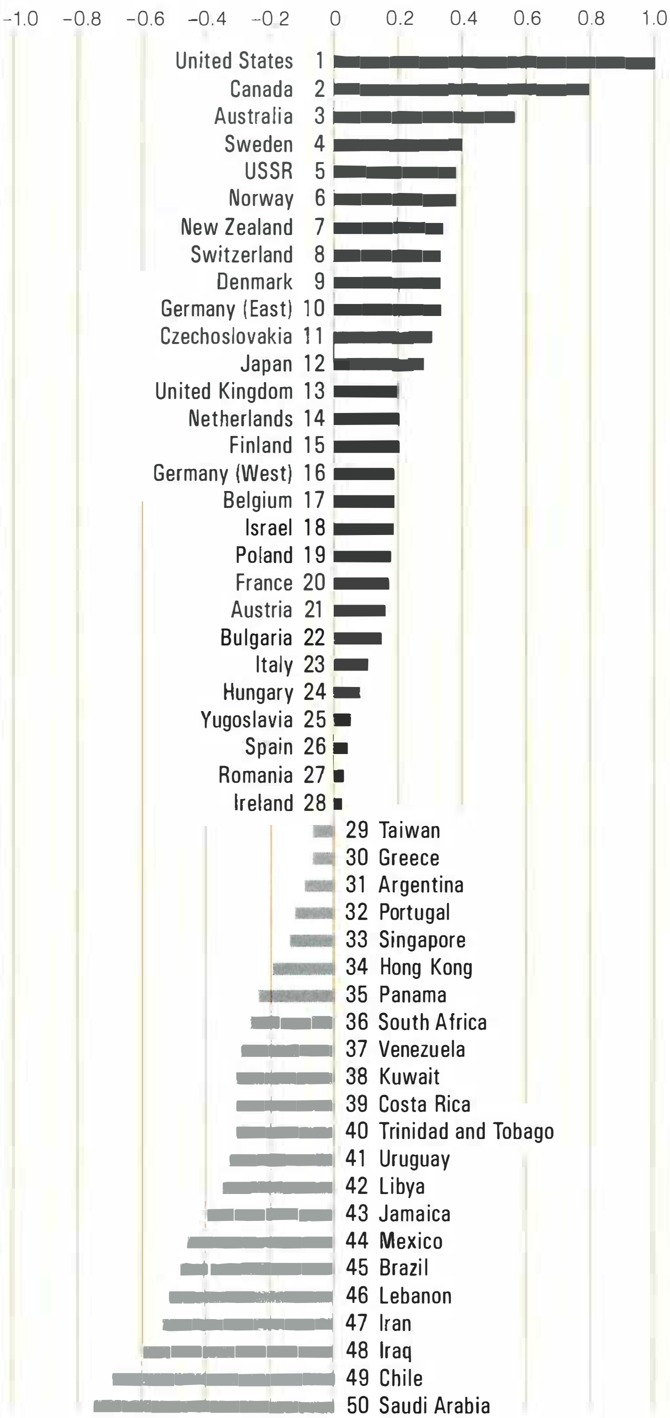
- \+ Export and import ratio
- \+ Percentage of labor force employed by manufacturing industries
- \+ Gross international resources in months of import coverage
- − Energy independence, percentage of imports for fuel
- − Percentage share of imports for food
- − Index of resource imbalance (gross domestic savings less gross domestic investment)
- − Dependence on foreign trade

Military power

- \+ Armed forces per 1000 population
- \+ Military expenditures as percentage of GNP
- \+ Military expenditures per capita adjusted by cost-of-living index

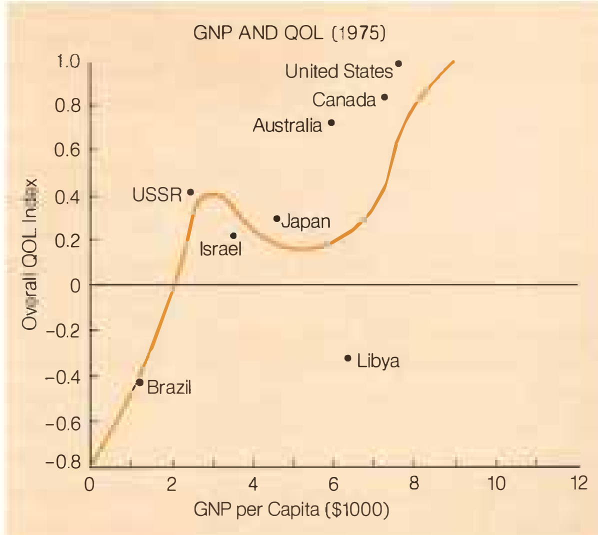
OUTCOME

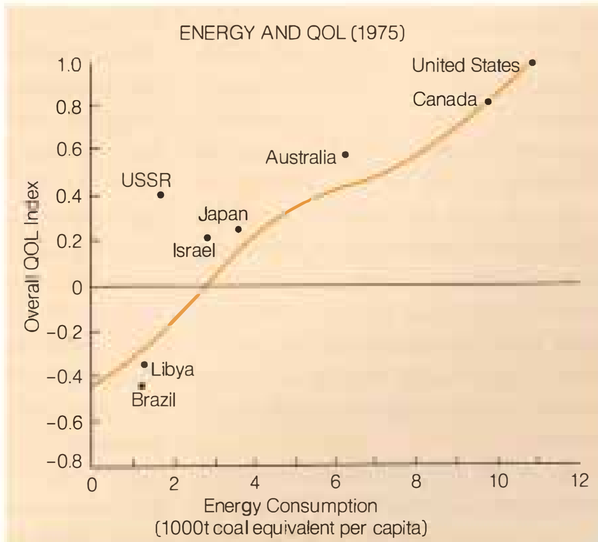
Each country's overall QOL value is expressed as a deviation (from −1.0 to +1.0) from the average value (0) of 50 countries.



RELATIONSHIP OF QOL TO GNP AND TO ENERGY CONSUMPTION

The data points represent the 50 countries included in this study. Initially, QOL is seen to improve as GNP per capita rises. At a certain point, however, QOL value tends to level off, and at even higher levels of GNP per capita, it may decline. The results of the study show a direct and positive relationship between per capita energy consumption and QOL; that is, they suggest a higher QOL value accompanies higher levels of energy consumption.





omist at the Midwest Research Institute, have developed a social indicator model to analyze the relationship between energy, GNP, and the QOL.

The QOL model is based primarily on criteria originally developed by President Eisenhower's Commission on National Goals and on results of global surveys of individual concerns conducted by Hadley Cantril, who is now president of the National Council of Publicity Polls, Washington, D.C. Based on these foundations, Anderson and Liu define QOL as being an output of two combined input factors, physical and spiritual. The physical input consists of quantifiable goods, services, material wealth, and so on, while the spiritual input, which is not quantified in this study, includes psychological, sociological, and anthropological factors, such as community cooperation, equality, freedom, and national prestige.

In reality, the relationship between output and input factors is enormously complex. To simplify this model, it is necessary to ignore those spiritual variables reflecting the cultural, religious, institutional, and political systems that organize individuals. As Liu explains, "What we call spiritual inputs are simply not quantifiable, and we have put aside their effects on the quality of life and concentrated only on those more definable variables that are available to measurement." Thus, only the physical inputs are employed in the model to measure QOL output. This physical input is described by some 50 variables in five major categories: social, economic, health and education, environment, and national vitality and security. (National vitality refers to natural and human resources, and security relates to dependence on foreign resources, among other variables.)

Each of the five categories and their subcategories is weighted. The importance of giving weights to these QOL categories is explained by Anderson. "People and societies don't value each of the categories equally, and it's important to make an adjustment for this fact." Thus, the five categories and their weights are derived from an opinion survey on the most significant individual concerns as reported by Cantril for four nations (United States, West Germany, Yugoslavia, and Poland). The major-category weights adopted are the average weights expressed by the people in these four countries.

Liu describes the method they used for the subcategories and their weights. "Whenever possible, we used externally generated weights, as we wanted to preclude any possibility of personal bias. But in some instances, we were forced to make our own estimates for the subcategories."

Fifty countries with a 1976 GNP per capita exceeding $1000 were selected for QOL comparison, of which 37 were listed by the United Nations as developed, and 13 as emerging.

Outcome of QOL study

The rankings of countries in the five major categories provide some insight into those areas where countries have excelled or have failed to develop. In the social category, Canada ranked first, the United States second, and Japan third. Iraq and Saudi Arabia ranked lowest on this scale.

Based on the available economic indicators representing individual economic well-being, societal economic structure, and national productivity, the United States ranked above Canada, which appeared second in the economic category. Ranking closely with Canada are Australia, Sweden, Switzerland, Norway, and West Germany. Chile was found to have the lowest economic QOL index, while the USSR placed twenty-first.

In the area of health and education indicators, the United States and Canada again occupy the first two places, while the Netherlands, New Zealand, Denmark, USSR, Norway, Israel, Australia, Sweden, and Japan follow closely. Considerably below the average are Brazil, Mexico, Lebanon, South Africa, Saudi Arabia, Iran, and Iraq.

Australia, Argentina, and the United States scored the highest in the environmental category primarily because they have either large expanses of arable land or relatively even geographic distribution of population. Singapore, Kuwait, and Hong Kong fell at the end of the list.

The national vitality and security category is described by various elements that indicate human, natural, and capital resources, technological growth, the degree of market stability, and the degree of military power and economic independence, including imports of fuel and food. Here, Israel, the USSR, Taiwan, Romania, and the United States rank as the top five countries.

In the overall QOL measure—the composite measure arrived at by combining the results from the five major categories—the United States ranks first by a wide margin. Canada is second, followed by Australia, Sweden, and the USSR. Japan, generally considered an economic giant, ranks twelfth in the overall QOL series.

In some cases, comparing the overall QOL index with a country's GNP per capita reveals a significant difference. For example, Kuwait would rank first if GNP per capita was the measure of its well-being; in the overall QOL index, however, it is thirty-eighth. Switzerland ranks second in GNP per capita, but eighth in overall QOL. Caution in interpreting these results is stressed by Anderson. "Let me emphasize that the QOL rankings depend on the weights we adopted. Any other weighting scheme would change our indicators and result in somewhat different rankings."

Energy, GNP, and QOL

From an international standpoint, how significant are energy production and consumption relative to QOL measures? How closely can GNP per capita represent and explain the worldwide variations in QOL? Anderson and Liu provide some insight into these questions. Their study shows a significant relationship between per capita energy production and consumption and the composite QOL indexes.

There are other researchers who have examined the relationship between energy, income, and some set of social indicators serving as measures of QOL. Work in this area includes the international study conducted in 1971 by Allan Mazur and Eugene Rosa, who conclude that reduced energy consumption will have little long-term effect on QOL. At an EPRI workshop on the environmental and social impacts of an electricity shortage, Mazur stated, "Our national energy activity is in large part identical with our national economic activity, and to that extent, a cutback in energy consumption is synonymous with a cutback in economic indicators; but it is not clear that this would necessarily have a long-term negative effect on the society."

Laura Nader and Stephen Beckerman conclude in a recent article that there is no evidence that shows increasing energy use will increase the quality of American life, and further, they maintain that contemporary rationales used to justify an increase in the production of energy are not viable in terms of QOL issues and patterns of living.

In another study, James O'Toole foresees few severe social or economic dislocations in the United States in the near term (up to 1990) as a result of energy scarcity.

On the other hand, a Brookhaven National Laboratory study prepared for the United States Agency for International Development (USAID) concludes that improvements in living standards for emerging nations are likely to require substantial increases in annual energy consumption per capita. Further, in a different study, Clark Abt asserts that "the degree and scope of lifestyle changes will be a function of the amount and rate of increase of energy shortages, or the suddenness thereof."

In his recent book W. Jackson Davis, too, argues that dwindling supplies of energy will alter our lives for the worse.

Anderson and Liu present their findings in two scatter plots that illustrate the relationship between GNP per capita and QOL and energy consumption per capita and QOL. QOL has a propensity to improve with higher GNP per capita, but tends to level off and possibly decline at even higher levels of GNP per capita. As Anderson explains it, "This result suggests that a country's QOL may initially increase or vary with the level of income, but beyond a certain level, income will not necessarily enrich a country's QOL proportionally."

In contrast, there appears to be a direct and positive relationship between per capita energy consumption and QOL. That is, the statistical results suggest that higher levels of QOL go along with higher levels of energy consumption. In a variety of QOL models that Anderson and Liu tested, they found that energy variables not only seem to have a higher predictive value on QOL than do income variables but are also more stable than income variables. This means that energy plays an important role in a country's objective to improve its QOL.

Additionally, electricity production per capita, which was employed in the model, was found to be strongly related to QOL indexes; again, more so than income. As Liu puts it, "Electricity production has the same relationship with QOL as total energy consumption." To further explore these issues, a U.S. state-by-state study has been initiated to examine specifically the relationship between electricity production and consumption and QOL.

In discussing the international study, Anderson emphasizes that the conclusions are preliminary and tentative. "At best," he explains, "the international analysis provides an opening wedge for further study. What we have provided is some evidence that QOL is not a simple linear function of material wealth and that the old formula 'the more, the better' may not be true. In this investigation we have found that energy and QOL are more closely linked than material wealth and QOL." ■

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National Academy of Sciences: Entering the Energy Debate

Through its unique system of volunteer committees and boards, the National Academy of Sciences (NAS) brings the best thinking of the scientific community to problems of science and technology. Increasingly, these problems have revolved around energy issues.

Across Constitution Avenue from the Lincoln Memorial in Washington, D.C., is the prestigious scientific academy that Lincoln helped to create in 1863 and that today has become a major voice in the national energy debate. Most recently, NAS drew widespread public attention with the publication of its 783-page report *Energy in Transition: 1985–2010,* the result of a four-year effort involving some 300 people working under the direction of the academy's Committee on Nuclear and Alternative Energy Sources (CONAES). In recent years NAS has also been in the forefront of discussions on such issues as the health effects of low-level radiation, the climatic effects of carbon dioxide (CO_2) buildup, nuclear waste management, and synthetic fuels.

Philip Handler, NAS president, is the first to admit that the academy is not generally well known to the public, and in many cases misconceptions exist about its role and objectives. A common misconception is that NAS is a government agency or, as Handler puts it, "some club of fuddy-duddies." He notes, "People don't understand that we're a private body created by the government, and that we're completely independent. We are free to be servant and critic of the government, and we do both. We bring to our role no political ideology of any color, and we do our best to see to it that scientific truth is our only yardstick."

The Academy Complex

NAS was established by an act of Congress signed by President Abraham Lincoln on March 3, 1863. The charter provided that the academy be self-governing and that it act as an independent source of counsel to the government on matters of science and technology. According to its charter, it may not accept a fee for such services.

From 50 charter members in 1863 NAS has grown to 1281 distinguished scholars in scientific and engineering research today. Election to the academy is considered a high honor in the scientific community, and membership is less than 0.5% of American scientists.

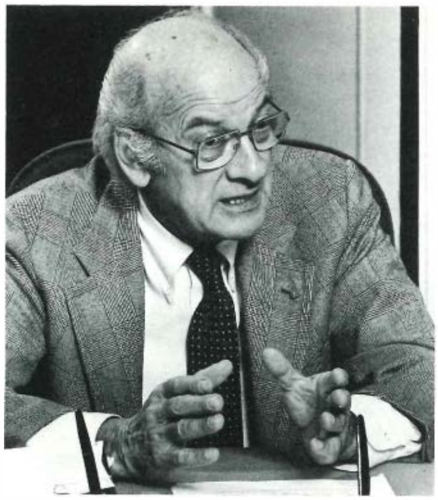
Although NAS is itself a single entity, when staffers of the organization talk about the academy they are usually referring to a group of four organizations under one roof that together make up the academy complex. In addition to NAS, this includes the National Academy of Engineering (NAE), the Institute of Medicine (IOM), and the National Research Council (NRC). "NAS is the mother organization, or the corporate entity," explains Barbara Jorgenson, associate director of the academy's Office of Information. She notes that NAE, NRC, and IOM are "ribs" formed from NAS almost a century later.

NAE was created in December 1964 as a parallel organization of distinguished engineers. It is autonomous in administration and selection of members, but with NAS shares the responsibility for advising the federal government. As of July 1, 1979, membership numbered 950, including Floyd Culler, EPRI president; Chauncey Starr, vice chairman; and Milton Levenson, director, Nuclear Power Division.

IOM was chartered by NAS in the summer of 1970 to deal with problems associated with the delivery of adequate health services to all sectors of society. As of January 1, 1979, membership stood at 357.

NAS, NAE, and IOM join forces, explains Jorgenson, in the National Research Council, which was established by NAS in 1916 as the operating arm of the academy complex. In the early years of NAS, academy members were able to handle most of the requests from government agencies for studies and information. They would organize themselves into committees to perform this service. With the outbreak of World War I, however, interest rose in problems of science and technology, and the academy found its membership insufficient to respond to all government requests. In 1916, therefore, NRC was established to extend and expand the academy's role by creation and management of committees, panels, and boards of volunteer scientists to carry out the studies of the academy. At the request of President Woodrow Wilson in 1918, NRC was made a permanent part of the academy.

NRC is the entity responsible for putting together the volunteer committees that are the heart of the academy's efforts. The 1100-person staff of the



Handler

academy complex works for NRC. Most professional staff members have technical backgrounds but are oriented toward policy work. Most reports emanating from the academy complex, with the exception of those from IOM, bear the NRC name. The entire academy complex operates on an annual budget of $60 million.

Philip Handler, by virtue of his job as president of NAS, also serves as chairman of NRC. Courtland Perkins, NAE president, is vice chairman of NRC. Both men sit on the 14-member NRC Governing Board, which acts as a board of directors and approves all programs and projects.

Structured for Quality Control

NRC operates by what Handler terms a time-tested set of mechanisms. Its structure is elaborate and gives to the academy a uniqueness that sets it apart from other organizations in Washington, D.C., that also render advice to government agencies and private foundations.

"There is nothing like it anywhere else in the world," notes Handler. "First of all, the academy as a body is the 1200-plus most distinguished scientists in the United States, and if what we have to say is credible, the credibility rests on the distinction and prestige of that body of members. Second, compared with most other organizations, our resource is the whole scientific community of the United States. Third, the machinery by which we do our work—the NRC—is a very carefully constructed hierarchical arrangement that ensures quality control."

NRC is divided into eight working units called assemblies and commissions. Assemblies examine fundamental scientific questions that are within the scope of a single set of disciplines. They are the Assembly of Behavioral and Social Sciences, of Engineering, of Life Sciences, and of Mathematical and Physical Sciences. Commissions address large national issues from the standpoint of a variety of scientific disciplines. They are the Commission on Human Resources, on International Relations, on Natural Resources, and on Sociotechnical Systems.

Working under these assemblies and commissions are boards and some 800 committees. Boards are formed to provide continuing advice to an agency or agencies in a particular program or issue area. For instance, there is the Environmental Studies Board under the Commission on Natural Resources. Committees, on the other hand, are created on an ad hoc basis to address a particular problem or conduct a specific study.

Committees are composed of scientists who volunteer their time and expertise for the duration of a particular study. Although the NRC staff may provide assistance to the committee in carrying out a study, the volunteer scientists themselves direct the work and are responsible for the conclusion of the report. To serve on a committee, a scientist need not be a member of either NAS or NAE. "This is the aspect that makes the academy different from almost any other group," notes Jorgenson. "It is NRC's great strength that it is able to marshal and mobilize the scientific community at large, both nationally and internationally."

Rarely, Handler explains, does anyone say "no, thank you" to an invitation to serve on an NRC committee or board. "They consider it at least a modest honor," he admits. "In the system at any given moment, there are something like 9000 people serving on somewhere between 750 and 800 different committees. The turnover rate is such that we make about 3000 new appointments to committees a year."

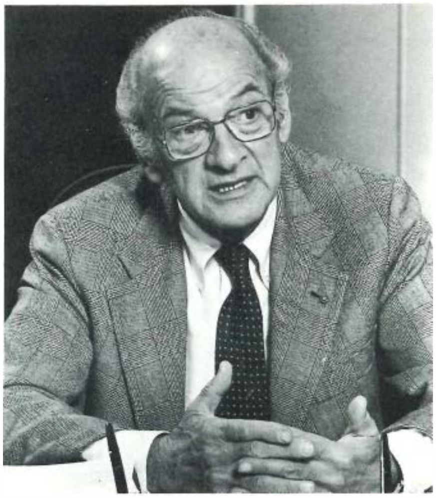
Handler sees this system as a particular strength in that it allows the academy to find the most competent people in any given issue area. "We don't have to say that we have 50 people here, and they're competent to do everything," he explains. "When a committee finishes its job, we disassemble it and look around for a new one. We don't have to find work for it."

This system also gives the advantage of collegiality. "We never have a study done by a single individual," he says. "That's not our style. We do almost everything, however trivial, by committee."

Last year, according to Handler, some 320 reports were completed, almost a report a day. They varied in size from a 10-page typed statement going to an agency to the 783-page CONAES report. Approximately 80 reports a year are published and sold.

Handler believes that NRC reports derive much of their credibility from the elaborate structure by which projects are chosen, a committee is selected, the work is conducted, and the final report is reviewed. This structure gives the reports several levels of what he calls quality control.

The first level of quality control lies in the NRC Governing Board and in the as-



semblies and commissions. These bodies decide the studies the academy will or will not undertake. They may also refine the original question. Although the academy's charter provides that it render advice to federal agencies, the academy exercises the option to choose which requests it will accept. Most of the academy's work is done in response to federal agency requests; however, according to Jorgenson, some 20% of it originates in requests from private foundations. At times the academy itself may initiate studies. For example, last fall the Governing Board convened a conference on synthetic fuels to explore areas in which NRC might make a future contribution to research on this technology.

The second level of quality control comes in the system for appointing committees, notes Handler. The primary source of recommendations for committee members is the assemblies and commissions, but the NRC staff also gets involved in this process. "We have on file names and notes about the competence of thousands of people," says Handler. A primary list of recommended committee members and a list of alternates are drawn up and sent to Handler's office, where a group of three professionals check on the recommendations. They make sure that the committee has all the kinds of competence it should; that it has the correct distribution in terms of disciplines, geography, and points of view; that it is balanced; and that the qualifications of the individuals are confirmed. The final recommendations are sent to Handler, who in turn appoints the committee chairperson.

Because the NRC seeks to appoint committees that will produce credible reports, it has established another level of quality control relating to conflict-of-interest. "Long before the government was concerned with conflict-of-interest in any way, we built a set of procedures for dealing with this problem," explains Handler. All committee members are required to complete a form, On Potential Sources of Bias, which asks the member where his or her income comes from, whether he or she has made any public statements relevant to the substance of the work of the committee, and the like.

"Then, at the first meeting of the committee, the committee members go around the table and tell each other what those forms say, so they all know who the other players are," explains Handler.

On the average, studies last from one to two years. During this time the committee usually meets once a month for two or three days at a time. After the committee completes its study and prepares a draft report, the fourth level of quality control comes in the report review system. The report goes through a review process set up within an assembly or commission. Then, in most cases, the report goes to the NRC Report Review Committee, which is chaired by the vice president of NAS and has 15 members, all of whom are members of NAS, NAE, or IOM. The Report Review Committee surveys the membership of the three academies and appoints an entirely different team to review the report.

The review team eventually sends

back to the committee a statement synthesized from those statements on the report made by each reviewer. The reviewers are identified in the final statement only by code letters—reviewer A, or B, for example. "It works better this way," says Handler. "If they know who each other is, they might be a little gentler in the process. This is a no-holds-barred game."

The report review team must be satisfied with the final report for it to be released. "It may become a very acrimonious debate," smiles Handler. "The committees have pride of authorship and they mean what they said." Sometimes a report goes back and forth a couple of times between the review team and the committee. If they continue to disagree, Handler is the final referee. No report may go out of the council unless he has initialed it.

The average report takes from four to six weeks to go through the review process. The CONAES report had 22 reviewers, who sent back to the committee what Handler terms "a small telephone book of comments." It took days and days for the committee to respond to the review.

"It is this elaborate system that gives our reports credibility," says Handler. "The fact that volunteers serve on all those committees and they're not paid for their services and then they sit still for the review process is really quite remarkable."

Energy Studies Expanding

Although the academy is involved in a broad range of science and technology issues, energy has occupied an increasingly large portion of its effort over the last several years. Don Shapiro, who coordinates energy studies for NRC, remarks that a recent survey of efforts under way in the energy area turned up an impressively large and broad selection.

"Absolutely, there has been a marked increase in the number of energy studies we have undertaken," affirms Jorgenson, who has been with the academy seven years. "And there's also been a change in the kind of problems we're addressing. In just this short time I've watched the academy grow toward broader policy areas. For example, rather than just looking at how much oil exists in a certain field, we are moving more toward analyzing options."

When asked about energy, Handler immediately points to the CONAES study. "After all, the CONAES report was the largest, most violent, most difficult, most frustrating exercise we ever undertook," he says. "And it probably took up more of my personal time than any other single study." He adds that the study was frustrating in yet another way—it held up many of the other energy studies NRC wants to conduct.

"We have a whole series of other things we intend to do about energy problems, but while CONAES was in progress, we just didn't feel free to do other things. For one reason," he explains, "CONAES occupied the time of 300 of the people in the United States who are the most knowledgeable about energy. And because we were using them for CONAES, we couldn't use them for something else. We've got lots of things we'd like to turn to next. Obviously, energy is going to be on the front burner for years and years to come."

For example, there is legislation before Congress directing NRC to keep an eye on the problem of CO_2 buildup in the atmosphere and its possible deleterious effects on climate. An NRC committee first flagged attention to the CO_2 issue and its possible greenhouse, or warming, effect in a report issued in 1977. "The climate effects of carbon dioxide release may be the primary limiting factor on energy production from fossil fuels over the next few centuries," said the committee in its report *Energy and Climate.* Although the CO_2 issue was not new, "that was the study that really brought the issue to the consciousness of policy makers in Washington," says Shapiro. "It opened people's eyes, and since that time there has been a tremendous growth of activity." The committee recommended that the problem be given "serious, prompt consideration by concerned national and international organizations and agencies."

NRC's Committee on the Biological Effects of Ionizing Radiation (BEIR) has recently revised a report issued last summer on the effects of low-level ionizing radiation on human populations. That document, in turn, updates a 1972 report prepared by an earlier BEIR committee that is widely used as a reference for standards in regulating levels of human exposure to ionizing radiation. "It's the bible in the field," notes Jorgenson.

NRC's Committee on Radioactive Waste Management will have its hands full for years and years, according to Handler. That group keeps surveillance over activities in this area of concern and "is more or less the last word in the field," he comments. NRC will also continue its studies on coal mining and burning technology, advanced energy storage systems, R&D needs in refining coal and oil shale liquids, and future energy alternatives.

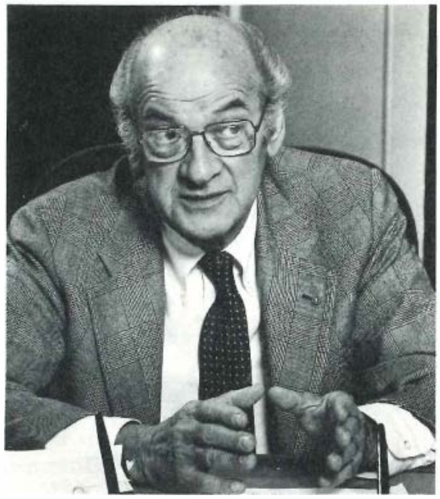
The CONAES Contribution

The CONAES study, by Handler's own estimate, has been NRC's most significant contribution to the national energy debate. What does he hope that the public will take away from reading it? Two main points: there really is an energy problem; the solutions are not easy. "I think this study makes it clear that compared with much of the American past, we can't just luck out on this one," he says. "We'll have to think our way out."

He also believes that the thoughtful reader will derive a sense of the immensity of the American energy production and consumption system. "It's very difficult to get your head wrapped around how large it is and until you do," the NAS president says earnestly, "it's easy to accept glib solutions; to think you have an easy solar energy solution, or a geothermal answer, or an idea that we'll build windmills. And that attitude has been worsened a bit by those of my friends who invented the word *quad* (quadrillion Btu). By compressing the scale into a few small numbers (we currently use 75 quads a year), they don't give the impression of immensity. What you have to get your head around is what 30 million barrels a day of petroleum really means or what a 100 million tons of coal is really like. And until you do, you can't learn to deal with these questions realistically."

Handler says that the American people must discover that they have some very political decisions to make. "It is true that we can get along on much less energy per capita than we do," he admits. "It would be a much different lifestyle, and it will be slow getting there from where we are, but we can do it. What we have to decide is, do we want to live that way or don't we?" He also concedes that we can continue to live the way we do and still have the ratio of energy to GNP fall steadily to two-thirds or one-half of what it is now if we do it carefully over years and if we provide "motivating mechanisms—deliberate political actions—to make it happen." Such mechanisms include price rises that may not be natural to the market and performance standards for which there is no motivation other than the desire to have energy use per person go down.

Handler hopes CONAES readers will come away with the understanding that



although conservation may be the one most important action we can take to address the nation's energy situation, it alone will not be able to solve critical problems. "They must also understand what we mean by conservation," he states. "It is something more than turning out the lights or driving at 55 mph. It's very complicated and although we can make modest, real improvements today, most of it is a very slow process." Explaining that it takes 10 years to turn over the automobile fleet, 30 to 35 years to turn over the entire industrial physical plant, and 50 to 60 years to turn over the nation's housing, Handler insists that "to try to do it any more rapidly than that is to take foolish, uneconomic measures. The effects of conservation will be real, but slow."

Actually, notes Handler, the CONAES report is really many studies in one. "It was the first study to point out that the time scale to find uranium is limited, and therefore the number of light water reactors that we can fuel between now and the year 2000 is also limited. And that isn't such a problem for the United States as a whole as it is for the administration, which has told our trading partners and allies that we hope they will forgo the breeder and in exchange we will make uranium available to them. That's a promise we may not be able to keep."

Handler also remarks that the study found nuclear power safer than coal for electricity production on a day-to-day basis, but that there is some statistical chance that one day there may be a large nuclear accident. "And whether you prefer day-by-day deaths or a single accident with hundreds—perhaps thousands of deaths—is a political decision."

He says the committee concluded that the radioactive waste problem is real but manageable, and that the breeder option should be kept open so that if the nation decides by 1990 or 1995 that breeders are needed, they can be built.

Although the CONAES report has been applauded by many, it has been criticized by some for not laying out clear recommendations for policy action. Such was not the purpose of the committee, explains Handler in his letter transmitting the report to DOE. "It is the thorough analysis of almost all aspects of our energy circumstances and the detailed consideration of the possible alternatives available to the nation that constitute the principal contribution of this report. The major decisions yet to be taken must occur in the political arena and in the marketplace."

This theme is central to the academy's role both today and in the future. "We shy away from those decisions we think are intrinsically political decisions because that is not our role," says Handler. However, NAS will continue to act through its unique system of volunteer committees to shed light on these decisions by providing the best of scientific thinking, fact-finding, and analysis on problems of energy and on other science and technology issues for the future.

"The machinery's in good working order, and we'll go on doing our thing," says Handler. ■

Funds Committed to Gasification Project

Coal gasification–combined-cycle plants look promising for future baseload operation. EPRI's $50 million contribution to one such system represents the Institute's largest single commitment of project funds.

A $50 million contribution by EPRI for the development of the nation's first commercial-size coal gasification power plant was announced in February.

The $300 million project was initiated in 1978 by Texaco, Inc., and Southern California Edison Co. (SCE). Each company committed $25 million to the effort. Bechtel Corp., also a $25 million participant, has been selected as the prime design and construction contractor. Negotiations are under way with several other organizations to complete the project funding.

The facility will be built at SCE's Cool Water Generating Station near Barstow in California's San Bernardino County. It will use the Texaco coal gasification process, in which coal is ground and slurried in water. The slurry is then fed into the gasifier. Synthetic gas is produced by partial oxidation of the coal feedstock.

Researchers expect to demonstrate the benefits of operating the 1000-t/d coal gasifier in conjunction with a combined-cycle power plant. In this type of operation, exhaust heat from a gas turbine is used to generate additional power by boiling water for a steam turbine, thus increasing overall plant efficiency. The process conserves fuel by using what would normally be waste heat.

The facility will be capable of producing about 100,000 kW/d of electricity—the equivalent of the electricity produced from approximately 3500 barrels of oil. Final engineering design has begun, and construction will start in 1981.

As EPRI Project Manager Thomas O'Shea explained, "Information gained from this research will establish the commercial basis for a new breed of coal power plants. These plants will be able to use various types of U.S. coal, operate efficiently and economically in an environmentally acceptable manner, and use less water than conventional coal plants."

O'Shea added, "Gas from coal is a clean-burning substitute for direct-fired raw coal used by electric utilities, and eventually it may be a substantial replacement for oil and natural gas. In fact, our studies indicate that the Texaco process is one of the most promising fossil fuel technologies for the power industry in the years ahead." ■

Coal Gasification Contract Signed

EPRI President Floyd Culler signs his name to a contract committing $50 million of EPRI funds to help develop the nation's first commercial-size coal gasification power plant. The contribution by EPRI represents the organization's largest single commitment of funds to a project. Looking on at a February press conference announcing EPRI's commitment are (left) James L. Dunlap, vice president, Alternate Energy Department, Texaco, Inc., and David J. Fogarty, senior vice president, Southern California Edison Co. Texaco, SCE, and Bechtel Corp. have already committed $25 million each to the effort.

Successful Tests on BGC–Lurgi Gasifier

Tests conducted for EPRI on the British Gas Corp.–Lurgi slagging gasifier show it has promise as a new and efficient alternative for producing electricity from coal. Researchers say recent tests indicate that this gasifier can more than satisfactorily meet the load management requirements of U.S. electric utilities.

These findings are based on three tests of five days each that were conducted on a 350-t/d coal gasifier at Westfield, Scotland. The tests are the result of a $2.6 million research agreement signed by EPRI and the London-based BGC in November 1978.

EPRI Project Manager John McDaniel described the test results as important because they mean the BGC–Lurgi gasifier may be an efficient alternative for power generation in the United States. McDaniel said the findings also indicate that the process may be an excellent candidate for combined-cycle operation.

EPRI studies have shown that integrated coal gasification plants using the combined cycle offer distinct environmental advantages and are economically competitive with conventional coal-fired plants that use flue gas scrubbers.

Environmentally acceptable uses of America's abundant coal resources become increasingly important as the country strives to decrease dependence on foreign sources of energy.

McDaniel said the recent tests of the BGC–Lurgi slagging gasifier demonstrated the following:

- Satisfactory load-following characteristics. This means the plant's throughput levels were able to be rapidly changed, upward and downward, without sacrificing stable operation.

- Excellent load downturn. This means the gasifier was able to operate at varying levels of output while retaining efficiency and stability.

- Satisfactory performance with different sizes and qualities of coal. Two of the three tests used a strong-caking, high-sulfur Pennsylvania coal containing up to 20% fines. The third used a weak-caking British coal, Rossington, which is similar in many characteristics to certain coals mined in Illinois.

A technical report on the test runs will be published by EPRI later this year.

The Lurgi process was originally developed and used in Germany during World War II. BGC has modified it for the higher-temperature slagging operation and is continuing to develop the slagging version at the Westfield Development Centre. ■

Countering Small-Break LOCAs

The Nuclear Safety Analysis Center (NSAC) has published a report, *Small-Break LOCA Mitigation for PWRs,* which concludes that such a loss-of-coolant accident (LOCA) can be successfully terminated at any phase of the transient. It discusses the manual and automatic actions available to prevent the transient from proceeding further and thereby posing a threat. (The TMI-2 accident is classed as a small-break LOCA, even though there was no piping fracture. The relief valve that stuck open permitted the loss of coolant water from the reactor cooling system.)

The report describes a number of scenarios for countering a generic small-break LOCA in a PWR. It finds that the probability of core melting is substantially lower than that given in the Rasmussen *Reactor Safety Study* (WASH-1400). There are many existing and improvisable options available in a PWR system that could provide effective countermeasures against the progression of a small-break LOCA.

Consideration of the range of options for supplying adequate cooling water to the core and the time available to take new or corrective actions shows that even in a major core melt the core would reform to a coolable frozen state. Therefore, core melt is not necessarily followed by containment failure, as nuclear critics charge and WASH-1400 conceded.

According to the NSAC report, several features of a PWR small-break LOCA enhance the ability to respond effectively and minimize damage.

- Sufficient time is available to select and apply effective countermeasures to control the progress of core damage at virtually any stage.

- The magnitude of countermeasures required is well within the capacity of each of several of the typical installed PWR coolant injection and heat-sink systems, meaning that there is inherent redundancy and a high probability of availability of at least one effective system.

- The deviation from normal system parameters and heat-sink capabilities that marks a small-break LOCA provides many observable conditions that indicate both immediate accident state and trends; the scope and time scale of these observables permit rational selection of effective countermeasures and of bases for making emergency planning decisions. ■

On Scene at Crystal River

When the Crystal River-3 nuclear plant near Crystal River, Florida, had a small-break LOCA on February 26, 1980, Florida Power Corp. requested that NSAC and the new Institute for Nuclear Power Operations (INPO) make full evaluations. An NSAC team left California for Florida the evening of the 26th and spent a week at the plant. An INPO team studied operational aspects of the event.

The transient was terminated within two hours, and as of this writing it is believed that there is no damage to equipment or to the core. The incident was triggered by loss of power to nonnuclear instrumentation, the cause of which is still under investigation. This malfunction caused the feedwater control valves to choke down the flow of water to the steam generators and to increase reactor coolant pressure and temperature. The loss of power deenergized the power-operated relief valve and opened it instantaneously. Nevertheless, after the initial malfunction, the reactor was automatically shut down because of overpressure in the coolant system. The reactor protection systems functioned as intended by design and shut down the reactor.

However, water from the primary coolant system escaped through the open relief valve and flowed through the drain tank into the reactor containment building. The entire incident was over within two hours, but more than 40,000 gallons of radioactive water had been dumped on the floor of the reactor building.

As of early March, significant progress had been made on processing that water to purify it. Filtering of gaseous and airborne activity within the leak-tight reactor building was under way. ■

Reviewing Nuclear Events

Some 30 reviewers representing 10 organizations gathered at NSAC in February for a week-long workshop on developing an optimal process for reviewing and evaluating reports of nuclear plant outages and off-normal events.

Each participating organization had previously reviewed 200 of 1000 randomly selected Licensee Event Reports (LERs) filed with the NRC in 1970. Two sets of 100 reports were distributed to each of the 10 organizations, so each report was independently reviewed by two different organizations. Each organization developed and brought to the workshop its own proposed criteria for separating significant events worth further study from routine, trivial, insignificant events.

It was generally agreed at the workshop that thorough review of LERs falls into two phases: a continuous coarse screening process to identify events having significant safety or cost implications, and an action analysis process applied to these events, including an in-depth review. The ability to recognize patterns of recurrence among events that would not be regarded as significant on an individual basis is of concern in both phases of review.

It was also agreed that the screening process must be conducted by experienced technical people familiar with plant equipment who can recognize unusual circumstances in an event that may warrant detailed evaluation or that may be of urgent interest to operating staffs at other facilities. ■

Coal Transportation Needs Studied

A major study of how U.S. transportation networks will keep pace with growing demands for coal will be undertaken by EPRI. The $500,000 study will analyze more than 3000 transportation links between mines and power plants in the United States. It will also take into account projected use of slurry pipelines and coal used at the mine itself.

EPRI believes the study is vital because current estimates show that coal movement between U.S. regions will increase from 600 million tons in 1978 to 1.5–1.8 billion tons by 1995. "This threefold increase in projected movements of coal is of particular concern to electric utilities," notes Edward G. Altouney, EPRI project manager, "because coal is increasingly viewed as the energy workhorse of the 1990s."

The study, which will continue through 1980, will provide important information to electric utilities by analyzing existing data on all transportation networks (railroads, highways, barges, and pipelines); using this information to paint a valuable picture of coal movement throughout the country; and forecasting where future movements of coal are likely to increase beyond the current projected transportation capacity.

The project will also take a critical look at rail capacity within the transportation network and develop improved methods for estimating track capacity under various physical and operational conditions. Using this information, the researchers will estimate the level of new investment required to upgrade existing and projected transportation systems.

A large share of the work will be carried out for EPRI by C.A.C.I., Inc.—Federal, of Arlington, Virginia. C.A.C.I., which has performed extensive studies for the U.S. Department of Transportation and other clients, will analyze the various transportation supply options.

Additional research is being done under a separate contract with Kenneth Ebeling, a professor at North Dakota State University and an authority in the field of coal movements. Ebeling is currently gathering data on the location of new mines and new power plant sites so he can analyze the impact of expanded coal development on the national transportation system. ■

Testing Light-Fired Thyristors

The first commercial test of a new, modified electric switching device that is expected to cut the cost of transmitting power over long distances was announced recently by EPRI. Called a light-fired thyristor, the device uses a tiny laser beam and fiber optics to activate the thyristor. Thyristors, or solid-state control valves, are essential elements that fine-tune ac transmission systems to allow maximum stable power.

Until recently, thyristor valves were triggered electrically. By using light as a trigger, false triggering signals from the electromagnetic noise created by high-voltage transmission lines can be eliminated. In addition, light-triggered thyristors do not require high-voltage pulse transformers and auxiliary power supplies operating above ground potential, as do electrically triggered thyristors. Costs, therefore, can be reduced.

Commercial testing of the light-triggered thyristors, which are being developed by Westinghouse Electric Corp. under a $1,175,000 EPRI contract, is being carried out at Minnesota Power & Light Co.'s (MP&L) Shannon substation.

Long-distance transmission of ac is important to MP&L because the company purchases power from Manitoba Hydro in Canada to help supply electricity for the large, energy-consuming taconite mines and mills in the iron-rich counties north of Duluth, Minnesota. This power is delivered over a 230-kV transmission line that extends some 300 miles. Capacitor banks are needed to maintain control of the transmission over such long distances, and thyristor valves are needed to continuously regulate the injection of reactive current from the capacitors.

EPRI's Gilbert Addis, an electrical systems expert who is managing the project, said the successful commercial testing of light-triggered thyristors represents a technical breakthrough that holds great promise for "allowing us to do the job of stabilizing ac transmission much more economically." Westinghouse will continue to work on improving the light-triggered thyristor to reduce external components and increase efficiencies during the next year.

The light-triggered thyristor is a technical extension of work previously undertaken in developing the static VAR (volt-ampere-reactive) generators that are needed for high-voltage transmission of energy over long distances. A VAR generator has been tested for a year on MP&L's system. If light-triggered thyristors succeed in reducing the costs of static VAR generators, these generators may become attractive as an alternative to the building of new transmission systems to maintain stability over long distances. ■

CALENDAR

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

MAY

1–15
Electric Utility Rate Design Study, Regional Conference
San Francisco, California (1–2)
Kansas City, Missouri (8–9)
Washington, D.C. (14–15)
Contact: Gene Oatman (415) 855-2629

21–29
Lime FGD Systems Databook and FGD Sludge Disposal Manual Seminar
Chicago, Illinois (21–22)
Atlanta, Georgia (28–29)
Contact: Dorothy Stewart (415) 855-2609
Dean Golden (415) 855-2516

OCTOBER

6–7
Third NO_x Control Technology Seminar
Denver, Colorado
Contact: Edward Cichanowicz (415) 855-2374

20–23
Coal Conversion Technology Conference
San Francisco, California
Contact: Seymour Alpert (415) 855-2512

27–29
Coal and Ash Handling Systems Reliability Workshop
St. Louis, Missouri
Contact: I. Diaz-Tous (415) 855-2826

Klein Named Senior Assistant

Milton Klein, a former top official with the International Energy Agency (IEA), recently assumed the position of senior assistant to EPRI President Floyd Culler.

Klein was director of research, development, and technology applications for IEA and was responsible for promoting and implementing the actions of the organization's member countries in developing new energy technologies. IEA is an organization that was set up by 20 industrialized countries after the 1973–1974 OPEC oil embargo and is concerned with finding ways to reduce oil dependence.

As senior assistant to Culler, Klein will be responsible for analyzing problems that involve the coordinated action of various EPRI programs and divisions. Specifically, he will assist in formulating technical and policy responses to issues and problems raised by government agencies, suppliers, and utility-sponsored organizations. Klein will also manage major studies aimed at resolving such problems.

Before his affiliation with IEA in 1976, Klein was associate technical director for The MITRE Corp. of McLean, Virginia, where he was in charge of directing energy programs. He has also held senior management positions with the U.S. Atomic Energy Commission, the Federal Railroad Administration, and the National Aeronautics and Space Administration.

Klein received his MBA from the Harvard Business School in 1950 and earned his BS in chemical engineering in 1944 from Washington University, St. Louis, Missouri. ■

Utility Experience With MSW

More than 100 representatives of investor-owned, municipal, and cooperative utilities participated in an EPRI seminar in Fort Lauderdale, Florida, and discussed their various experiences in using municipal solid waste (MSW).

Two strongly held points of view developed in the January seminar on municipal solid waste as a utility fuel. Some utilities have committed their large power boilers to cofiring refuse-derived fuel (RDF) with coal or oil, while others felt that specifically designed units, basically water-wall incinerators, are the best way to recover energy from MSW.

Several key conclusions emerged from the presentations.

- Every utility boiler cofiring RDF had some significant startup problems, but several are now operating well.

- Even with today's high fossil fuel cost, it is not clear that MSW should be regarded as a cost-effective energy resource for electric utilities. However, long-range regulatory and economic trends may change that picture.

- Despite a high level of commitment, many utilities were held partially accountable when solid waste projects got into trouble, even if the causes were totally out of the utility's control.

- Fuel specification and supplemental firing guidelines are not available to help utilities make some very important design decisions. R&D is needed to develop these guidelines and to help utilities specify (and then enforce) quality limits for RDF. An RDF plant in which fuel quality is the primary objective has never been designed. The synergism of glass-rich RDF with coal ash has not been established and, most important, all the costs of using RDF (and there are many extra costs) have not been defined.

EPRI is attempting to answer some of these questions and a number of utilities are cooperating in several research projects. For further information on the seminar and EPRI's program, contact Charles McGowin at EPRI (415-855-2445). ■

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

ADVANCED PRECIPITATOR RESEARCH

A key environmental problem facing the electric utility industry is the increased emphasis by regulatory agencies on the application of high-efficiency particulate control devices to pulverized-coal-fired boilers. This increased emphasis is manifested in the revised new-source performance standard for particulate emissions of 0.03 lb/10^6 Btu recently promulgated by EPA. In addition, considerable attention is being focused on control of fine particulates (less than 2 µm in diameter), trace element emissions, and plume opacity. In response to these constraints, EPRI is conducting a major research program to improve existing technologies and develop cost-effective alternatives that promise high-efficiency particulate control. Several research efforts are directed at optimizing design and operating practice for electrostatic precipitators (ESPs) and at developing advanced precipitator configurations to achieve higher efficiencies and reliability.

Until recently the ESP has been the primary emission control device for coal-fired power plants because of its low capital and operating costs. However, new federal and state emission standards have required disproportionately larger and more costly ESPs, resulting in reliability and availability problems. In addition, fine particles are difficult to collect with ESPs. The objectives of EPRI's particulate control research are to reduce the size and cost of control equipment, to increase collection efficiency, especially for fine particles, and to improve reliability. Much of the development work is being performed at EPRI's Emissions Control and Test Facility at the Arapahoe station of Public Service Co. of Colorado, which is capable of testing devices at temperatures of 300–700°F (150–370°C) and at gas flow rates of 5000–50,000 actual ft³/min (2.4–24 m³/s). This research is divided into two main areas: ESP technology and fabric filtration. The latter area was discussed in an earlier report (*EPRI Journal*, October 1979, p. 35).

Improving ESP design and reliability

Flue Gas Conditioning (RP724) EPRI is investigating the influence of chemical additives on precipitator collection efficiency. Normally, a precipitator is designed to meet certain performance criteria based on the properties of a specified coal and other operating parameters. If important coal properties should change (e.g., the sulfur content), the resulting ash may be more difficult to collect and the precipitator may no longer meet the design performance criteria. In some such cases flue gas conditioning can restore precipitator performance. Conditioning agents that are presently being used with success include sulfur trioxide, ammonia, and ammonia-related compounds.

Although gas conditioning has restored satisfactory precipitator performance in some installations, the results have been variable and sometimes disappointing. This project is investigating important aspects of gas conditioning through both laboratory and field studies. All the agents in widespread use will be examined. The product of this research will be a flue gas conditioning user's manual that will describe situations in which gas conditioning is effective and present an economic comparison with alternative methods of solving precipitator performance problems. Preliminary results will be available by mid-1980.

Minicombustor (RP629) Certain properties of fly ash are significant for ESP design. EPRI is developing an improved procedure for predicting these properties by laboratory-scale testing of the parent coals. The procedure involves burning small samples of coal in a laboratory combustor under conditions that closely simulate the physical and chemical conditions in a power plant boiler.

In this development program, a data base is being compiled that consists of critical measurements (fly ash mass loading, size distribution, composition, resistivity, and gas-phase SO_3 concentration) taken at the precipitator inlet of utility coal-fired plants. Samples of the same coals are then burned at a rate of 5 lb/h (heat release, approximately 60,000 Btu/h) in a versatile laboratory combustor capable of reproducing the temperature/time profile of the boilers in the data base. Measurements of the same parameters are made at the combustor exit, permitting a comparison of the laboratory values with the full-scale results.

Preliminary results from a limited number of coals suggest that fly ash resistivity can be predicted to within an order of magnitude for low-sulfur coals, a significant improvement over the capabilities of current laboratory procedures.

Additional efforts in progress to improve the design basis of ESPs include a field evaluation of pulsed electric power equipment, an assessment of the causes of performance deterioration in hot precipitators, and improved plate-rapping procedures that minimize reentrainment.

Reliability Field Study (RP1401) One of the most significant factors involved in the selection of any particulate control technology is the confidence utilities have in the reliability of the device. It is important to quantify the operating experience of ESPs and baghouses on coal-fired plants to define the reliability issues and develop a set of guidelines to assist the utilities in specifying these systems. This project is doing that by comprehensive engineering evaluations of 16 ESP and fabric filter installations and their associated ash removal systems.

The selected ESP systems represent a sampling of high-design-efficiency units (99.5% removal and above) in western and eastern coal applications. The fabric filter systems evaluated will be limited to those used on pulverized-coal units that have come into service since 1977. Initial results are expected to be available later this year.

Advanced ESP technology

High-Intensity Ionizer (RP725) EPRI is testing a high-intensity ionizer developed by Air Pollution Systems, Inc. These tests are being carried out at the Tennessee Valley Authority (TVA) Shawnee steam plant, as well as at the Arapahoe test facility. The ionizer consists of an electrode assembly that produces a high-intensity corona to charge particulate matter to a much higher level than possible with conventional ESPs. When the ionizer is combined with a conventional ESP to form a two-stage precipitation device, the higher particle charge should result in higher overall collection efficiency.

In tests at Arapahoe a high-intensity ionizer–precipitator combination has been operating at an ionizer field strength level of about 7 kV/cm, significantly higher than the 4-kV/cm level that can be maintained in a conventional precipitator. Ionizer field strengths up to 7 kV/cm resulted in reduced precipitation emissions. Higher fields (up to 11 kV/cm) did not result in expected improvements with the configurations tested to date. Modifications are being made that are expected to bring the test unit up to the theoretically attainable performance levels.

Complementary larger-scale tests of the ionizer concept are being conducted at the Shawnee steam plant. TVA has installed an array of 90 ionizers in the duct just in front of one of the two precipitators on a 150-MW unit (i.e., the ionizer array treats an amount of flue gas equivalent to 75 MW of power generation). The ionizer array at Shawnee was first operated in July 1979. EPRI-sponsored tests characterized the operation of the precipitator alone, the ionizer alone, and the precipitator-ionizer combination (RP1456). Further tests at Shawnee are scheduled for mid-1980.

Advanced ESP Prototype (RP1835) Although baghouse technology is a promising alternative to ESPs, the development of cost-effective improvements in ESP technology must still be pursued, especially in view of the over 5800 utility ESPs already installed in the United States. Improved particulate collection may even be required for boilers already equipped with particulate control devices, and upgrading of existing ESPs must be regarded as the only cost-effective solution for most of the plants involved.

The objective of another project (RP1835), which began early this year, is to demonstrate at prototype scale (1) technology to reduce the basic size and cost of ESPs; (2) improvements in fine-particle collection efficiency; (3) reductions in the ESP's sensitivity to ash resistivity; and (4) technology to improve operating reliability. The initial efforts emphasize the near-term need to reduce ESP costs. This project will systematically bring together the most promising ESP improvements developed and tested by EPRI, as well as by various ESP suppliers, to determine the most effective ESP configuration commercially practical today.

In addition to the high-intensity ionizer, promising technologies in this area are pulsed high-voltage power supplies, wide electrode plate spacing, and compartmentalized rapping. While each of these technologies is currently commercially available, their performance characteristics in utility precipitator applications and their cost-effectiveness have not been established. Furthermore, no information is available to predict the effects of combining these technologies. The technologies all address the critical problem of improving collection efficiency for fine particulates, and thus their successful development should lead to cost reductions for new units and provide sound engineering alternatives for existing units.

The prototype ESP at the Arapahoe facility will be used as the primary vehicle for testing advanced concepts on a continuing basis. It is well suited to this purpose because of its size (flue gas equivalent to 5–15 MW of power generation), which permits extrapolation of results to full scale, and the inherent flexibility of its design. The prototype will undergo baseline tests to characterize its initial fine-particle collection performance; subsequent modifications will be tested separately and in combination.

The results of advanced ESP research will become available over the next two years. Additional efforts to improve ESP technology include measurements of ESP performance (RP780) and development of a fine-particle agglomerator (RP533). *Subprogram Manager: Peter Gelfand*

TURBINE–GENERATOR RELIABILITY

Statistical data from the Edison Electric Institute (EEI) indicate that large turbine-generators (not including auxiliary systems) account for an availability loss in fossil-fueled power plants of approximately 13%, a large portion of the 35.5% total plant availability loss. EPRI's turbine-generator performance and reliability subprogram was structured to develop technology options to reduce outages caused by generic, industrywide problems relating to design, operation, and maintenance. A continuing planning effort based on EEI equipment outage data and input from utility industry working groups, the EPRI advisory structure, and manufacturers has produced an R&D program that allocates funding to turbine-generator components in relation to their contribution to availability loss. This work is expected to provide significant short-term and mid-term benefits to the utility industry.

The elements of the turbine-generator subsystem that are responsible for the largest availability losses and, therefore, have the highest research priorities are turbine blades, bearings, and generators. In addition, the requirements of unit cyclic operation in terms of plant availability represent an important area of study.

Turbine blades

Blade failures that cause forced outages or extend scheduled outages pervade the utility industry. Most of these failures involve first-stage high-pressure and intermediate-pressure blades or later-stage low-pressure blades. The high- and intermediate-pressure blade failures generally result from solid-particle erosion, whereas the low-pressure blade failures result from stress corrosion or corrosion fatigue. The failure mechanisms are basically different and require different research approaches.

Low-Pressure Blades Low-pressure blade failures occur primarily in the next-to-last (L − 1) stage. As shown in Figure 1, 40% of all blade failures that result in forced outages occur in this stage. Thus EPRI has established a major effort aimed at developing a fundamental understanding of the failure cause mechanisms in existing designs and providing blading options that can eliminate the problem.

The service viability of a particular blade configuration depends on the interaction of steady stress, alternating stress, steam environment, and material. This interaction is more complex at the L − 1 stage because it is a transonic stage (contains a shock wave) and is the normal location for supersaturated steam condensation (Wilson point) in the low-pressure turbine. The steam contains small amounts of dissolved salt impurities that condense in concentrated form just before the Wilson point. When the Wilson point moves (as a function of load), regions of periodically moistened salt deposits are created that promote pitting and cracking of the blade material. The goal of RP912, a four-year project initiated in conjunction with RP1068 of the Nuclear Power Division,

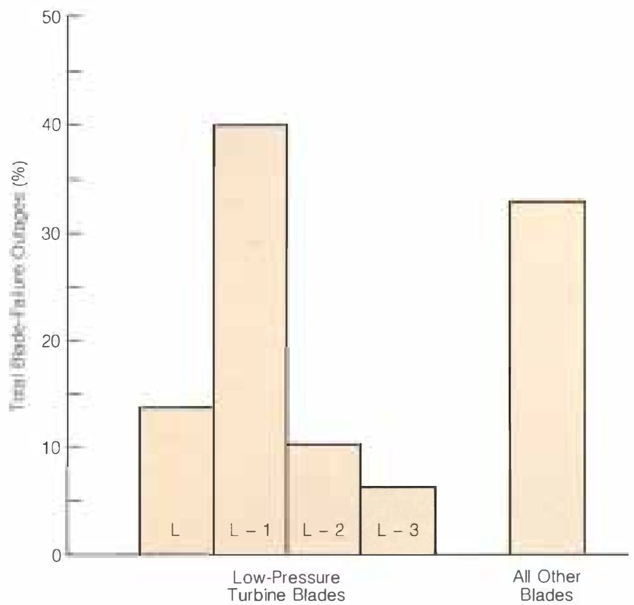


Figure 1 Blade failures in the later stages of the low-pressure turbine account for most of the blade-related forced outages in steam turbines. The L – 1 row constitutes the most troublesome stage. Percentages are based on EEI data for the years 1969–1977.

is to gain a more quantitative understanding of environmentally related fatigue in low-pressure blading materials. The project will provide recommendations on acceptable water treatment practices, allowable levels of steam contaminants, and allowable static and dynamic stresses as a guide for plant operation that minimizes corrosion fatigue damage. It is scheduled for completion in mid-1981.

The process of steam condensation in low-pressure turbines is not well understood. Yet to be experimentally determined are the effect of dissolved and particulate impurities on the condensation mechanism, the location of the Wilson point, the size of droplets at formation, and the droplet growth propensity. Work under RP735 will provide this critically needed information, which will facilitate the development of improved turbine steam-path design methods to reduce moisture losses and erosion damage. In addition, recommendations for the control of steam condensation and impurity deposition through feedwater chemistry will be developed. This project will be completed in December 1980.

Some limited field testing has revealed high cyclic stresses in later-stage blades during operation at off-design conditions—low reheat temperature and high back pressure. A probable reason for these stresses is the unstable interaction between a pressure shock wave and supersaturated steam condensation in the blade passage, which creates blade excitation from periodic motion of the pressure shock wave. In RP1407 this phenomenon is being investigated to experimentally determine the amplitudes, frequencies, and boundaries of the flow instability, as well as the possible forces on blade surfaces. The information obtained will help turbine blade designers accommodate the excitation levels created and lead to operating procedures that minimize the undesirable effects.

Knowledge of damping characteristics is a critical element in the fatigue design of turbine blades. Performing in situ tests presents substantial difficulties, however, and data on steam turbine blade damping are sparse. RP1185 was initiated to develop an alternative testing method that simulates operating conditions and to provide damping data on steam turbine blades with three different root configurations. The first phase of this project was completed in 1979, and a report will be available mid-1980. This phase developed and demonstrated the new testing method and provided data on blade damping as a function of axial load, vibration mode, and vibration amplitude. The second and third phases of the project will determine more detailed damping characteristics for a wide range of blade designs and will investigate various means of increasing blade damping, thereby making a more fatigue-resistant design possible.

Titanium alloys and coatings show promise for reducing corrosion-related failures in low-pressure turbine blades. Under RP1264 a free-standing titanium L – 1 blade that can be retrofitted into an existing machine is being designed, developed, and tested. In-plant telemetry testing is expected to be completed by the end of 1980, and the blade should be commercially available in 1981. RP1408 will identify and evaluate one or more coating systems that can successfully protect turbine blade and rotor areas from hostile environments. This project will be completed in 1982.

High- and Intermediate-Pressure Blades
The erosion of turbine parts, especially of the first-stage high- and intermediate-pressure blades, by hard particles has long been recognized as a utility problem. Typically, solid-particle erosion results in efficiency loss rather than forced outages. Experience has shown that substantial costs ($50–$100 million a year) are associated with this phenomenon as a result of degraded efficiency, extended outages, and maintenance expense. The root cause of the problem is generally believed to be exfoliated oxides from boiler superheater and reheater tubing and from main steam piping. The hard particles produced are blown into the turbine and cause erosion of valves, nozzles, and blades. Thus far, research on this problem has emphasized the exfoliation process within the boiler. A chromate conversion method that eliminates rapid exfoliation is being developed and tested, and a full-scale retrofit application will be conducted this year (RP644).

Projects exploring ways to reduce the effect of erosion on turbine parts are under consideration for funding in late 1980. One method involves turbine steam bypass systems that circumvent the turbine during startup and blow the particles into the condenser. More direct methods include blade coatings that reduce erosion susceptibility, steam admission strategies that reduce particle velocity, particle traps that separate particles from inlet steam, and monitoring systems that indicate when erosion is occurring. A comprehensive approach incorporating all these methods is presently being planned.

Bearings

Development of technology options that will help the utility industry reduce bearing-system failures, which are the leading cause of forced outages in turbine-generators over 600 MW, is a major objective of the turbine-generator subprogram. Work in this area is divided into three categories: lubrication systems, bearings, and rotor-bearing systems.

A comprehensive analysis of past failures is being conducted to identify, define, and rank the root causes of generic bearing-system problems, and to develop a long-range R&D plan to address the significant problems identified (RP1265-3). This project will be completed in early 1981. Two projects addressing particular problem areas have already been initiated. One is examining how to reduce bearing power losses (RP1648-1), and the other is assessing rotor-bearing analysis techniques (RP1648-2).

In addition, projects will be started this year in the following areas.

- Development of a device for monitoring particulates and water content in lubricating-oil systems
- Low-speed wear of large journal bearings
- Transient performance of lubrication systems during emergency shutdown
- Full-flow filters for lubricating-oil systems
- Design and construction of lubricating-oil systems

The principal emphasis in each of these projects will be on problem prevention and reduction through improved analytic methods, proper specification guidelines, and improved hardware designs for new and existing bearing and lubrication systems.

Because work in this area has just begun, results in a form directly transferable to the utility industry will not be available until early 1982.

Generators

Problems with large generators account for a plant availability loss of approximately 9%, according to EEI statistics. Because it is likely that conventional generators will supply the major portion of the utility industry's needs during the next 15 years, it is important to improve their reliability through R&D in the areas of design and construction; operation; monitoring and diagnostics; and maintenance. To provide a rational allocation of resources in this effort, a root cause analysis project similar to that described for bearing systems will be initiated this year (RP1265-4).

Unit cyclic operation

There is a trend in the utility industry toward cycling of large fossil units in the form of two-shift operation and load following. This trend is the result of many factors, including increases in nuclear generating capacity and increases in fuel costs. New fossil plants over 500 MW are being specified for cyclic operation; older plants are being relegated to cyclic operation after years of baseload operation.

These operating strategies are producing a demand for more extensive engineering analyses of power plant components and for validation of these analyses. Turbine and boiler manufacturers are being asked to predict thermal stresses and corresponding fatigue life and to determine component response through the use of modeling techniques. Such predictions will help utilities assess the reliability and economics of various operating modes when considering new plant designs or modifications in the operation of existing plants.

RP911 is examining turbine and boiler metal temperatures and thermal stress in cyclic operation in an effort to optimize starting and loading procedures and thus improve the reliability and economics of this mode of operation. In addition, plant modeling techniques and thermal stress models will be validated, and heat transfer correlations improved. This project will be completed late this year.

Turbine bypass systems offer the opportunity for significant improvements in plant cyclic operation. When successfully developed in this country they will

- Increase operating flexibility between boiler and turbine systems, thereby decreasing startup and shutdown times and improving availability
- Improve matching of steam and metal temperatures during startup and transients, thus reducing rotor and cylinder thermal stresses
- Reduce solid-particle erosion of turbine valves and blades by reducing tube wall overheating and subsequent internal oxide formation and carryover during startup
- Enable boiler cleanup to be achieved before steam is introduced into the turbine, thereby minimizing corrosion

A conceptual design and economics study of turbine bypass systems will be initiated this year to investigate their viability in new and retrofit situations.

Further research

In addition to the four major areas discussed above, the turbine-generator subprogram is planning significant research in the areas of monitoring and diagnostics, turbine maintenance, and thermal performance. Several projects are ready to start, and work will be expanded in the near future.

The goal of this subprogram—improving plant availability, especially for coal-fired baseload plants—is in keeping with the national goals of efficient energy use and reduced dependence on oil and gas. The R&D investment in this effort is relatively small and the possibilities of success are high, with potentially significant benefits for the utility industry. *Project Manager: John Parkes*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

OVERHEAD TRANSMISSION

Wind-induced vibration

Wind-induced aeolian vibrations are responsible for fatigue failure of transmission line conductors throughout the world. Utility companies often must decide whether to replace minimally damaged conductors (one-to-three-strand breaks) or to add vibration amplitude reduction devices (dampers) to the line in an attempt to arrest further conductor damage. The addition of dampers does lower line vibration amplitudes; however, it is not known if this corrective procedure is sufficient to ensure the full design life of the line.

The question addressed in this research effort is whether the addition of dampers significantly prolongs the fatigue life of a line that has been minimally damaged by aeolian vibration (RP1278). If this is shown to be the case, utilities using dampers could expect economy in the maintenance and replacement of overhead conductors and fewer outages caused by conductor fatigue failures.

The approach in this investigation is to experimentally evaluate the effectiveness of two levels of amplitude reduction in arresting deterioration of minimally damaged aluminum cable steel-reinforced (ACSR) conductors supported by standard short-radius suspension clamps. All experimental work is being conducted in the laboratory at Auburn University. Three representative ACSR conductors are being tested—a 4.03-cm^2 (795-kcmil) conductor with 45/7 stranding, a 4.03-cm^2 conductor with 26/7 stranding, and a 2.01-cm^2 (397.5-kcmil) conductor with 26/7 stranding. Aeolian vibrations are simulated in the laboratory by inducing mechanical vibrations at a natural frequency of the conductor. After one-to-three-strand breaks are experienced, the addition of dampers is simulated in the laboratory testing by reducing the vibration amplitude. In each test the suspension clamp is fixed (articulation is restrained) to accelerate fatigue.

Fatigue failures are generally governed by highly localized material and geometric properties. Hence, fatigue tests, with their inherent sensitivity to local imperfections, tend to show considerable data scatter. To mitigate this effect, several tests are made on each conductor configuration and condition to give statistical credence to the results obtained. Results to date indicate that amplitude reductions that simulate the addition of dampers for 2.01-cm^2 (397.5-kcmil) 26/7 and 4.03-cm^2 (795-kcmil) 26/7 ACSR conductors under the conditions tested do mitigate fatigue damage. Tests indicate no appreciable additional fatigue damage after the simulated addition of dampers for test durations on the order of 30×10^6 additional vibration cycles.

The addition of dampers to reduce aeolian vibration amplitudes for minimally damaged transmission lines has been experimentally validated as a sound approach. The research is continuing to more clearly define the effect and to extend the testing. It is expected that this effort will aid the transmission line design engineer in determining whether fatigue failures have occurred or are likely to occur on a line and how these effects can be mitigated. *Project Manager: Joseph Porter*

Phase-to-phase switching surge

One of the problems to be considered in implementing transmission line compacting techniques, such as those developed under RP260, is the possibility of phase-to-phase flashover from switching surges. How flashover is influenced by such parameters as line length, hardware, spacing, and phase configuration is not accurately known. A project was established with Power Technologies, Inc., to conduct phase-to-phase flashover tests on a prototype transmission line (RP1202). The line was constructed and tested at Westinghouse Electric Corp.'s EHV laboratory in Trafford, Pennsylvania.

Switching-surge flashover measurements were made for phase-to-phase spacings of 3, 6, and 12 ft on 30-, 150-, and 1200-ft-long lines, strung with two or three conductors. The project data relate specifically to the design of 115–138-kV compact transmission lines, but the results are applicable to all designs using phase-to-phase spacings in the range tested.

Advanced statistical methods were used to plan and execute the tests. Data analysis combined conventional computer methods of data processing with statistical analysis techniques specially developed for this project. The effects of weather on the possibility of flashover were obtained as concomitant variables, a procedure made possible by planning a sufficient number of tests over a range of weather conditions. All measurements were made with digital equipment to a high level of consistency.

Results will be presented in a simplified form suitable for use in switching-surge design procedures similar to those described in EL-1314, a report on 115–138-kV bundled-circuit design (RP260-2). When combined with the system performance data given in that report, these new results should provide a significant improvement in confidence for phase-to-phase switching surge performance, which may lead to construction savings. The results confirmed the ease of compensation for design variables, established limitations for conventional weather correction factors, isolated features of the data that limit the accuracy of conventional analysis methods, and developed improved accelerated test methods. *Program Manager: Richard Kennon*

HVDC transmission between ±600 and ±1200 kV

In 1976 EPRI and Bonneville Power Administration published *Transmission Line Reference Book, HVDC to ±600 kV.* Now that planners envision dc lines in the ±600-kV to ±1200-kV range, an extension of the previous work is called for.

Although construction of dc lines has been limited in the United States, this may soon change. The development of the thyristor has held down the cost of converters, and the line cost for dc is less than for ac of equivalent capacity. In preparation for an expected increase in HVDC line construction, EPRI is sponsoring two complementary studies of lines above ±600 kV. The first (RP430) is being carried out at the Institut de Recherche de l'Hydro-Québec (IREQ). The other study (RP1282), with General Electric Co., was reviewed earlier (*EPRI Journal,* December 1979, p. 54).

The IREQ project is divided into three parts: power supply studies for insulator pollution tests, insulation coordination studies, and corona studies for overhead line and bipolar cage configurations. The most recent phase of this work analyzes long-term observations of a test line constructed at IREQ's facility near Montreal (Figure 1). Several conductor bundles were operated at voltages from ±750 kV to ±1050 kV, and measurements were taken of line voltage, corona losses, radio interference, and audible noise under a variety of weather conditions.

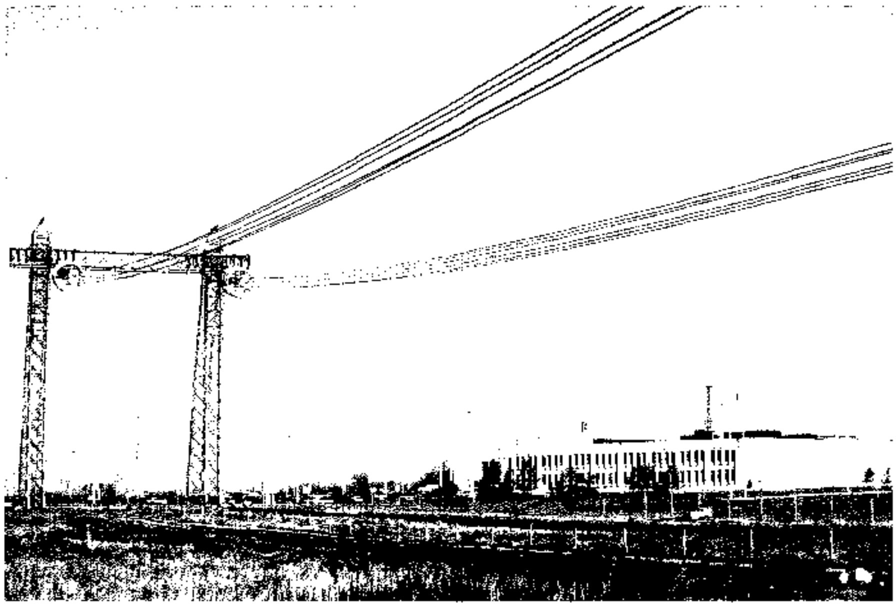
A convenient and inexpensive method of simulating dc line conditions for a variety of conductor sizes and spacings is cage testing. By installing the conductors inside a metal cage (Figure 2), the electric field found on an operating line can be duplicated at the conductor.

Of special importance to the station designer is a study of corona and electric field effects of buses at various voltage levels. Bus size (for both single tubes and bundled tubes) and pole spacing were varied.

Information on the work outlined above is contained in EL-1170. Results of the insulation coordination studies (EL-395) and the power supply study for insulator pollution tests (EL-397) are also available.

Research under RP430 will continue through 1980 and will include additional evaluation of cage studies, as well as a subjective evaluation of the annoyance effects produced by radio interference and audible noise. The development of an instrument to accurately measure the electric field of a dc source at any point above ground will be completed. This project is the first step in the investigation of dc lines above ±600 kV. It provides much useful information to the line designer and the station designer and gives direction to additional research, which will continue through 1984. *Project Manager: John Dunlap*

Figure 1 HVDC test line (6-conductor bundles) at IREQ on which long-term operating conditions are being measured at voltages between ±750 kV and ±1050 kV.



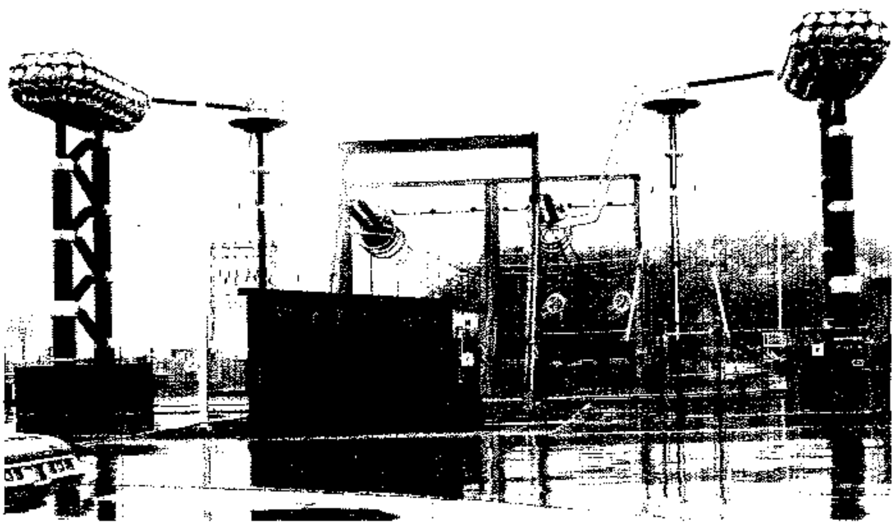


Figure 2 Outdoor cage tests at IREQ for HVDC conductor bundles. All bundles that can be tested on the line can be tested in the 18 × 18-ft (5.5 × 5.5-m) cages. For the EPRI project, the central panels of each cage were removed so the cages could be combined for bipolar dc tests.

UNDERGROUND TRANSMISSION

Oil leak location systems

Most of the 3000 circuit miles of high-voltage underground transmission line installed in the United States are 69–345-kV pressurized cables, insulated with oil-impregnated paper. Over 75% are pipe-type cables, in which three insulated cables are installed in protected steel pipe, then filled and pressurized with dielectric fluid. Some 500 circuit miles are lead-sheathed, self-contained, oil-filled cables, and the remaining 10% are gas-pressurized pipe-type cables.

To maintain their high dielectric strength and long-time service integrity, these transmission cables must be maintained at rated operating pressures; if these pressures are not maintained, the cables must be taken out of service.

Some utilities with extensive underground transmission circuits in large metropolitan areas have encountered serious and expensive leaks leading to shutdown of pipe-type cables. In some instances, it has taken months to find oil leaks with present location methods.

The objective of RP7869 with Power Technologies, Inc. is the development and testing of advanced, accurate systems for locating leaks of cable oil and gas. The gases involved are nitrogen and sulfur hexafluoride.

Methods under investigation include acoustic emission, infrared survey, ground-penetrating radar, radioactive and stable isotope tracers, liquid and gas tracers, and thermal flow indicators.

The final system will have two modes of operation. The first will define the general location of the leak—for example, in an area between particular manholes. The second mode will employ one or a combination of methods to pinpoint the leak. The system should be able to detect leaks with flow rates as low as 3 gal/h (0.0114 m^3/h).

The thermal flow indicator, for example, is an established tool that can be made more reliable, sensitive, and accurate by upgrading instrumentation and application. In the manholes, access for a probe into the oil pipe is made in the joint with fitted valves. The thermal probe can detect a leak flow direction when the oil flow rate is as small as 3–5 gal/h (0.0114–0.0189 m^3/h). An acrylic mock-up of a joint casing, with connecting line pipes, insulated cable splices within the casing, and heating and instrumentation facilities is now being used to conduct sensitive flow tests under simulated field conditions.

To date, indications are that improvements of about one order of magnitude in sensitivity and accuracy should be possible. With confirmation of the flow directions between adjacent manholes and with the increased sensitivity anticipated, it may be possible to identify in which quarter of the length the leak should be found by detecting minute differences in flow rates.

It is obviously preferable to use tracer fluids as permanent additives to the dielectric oil in the operating system because such a detectable additive would exit at the leak source immediately after the leak starts. However, the need for long-time electrical and chemical stability and compatibility impose appreciable restraints on the types of fluids that are acceptable. At present, some 30 candidate liquid and gas tracers are being characterized, and further analyses of detectability and required concentration level are expected to reduce the selection to 10 or less. Additional tests, including measurement of absorption and dispersion of the tracer fluids by soils and backfills, are being conducted at buried-pipe facilities at Saratoga, New York; here the controlled leak rates can be examined in various soils and under blacktop roadway.

Additional promising detection methods and location techniques are being investigated and will be reported as more results become available. *Project Manager: Stephen Kozak*

TRANSMISSION SUBSTATIONS

Advanced thyristor valve

A recent status report (*EPRI Journal*, July/August 1979, p. 51) announced the start of a project in which General Electric Co. is developing an advanced thyristor valve for HVDC transmission systems (RP1291). The thyristor under development will be a light-fired, 77-mm (3-in) diameter cell with a 5000-V blocking voltage, a low thermal resistance package, and zinc oxide block overvoltage protection for individual thyristors.

In addition to the low thermal resistance package, which can significantly lower temperature excursions caused by transient overload, a related project with General Electric is developing a system for forced vapor cooling of thyristor valves (RP1207). This cooling technique, which also tends to lower transient temperature excursions, is of primary value for improving steady-state heat dissipation. Success in these projects will not only lower HVDC converter costs (because fewer thyristors will be needed for a given power level) but will also lower the cost of capitalized losses by decreasing power losses.

The project is progressing as scheduled in all respects. A 77-mm, 5-kV, electrically gated thyristor has been developed. Modifications of the design necessary to reliably trigger the thyristor with infrared light are progressing with no serious problems. The advanced package has yielded the anticipated gain of 30% in heat transfer capability for both surge and steady-state heating, while pilot tests of forced vapor cooling (using prototype coolant passages) indicate a further increase in steady-state cooling of up to 100% when the two techniques are combined. Paper design of an advanced valve (possibly 133 kV at 2000 A) is anticipated by mid-1980, and a search for a host utility is now under way. *Project Manager: Gilbert Addis*

EHV current transducer

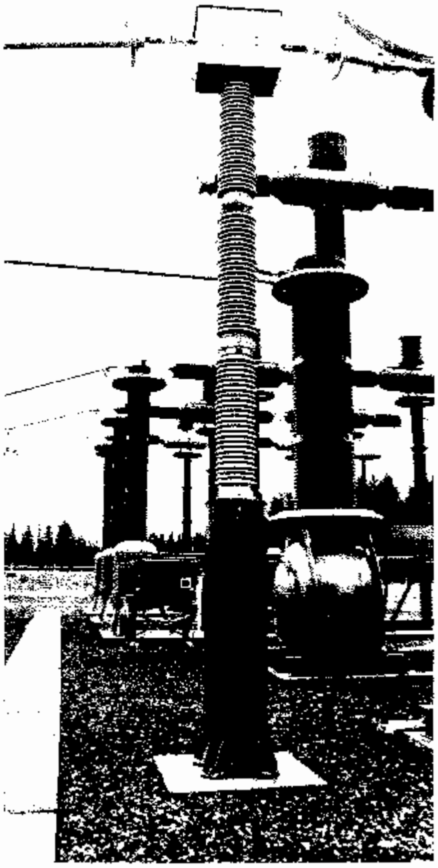
A digital EHV electronic current transducer (ECT) has been developed by Westinghouse under EPRI sponsorship (RP560). The target specification for the transducer was to meet metering, relaying, and fault-recording requirements without provision of a battery supply at the high-voltage level. The frequency response, specified at 10 kHz minimum, should be adequate for future current limiter control systems and ultrahigh-speed relays as well. Digital techniques were specified for the conversion and signal transmission system of the ECT to gain experience with a design that could be directly interfaced with future digital protective relays. Fiber-optic links were specified for the communication system.

When last reported on (*EPRI Journal*, May 1978, p. 51), the ECT had been installed in a Bonneville Power Administration 500-kV substation (Figure 3), where it has been operating since August 1978.

The ECT is the first utility application of low-loss optical waveguides in which the waveguide is brought all the way from the control house up to an energized bus. The system uses two types of fibers. The first portion from bus potential to ground is a special Siecor fiber with a void-free mylar buffer. The major length, a 300-m section that runs from the base of the ECT to the control house, uses a conventional Siecor two-fiber cable.

The 300-m fiber cable was installed in a conduit for the first 70–100 m, and the rest was laid on conventional cable trays. Installation was very fast and simple. No special precautions were taken except for some care not to exceed the maximum specified pulling force and minimum allowable bending radius. The installation demonstrated that utility crews can handle a fiber cable by following relatively normal procedures, even though the installation was not copletely problem-free. The mylar-buffered fiber was broken several times, and two problems were encountered during the installation of the ECT electronics. Special precautions taken during the installation eventually resolved these problems, which can easily be avoided in future installations through slight modification of the packaging of the electronics at the top of the ECT. Also, one of the fibers in the main run to the control room failed in the first few months of operation. The fault was traced to a fiber breakage near a connector. The cause of this break is not known, although it is believed to have resulted from handling. The faulted fiber-optic cable was replaced, and the system has been operating continuously

Figure 3 The ECT installed in a substation on the Bonneville Power Administration's system, against a background of conventional current transformers. Benefits of the ECT include improved safety features and the first application of low-loss, hair-thin optical fibers for transmitting the current signals.



without further fiber problems since August 1978. Since then, there has been one electronic component failure in the decoder unit, probably just a normal early failure.

The test program specifies monitoring of several key parameters, the most important of which are the number of parity errors in received messages from the ECT encoder and changes in amplitude and phase errors in the output of the ECT.

Over a four-month period, there were only 44 messages with a parity error out of an estimated 4.3×10^{11} total transmitted messages. Since each message has 14 bits, this would indicate a bit error rate of between 7×10^{-12} and 2×10^{-10}. Thus, the security of the fiber-optic data transmission appears to be quite good. To date, no major change has been detected in the accuracy of the ECT. The evaluation of the ECT is continuing. *Project Manager: Stig Nilsson*

POWER SYSTEM PLANNING AND OPERATIONS

Advanced computer concepts

New analytic techniques for the advancement and application of modeling theory, control systems, large systems concepts, and network theory are being pursued in a project on advanced computer concepts (RP1355). The topics for research result from periodic solicitations to universities. Four contracts have been let, and from four to six additional contracts are likely to be awarded in 1980. Three of the four current contracts are discussed below.

Researchers at Northwestern University are investigating improved methods for solving power system network problems by means of a parallel array of inexpensive microprocessors (RP1355-1). The objective is to see if approximately 50 small, inexpensive microprocessors, working in parallel, can do the work of one large, expensive computing system. Executive software has been written to coordinate a series/parallel array of microprocessors that are programmed to solve a sequential power system network algorithm. In this phase of the research the 50-microprocessor array is simulated on a CDC 6600 computer system.

Under RP1355-2, researchers at Cornell University are evaluating the computation efficiencies possible for solving ac power flow values when a modified, fast-decoupled algorithm is executed on an array processor (Floating Point System's AP120B). The array processor is connected to a host serial digital computer. The host computer addresses the array processor and passes a portion of a problem to the array for its solution. While the array processor is working on the solution, the computing resources of the host computer can be used for other tasks. When an array processor is used with a host computer, the result is a multiprocessor configuration capable of distributed processing. Such a configuration can increase the amount of work that can be accomplished in any time interval by a significant amount. After the ac power flow solution has been checked out on the Cornell hardware, timing runs will be made. The solution time for problems of various sizes are to be measured on three computer systems: the host-array hybrid system, a single serial digital computer (e.g., IBM 370), and the EPRI analog-digital hybrid. The cost and performance of each computing alternative will be documented. Validation of more responsive computing alternatives will improve support for power system planners and power system dispatchers.

At Iowa State University a research team is developing a methodology whereby operators can recognize and predict when their systems are in a state of transition between the normal, alert, and emergency states (RP1355-3). The purposes of such a capability would be to alert the system operator to situations in which a breach of security may occur and to recommend preventative measures, if possible.

System security, in the dynamic sense, is not well defined. Assessment of system transitions requires estimates of the final operating state of the system (which would define acceptable and unacceptable operating conditions) and an estimate of the system trajectory during the transition period (which would define an acceptable dynamic performance of the system).

The successful methodology for dynamic security assessment must perform five functions.

- Provide a clear definition of the operating states of a power system and of acceptable dynamic system performance
- Recognize (in real time) the dynamic state of the system
- Detect potential contingent situations that may require correction
- Assess the security of the system (the degree of the alert)
- Identify the weak links and suggest appropriate preventative measures

Researchers at Iowa State believe their transient stability margin assessment tool is a valid means for predicting the dynamic response of the power system to power perturbations. The power perturbations studied include the additional negative load (accelerating power) at the faulted bus at the instant of fault clearing, the additional negative load at the faulted bus at a later instant (after fault clearing), the additional negative load at a bus other than the faulted bus, and changes in the mechanical power of certain generators.

The researchers intend to carry out additional validation studies and will explore ways of expressing the transient margin in terms of other types of system disturbances or perturbations. *Project Manager: Donald Koenig*

Modular generation expansion

Electric utilities are confronted with a formidable challenge to evaluate an increasing number of alternatives for planning future generation requirements. Turbulence in the socioeconomic arena and the unsettling political climate during the past decade have added a new dimension to the planning of electric utility capacity expansion. Although utility planners could once confidently opt for the lowest overall cost, the uncertainties in future fuel prices, capital costs, and rate of growth of electricity demand now make the job of generation expansion planning more formidable. For example, new generation technologies and energy storage devices have increased the variety and flexibility of electric power sources available to utilities. Management decisions for generation additions must now balance short- and long-term policies for supplying electric power and must weigh present certainties in generation alternatives against future uncertainties in new technologies. There is increased pressure to include an analysis of the complex environmental regulations, regulatory requirements, and financial constraints. With this backdrop, a need exists to develop a strategy for the expansion of a utility's future generation that takes into account all these competing factors.

A research project has been initiated with Massachusetts Institute of Technology to focus on the development of a flexible, modular software program suitable for electric utility capacity expansion planning (RP1529). The contractor will develop the expansion computer program with special emphasis on a common data base. The program will be based on a selected set of existing operating and capacity expansion criteria, as well as on additional factors developed during the study for analysis of the complex choices now facing electric utilities. For example, the electric generation planning framework will be expanded to include the ability to analyze the effects of consumer energy cost changes, load management techniques, environmental screening capabilities, renewable energy technologies (such as solar and wind energy storage), financial data, transmission interconnections on reliability, and production cost. This software logic will also develop mathematical models to represent the use of energy storage devices in the evaluation of production cost and an optimal generation mix. Production-grade generation expansion computer programs will be delivered at the completion of this project in mid-1981. *Project Manager: Neal Balu*

DISTRIBUTION

Development of a failsafe surge arrester

Present surge protection practices dictate the use of arresters on most overhead distribution equipment in most geographical areas of the United States. Surge arresters are also frequently used to protect padmounted transformers and switchgear. This practice has resulted in a substantial number of surge arresters being used by the utilities. Arresters in general have demonstrated an excellent field service record with a failure rate of 1% or less per year. The total number of failures, however, is significant because of the very large number in service (presently estimated at 150 million).

When an arrester fails, the normally open or very-high-resistance circuit through the arrester changes to a low-resistance circuit, resulting in a phase-to-ground fault. This fault may be cleared in several ways, one of which is for the arrester to literally self-destruct. With virtually all of today's arresters designed for porcelain housings, a destructive failure results in the scattering of porcelain fragments and arrester parts with sufficient force to harm nearby equipment, personnel, and public property.

Of the total failures, a significant portion will occur in the self-destruct mode with sufficient violence to be a matter of concern to the utility industry.

General Electric has started a 2½-year project to determine the feasibility of eliminating or substantially reducing distribution surge arrester failures that result in fragmentation (RP1470). An investigation of the mechanical and physical conditions that exist during arrester failure will be conducted under various fault currents and durations.

Models will be developed, fabricated, and evaluated. Designs that show promise will be selected, and prototype 10-kV and 27-kV arresters will be built and evaluated in accordance with applicable ANSI standards. A significant quantity of completed units will be deliberately failed to verify that the arrester developed is truly nondestructive. *Project Manager: Robert J. Stanger*

Distribution load forecasting

Because of the size and nature of future distribution systems, system planners need a more refined load-forecasting and planning tool so they can make the most efficient use of scarce capital. Such a tool would be particularly valuable for small areas involving specific feeders and substations because growth rates tend to vary radically across a wide service area.

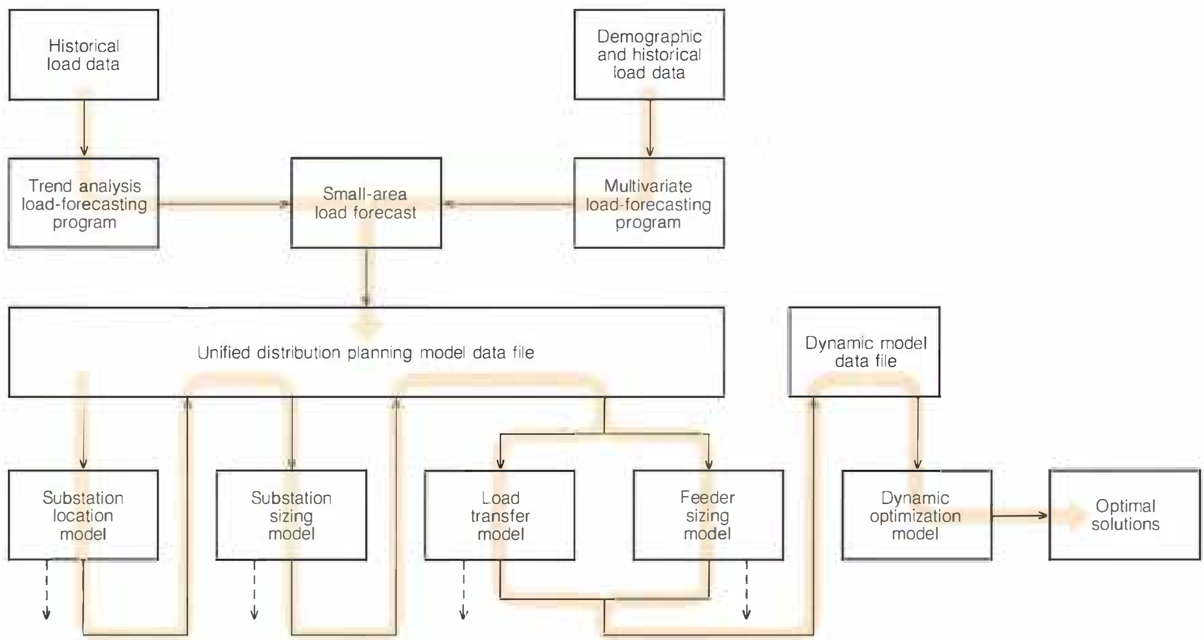
EPRI has just completed a four-year project that improved the existing forecasting methods (trend analysis) and provided new methods (multivariate spatial analysis) that will produce small-area load forecasts in which the distribution engineer can place increased confidence (RP570). Emphasis has been placed on the underlying factors that cause load growth, rather than on historical trends. Figure 4 illustrates that either the trend analysis or multivariate load-forecasting technique can be used to arrive at a small-area load forecast. Then, using the substation sizing model, location model, feeder model, and load transfer model, a utility can arrive at an optimal plan for any future year up to the horizon year. This project produced all the above computer models for utility use.

The load-forecasting models (either trend or multivariate) can be used with a range of computer hardware. The trend model should be attractive to the small utility that has a limited computer capability. Those with large computer capability can handle the factors responsible for load growth and take advantage of the multivariate model. This choice between fully developed distribution load-forecasting models has never been available to the distribution system planner before. Forecasting and planning programs and their respective user guides are available from the Electric Power Software Center. These models have been tested by using actual data from operating utilities—Pacific Gas and Electric Co. and the Salt River Project. The final report, EL-1198, is available from Research Reports Center. *Program Manager: William Shula*

Distribution data base design

Many utilities are in the process of designing and implementing computer-supported distribution system programs for planning, analysis, and control. Because of the size and complexity of utility distribution systems, the amount of data required for these programs is often staggering. In many cases, the ability to compute and analyze

Figure 4 Distribution load forecasting is a complex task, but it is also modular in nature and can be handled in serial fashion. Once a small-area load forecast is made (using either of two methods), these data can be applied to the planning models—substation location, substation sizing, load transfer, and feeder sizing—to arrive at the optimal expansion plan for any year up to the horizon year. Although the data are ultimately developed in the sequence indicated by shading, they can also be accessed at any time from the four planning models (dashed lines).



has exceeded the ability to organize the necessary data.

The design and implementation of such a data base is also very costly. A previous EPRI project (RP329) has shown that many commonalities can be expected in data bases designed by different companies. By determining where such commonalities exist, utilities planning to implement a distribution data base can avoid costly duplication of effort.

A recently completed project (RP1139) with Boeing Computer Services, Inc., had the following objectives.

▫ Determine the functions performed within a distribution department that should be supported by a distribution data base, considering present and future requirements.

▫ Develop a data base structure that will support the defined functions without tailoring the design for any particular utility, computer, operating system, or data base management system. The design must permit utilities to implement the various distribution functions on a piecemeal basis and in any chosen sequence.

▫ Develop the data base support system requirements.

▫ Provide guidelines for an economic analysis that will enable a utility to determine whether there is justification for implementation of a distribution data base.

The final report on this project is now available (EL-1150, 3 volumes). *Program Manager: William Shula*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

INDUSTRIAL RESPONSE TO TIME-OF-DAY PRICING

The combination of rapidly rising energy prices and increasing construction costs for new electric generating capacity has renewed interest in load management as a cost-saving tool for utilities. Load management can be direct load controls on end-use equipment or a pricing system in which electricity rates vary by time of day. One major factor in evaluating the desirability of such a pricing system is determining how customers will respond to the rates. EPRI's Demand and Conservation Program recently received results from one phase of a major project designed to investigate the potential response of industrial customers to time-of-day (TOD) rates (RP1212). This research identified several potentially effective strategies that industrial customers could follow in response to the adoption of TOD pricing. One particularly promising option appears to be increased use of in-plant generation during the time of peak period rates.

The idea of time-varying prices for electricity is based on the fact that generation costs vary by time of day, depending on the shape of the load curve and the fuel and generation mix employed. It is becoming increasingly clear that it would be efficient and cost-effective for utilities and for society as a whole if electricity rates corresponded to these time-varying costs. In fact, some electric utilities have already adopted TOD rates. Other utilities and state regulatory commissions are currently analyzing the feasibility and desirability of implementing TOD pricing of electricity, particularly in response to requirements set forth in the 1978 Public Utility Regulatory Policies Act.

EPRI's Demand and Conservation Program has sponsored several research projects dealing with the probable response of both residential and industrial customers to TOD rates. Projects focusing on the residential sector are RP882 (residential demand by time of day), RP943 (TOD and seasonal load forecasting), and RP1363 (residential response to TOD pricing).

A separate study is investigating the potential response of industrial customers to TOD rates (RP1212). Since such rates have not been employed extensively in the United States, historical data from which to statistically estimate responses are sparse. Thus the project was divided into two parts, one of which is examining European experience with TOD rates in the industrial sector and determining how applicable those results are to the United States. The other part of the project, recently completed, examined several U.S. industries from a detailed engineering perspective in an attempt to determine the potential response here.

The European portion of the project, undertaken by The Rand Corp., is using utility data and interviews with plant managers to identify the range of response to TOD rates in six major industries. Factors that appear to enhance or constrain responsiveness are examined in detail. These include production processes, labor shift wage differentials, demand for the industry's product, and regulation of cogeneration of electricity. Load data are being studied for the majority of very large industrial customers in England and France, along with data on industrial cogeneration in Sweden. This portion of the project is expected to be completed during the current year.

The U.S. portion of the project, performed by Gordian Associates Inc., was designed to provide an in-depth study (at the specific plant level) of the technical and economic potential for load shifting in response to TOD pricing for certain key industries. The procedure was to formulate specific load management strategies that are technically feasible under TOD rates and then assess the economic feasibility of each strategy on the basis of a cost-benefit analysis.

Seven industries were studied: petroleum refining, chlorine and caustic production, steel production, cement production, pulp and paper production, aluminum production, and pumping and pipelines. These were chosen because of the large amount of energy they use (in particular, electricity), and their likely amenability to load shifting. For each industry a representative sample of three or four plants (six for petroleum refining) were chosen to maximize the diversity of plant age, size, location, production processes employed, and level of self-generation of electricity. Data were collected from each plant on thermal energy consumption, electric energy consumption, and load patterns.

The study relied greatly on assistance from both plant personnel and utility personnel. The local electric utility was contacted and a meeting with the plant manager was requested. All on-site interviews were conducted in the presence of a utility representative and the plant manager or his designated representative. On the basis of engineering information about the production processes used by the plant, Gordian developed potential load management strategies that could be employed under TOD rates. The plant manager was asked to evaluate the technical feasibility of these strategies and to suggest alternatives.

Load management options

The following load management options were considered in the study.

▫ Petroleum refining industry: off-peak product loading; increased cogeneration equipment for maximum electricity generation during peak hours; incorporation of fuel cells

▫ Chlorine industry: increased production capacity in diaphragm cell plants; replacement of existing cells with membrane cells

▫ Steel industry: increased production capacity and holding furnaces in minimills; increased bar mill capacity in integrated mills

▫ Cement industry: increased raw material grinding and storage capacity; increased clinker grinding and storage capacity; demand limitation through off-season grinding; increased use of grinding capacity during off-season, off-peak hours

▫ Paper industry: storage of waste pulping liquors for increased self-generation during peak hours; increased digester capacity; increased capacity for self-generation during peak hours

▫ Aluminum industry: rotating load reductions from cell to cell during peak hours; incorporation of Alcoa's chloride process

▫ Pipeline industry: maximum scheduling of pumping during off-peak hours and increased storage capacity, as necessary

Some of these options represent minor technological changes in existing processes or changes in scheduling, whereas others represent major changes in capital equipment or traditional manufacturing methods. From a technical standpoint, however, each of the strategies is feasible.

The options requiring investment in new equipment fall into three general categories, which involve the following.

▫ Increasing production capacity so that loads can be shifted from the peak to the off-peak period

▫ Installing some type of storage device so that an electricity-intensive process can be performed during the off-peak period and the output held for further processing during the peak period

▫ Installing or increasing the capacity for cogeneration during peak hours

It is interesting to note that the goal of these load management options is somewhat different from the usual goal of load management (i.e., flattening or leveling a load curve). Most of the industries studied here are very capital-intensive and already have load curves that are nearly flat. Thus the problem is not to shave the peak off a peaked load curve, but to take a portion of a relatively stable load and move it from the time of the system peak to the off-peak period.

Economic feasibility

To evaluate the economic feasibility of each load management option, the estimated investment costs (on an annual basis, including return on investment) and any additional operating costs associated with the option were compared with the anticipated savings under a hypothetical TOD rate schedule. The resultant costs and benefits were then evaluated in terms of the peak–to–off-peak rate differential that would be required to make the option cost-effective. The conclusions are naturally sensitive to arbitrary financial assumptions about the required investments and to assumptions about the structure and level of utility rates. However, the intent of the study is to provide a rough filter for screening out those load management options whose costs far outweigh the anticipated benefits under reasonable rate structures. The remaining options can then be labeled potentially cost-effective.

On the basis of these assumptions and methods, the load management strategies listed below appear to be potentially cost-effective under industrial TOD rates.

▫ Petroleum refining industry: increased cogeneration equipment; incorporation of fuel cells

▫ Steel industry: increased production capacity and holding furnaces in minimills

▫ Cement industry: increased use of clinker grinding capacity during off-season, off-peak hours

▫ Paper industry: storage of waste pulping liquors for increased self-generation during peak hours; installation of cogeneration equipment for use during peak hours

▫ Pipeline industry: maximum scheduling of pumping during off-peak hours

These strategies, about a third of the technically feasible options considered in the study, represent all the general categories of options. About half involve cogeneration in one form or another.

Although cogeneration appears to be cost-effective as a load management strategy under TOD rates, there are numerous barriers to its widespread adoption by industry. These include institutional barriers and an aversion to economic risk on the part of industrial customers. Many of the barriers and risks involved were discussed at an EPRI workshop on cogeneration sponsored last spring in San Antonio, Texas, by the Demand and Conservation Program as part of RP1050. A quantitative assessment of the future impacts of industrial cogeneration on utility system loads will be made in 1980, using a forecasting model developed under RP942.

It should be noted that the cost-benefit analyses performed as part of this study are not intended to be definitive for any of the participating plants, companies, industries, or utilities. Instead, they are intended to serve as general guidelines for future work by indicating potentially cost-effective load management strategies under industrial TOD rates. However, the strategies examined are technically feasible in the sense that they represent real alternatives to present operations in the seven industries. The identification of technically feasible load management options provides a basis for potentially fruitful discussions between utilities and industries. Such discussions are a necessary first step in designing programs to reduce both utility system costs and customer service costs. *Project Manager: Steven Braithwait*

SULFATES AND MORTALITY: RISK ASSESSMENT

Recent newspaper and scientific journal articles have cited studies that associate large numbers of deaths with sulfate pollution from coal- and oil-burning power plants. EPRI-sponsored research (RP1316 and extensive in-house research) has carefully examined the studies relating sulfates to mortality and finds no general conclusion can be reached. Ambient levels of sulfate follow a general geographic gradient (west to northeast) and are highly associated with socioeconomic and demographic variables that follow the same gradient. This concurrence leads to confusion about what specific effects can be attributed to each type of variable. To date, studies have not sufficiently addressed this problem. A report by two members of EPRI's Integrated Assessment Program detailing these findings was recently submitted to the National Commission on Air Quality at its request.

The media have recently given attention to studies purporting to show that large numbers of deaths in the United States are due to pollution by sulfates. The *New York Times*, for example, cited an estimate by Brookhaven National Laboratory that 21,000 extra deaths occur each year east of the Mississippi because of sulfates in the atmosphere. The article also cited an estimate by two Yale University researchers that 140,000 deaths each year are related to air pollutants, principally sulfates (*1*).

EPRI is sponsoring research to assess the health effects of sulfates. To date the results from several animal toxicology and human clinical studies do not support any hypothesis that health effects are related to sulfates at ambient concentrations that typically occur in the United States (*2*). An ongoing epidemiological study (RP1001) is also examining the health effects of sulfates, but there are not yet sufficient results to allow inferences to be made.

Cross-sectional studies

The studies cited by the media are known as cross-sectional studies. They compare mortality rates at several different locations (e.g., cities or counties) and try to relate the geographic variation in mortality rates to the geographic variation in air quality. Mortality rates, however, depend on many factors in addition to air pollution. These include demographic factors (such as age, sex, race), socioeconomic factors (such as income, education), climate, occupational exposure, stress, personal habits (such as smoking, diet, exercise), and past medical history and care. To correctly estimate any association between mortality and air pollution, these factors must be considered; otherwise, some of the health effects attributed to air pollution could really be due to an ignored factor that is associated with both mortality and air pollution.

This problem is particularly troublesome in the case of sulfates because of their geographic distribution. Sulfate concentrations tend to be highest in the industrial Northeast and lowest in the West, with intermediate concentrations in the South. Several other factors that could influence mortality also vary geographically, such as climate, age and race distributions, occupational mix, diet, level of exercise, income, educational level, and quality of medical care. Unfortunately, good measurements of many of these factors are not available for the areas of study.

The Brookhaven estimate of 21,000 annual sulfate-related deaths east of the Mississippi is largely based on the work of Lave and Seskin (*3*). Their study, probably the most widely cited one that links mortality to sulfate pollution, uses a multiple regression statistical procedure to examine differential mortality in over 100 urban areas (standard metropolitan statistical areas) throughout the United States. The authors conclude that an 88% decrease in sulfur oxide emissions and a 58% decrease in particulate emissions from the 1971 control levels would lead to a 7% reduction in the unadjusted total mortality rate.

The Lave and Seskin study analyzes data for three years: 1960, 1961, and 1969. The 1961 data set overlaps substantially with the one for 1960 and cannot be considered an independent set. The greater part of the study involves analyses of the 1960 data. These analyses suffer from data quality problems, particularly for sulfates. Of the 117 sulfate data points for 1960, only three were actually measured in 1960. Most are from 1958, and some are from 1957 and 1959. This is of concern because there is apparently some downward trend in sulfate data during the 1957–1960 period. Moreover, three different measures of sulfate are used, and the sulfate value used in the analyses depends on the analytic method by which it was determined. It is impossible to determine how these inconsistencies in the data will affect the results of the analyses.

Despite the authors' conclusion, their results, particularly for sulfates, demonstrate variability. The conclusion is based on a linear model; however, some nonlinear models seem to fit the data better. One of these, the quadratic model, suggests that at elevated levels of minimum sulfates, health benefits can result from increasing sulfate levels.

In addition, Lave and Seskin's results are highly dependent on the adjustment variables used (e.g., socioeconomic, demographic, climate). In the fundamental analyses on which they base their conclusions, they use a minimum of adjustment variables. When the full complement of adjustment variables is used, the sulfate effect becomes negative (i.e., mortality decreases with increasing sulfates). It is noteworthy that this finding has been ignored by Lave and Seskin in their conclusions, as well as by the Brookhaven group. Other details of the Lave and Seskin study (statistical problems, for example) bring into question the validity of the conclusions that have been drawn from it.

The second study mentioned in the *New York Times* article, the one estimating that 140,000 deaths annually are related to air pollutants, is by Mendelsohn and Orcutt (*4*). This study is relatively recent and has not been presented in great detail; hence, scrutiny of its findings has been limited. It considers more adjustment factors than the Lave and Seskin study and compares the differential mortality of broader geographic units (county groups). The overall results of this study show a strong positive association between sulfates and mortality. However, statistically significant negative associations are found between mortality and other pollution variables—NO_2, ozone, nitrates, and particulates. These findings, which are contrary to biological and medical knowledge, strain the credibility of this study.

Other cross-sectional studies have examined the sulfate-mortality association. An EPA study (*5*) reports no quantitative results but concludes that "sulfate air pollution is statistically insignificant across all diseases." A study by Lipfert (*6*), who is presently at Brookhaven, estimates largely negative associations between mortality categories and the sulfate variable. Thomas (*7*) used the 1960 Lave and Seskin data but reports few results for sulfates because the data are not consistent.

Other studies have found positive associations between sulfates and mortality. These include a study by Schwing and McDonald (*8*, *9*) and one by Hickey et al. (*10*). Neither study considers total particulate pollution, however, which has been found (except by Mendelsohn and Orcutt) to be positively associated with mortality. With no consideration of this variable, it is difficult to determine the extent to which the sulfate variable is serving as an index for total suspended particulates and/or inhalable particulates.

In-house review

An in-house literature review prepared for the National Commission on Air Quality (*11*) examined the cross-sectional studies that attempt to estimate the risk of exposure to ambient sulfate concentrations. This review concludes that there is no clear-cut evidence of either the presence or the absence of a risk. Existing studies suffer from statistical problems and from ignorance about what adjustment factors are appropriate to consider. The results of existing analyses can be shown to be highly dependent on the choice of adjustment factors. Moreover, data from many potentially important adjustment factors are not available, thus limiting the comprehensiveness of analysis. In the absence of a consideration of all the potentially important factors, it would be unwise to draw any conclusions. *Program Manager: Ronald E. Wyzga*

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R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

DECAY HEAT CONSERVATISMS

Design standards for reactor cooling systems are set according to models that predict plant behavior under abnormal operating conditions. Because there is some uncertainty in the understanding and representation of certain physical phenomena that can occur during abnormal operation, safety margins (conservatisms) are built into the models. If such phenomena can be defined with greater accuracy and certainty, these margins can be narrowed, permitting greater reactor operating flexibility without reduction in real safety. One of the physical phenomena of interest is decay heat—the heat generated by radioactive decay of fission products after shutdown of the reactor core.

Decay heat conservatisms are specified by NRC in 10CFR50, Appendix K. For nuclear power plant licensing applications, these regulations specify that the estimate of decay heat given in the 1973 revision of American Nuclear Society (ANS) draft standard 5.1 be increased by 20%. Recent experiments sponsored by NRC at Oak Ridge National Laboratory and Los Alamos Scientific Laboratory, together with EPRI-sponsored experimental efforts by the University of California at Berkeley and IRT Corp., have significantly improved the accuracy to which decay heat from ^{235}U is known. ANS has arrived at a new draft standard by using this experimental information and a summation method based on the national nuclear reference library, ENDF/B. This method sums the decay energy contribution from the various ^{235}U fission products. The energy contribution of each fission product has been determined in independent experiments, which were evaluated prior to inclusion in ENDF/B. These analytic efforts were performed at Oregon State University (sponsored by NRC) and the University of California at Berkeley (sponsored by EPRI). Early in 1979, the 1978 revision of ANS 5.1 was adopted by ANS and the American National Standards Institute.

The 1978 revision of ANS 5.1 incorporates improved knowledge in two areas. First, the decay heat values are known to a better degree of accuracy. Second, the uncertainty of the decay heat values is specified in statistical terms, whereas the 1973 revision used an engineering estimate of uncertainty. As a result, the decay heat standard for the first 100 seconds has been slightly lowered, and the range of uncertainty has been narrowed significantly. The new standard falls entirely within the uncertainty band of the old (*EPRI Journal*, October 1978, pp. 61–63).

To evaluate the impact of improved knowledge about decay heat values, sensitivity calculations were performed for a generic representation of a PWR plant. The PWR accident studied was a double-ended, instantaneous cold-leg break, which can also

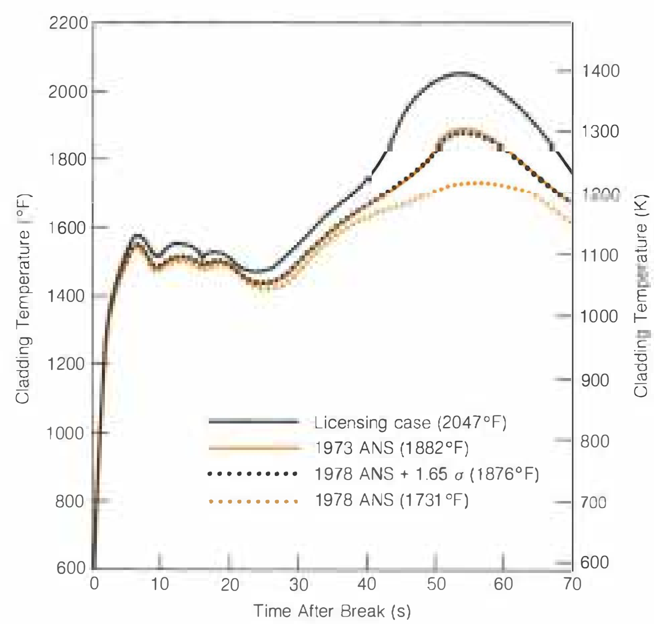


Figure 1 Cladding temperature calculations based on decay heat values from the 1973 and 1978 revisions of the ANS 5.1 standard. The licensing case is the standard required under 10CFR50, Appendix K, which adds 20% to the 1973 ANS values. The 1978 ANS + 1.65 σ curve results in a 95% probability with a 95% confidence level that the calculated decay heat is less than or equal to the specified decay heat. The temperatures in parentheses are the peak cladding temperatures during a large-break LOCA. NRC regulations require that the peak temperature remain below 2200°F (1478 K) to ensure the mechanical integrity of the cladding and the coolability of the reactor core under accident conditions.

be referred to as a large-break LOCA. Thermal-hydraulic boundary conditions were taken from a RELAP-4 computer code calculation, and NRC's FRAP-T code was used to generate the curves shown in Figure 1. Four cases were run.

- A licensing case with the decay power specified by ANS 5.1 (1973 revision), plus 20%
- A case with the decay power specified by the 1973 revision of ANS 5.1
- A case with the decay power specified by the 1978 revision of ANS 5.1
- A case with the decay power specified by the 1978 revision of ANS 5.1, plus 1.65 σ (where σ is the standard deviation)

This last approach is called the 95/95 approach because there is a 95% probability with a 95% confidence that the decay heat will be less than or equal to the ANS 5.1 standard, plus 1.65 σ. The 95/95 approach has been accepted by NRC licensing authorities as ensuring adequate conservatisms in other nuclear safety areas, and it is one option being informally considered in the revision of 10CFR50, Appendix K, which has been under way since 1978.

It is interesting to observe that the 1973 revision of ANS 5.1 is as conservative as the 95/95 approach. The more realistic 1978 revision results in a peak cladding temperature that is 175 K (316°F) lower than the one based on the current Appendix K standard. It should be emphasized that the calculations were representative and not performed according to strict licensing methods. Results are expected to differ on a plant-specific basis. The goal of this exercise was to demonstrate that the margin of safety intended by Appendix K can be maintained by adopting a scientifically more accurate and defensible rule based on the 1978 revision of ANS 5.1, with potential benefits in terms of fewer operating penalties for nuclear power plants and more operating flexibility. *EPRI staff contact: Richard N. Oehlberg*

FUEL FAILURE MODELING

LWR fuel rods are susceptible to leaks caused by cracking in the Zircaloy cladding tubes. Cracking occurs when high stresses to the cladding tube are combined with the movement of volatile fission products from the fuel pellets to the tube's inner surface. Fuel suppliers have found that these fuel failures can be avoided by limiting stress buildup through restrictions on power ascension rates. However, by increasing the time spent at lower power, such restrictions reduce the capacity factor of nuclear plants; this lost capacity currently costs U.S. utilities an estimated $150 million a year for replacement power. A portion of these costs can, in principle, be recovered if an accurate fuel failure model is available to help guide fuel purchasing and operating decisions. This has motivated a large EPRI effort to improve fuel failure prediction capability.

Historically, there have been two approaches in the development of fuel failure models. One, based on a mechanistic philosophy, involves modeling the separate phenomena of fuel failure—the stresses to the cladding, the transportation of volatile fission products to the cladding tube's inner surface, and the propagation of a crack across the tube wall. Belgonucléaire's COMETHE code is an example of this approach. The other approach, based on an empirical philosophy, involves the direct correlation of instances of in-reactor failure or nonfailure with design and operating experience for a specific fuel. The POSHO code, developed by Scandpower Inc., is an example of this approach. EPRI's involvement with both COMETHE and POSHO has been confined to evaluating their prediction capabilities and making relatively minor improvements.

In formulating plans for developing its own code, EPRI recognized that it was impossible to predict which approach, the mechanistic or the empirical, would ultimately prove most useful. Accordingly, the plans for EPRI's SPEAR code development program included both (RP971). Fuel failure predictions from a mechanistic model were combined with predictions from a separate empirical model; the relative weights assigned the two models in reaching a final prediction depend on their relative regime-by-regime prediction capability. The two approaches were further combined by using some intermediate variables from the mechanistic model (e.g., predicted cladding stress) as independent variables in the empirical model.

Some results on the relative merits of these approaches to fuel failure modeling have recently become available. COMETHE has not been tested against statistically relevant quantities of experimental data, but some indication of its prediction capability is provided by experience with the mechanistic model of SPEAR. This model is similar in scope to COMETHE and uses several of the same submodels for mechanics and chemical kinetics, but it is probably superior in that it contains several substantial improvements. The prediction capability of SPEAR's mechanistic model is shown in Figure 2, which compares the results of simulation

Figure 2 Prediction capability of the mechanistic model of the SPEAR fuel failure code. The results shown represent 170 events, aggregated into 10 equally populated groups. The shaded band defines the expected statistical scatter from a perfect predictor.

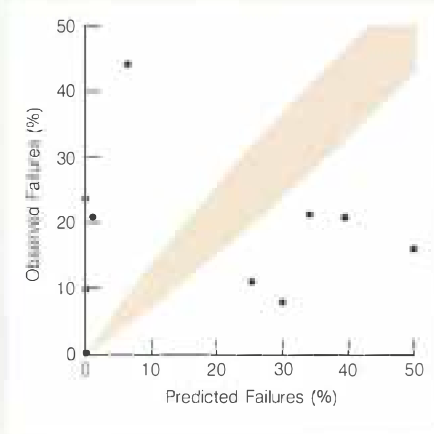


Figure 3 Prediction capability of the complete SPEAR code, which combines the predictions of separate mechanistic and empirical models. The data base is the same as in Figure 2.

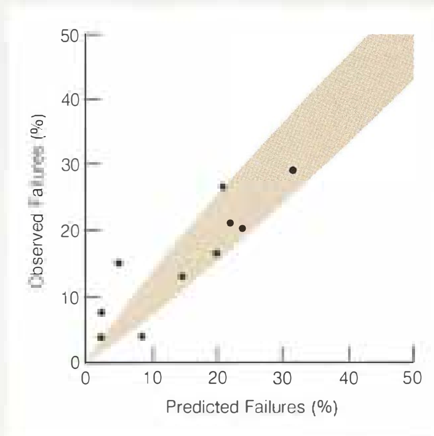
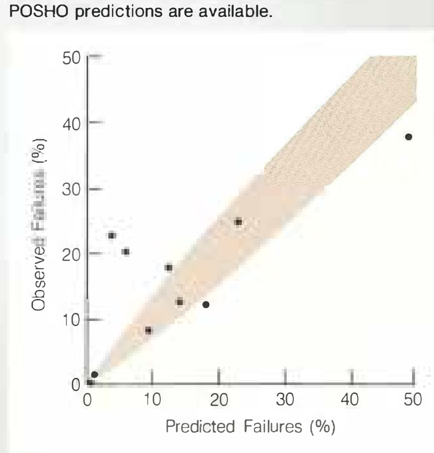


Figure 4 Prediction capability of a version of the POSHO code tested by EPRI in 1977. These results are based on the same data used in Figures 2 and 3 except for 4% of the events, for which no POSHO predictions are available.



runs with data from Maine Yankee (PWR), Quad Cities-2 (BWR), and Riso (test reactor). The results from the 170 runs are aggregated into 10 equally populated groups. The prediction capability is found to be mixed, being good for the group with the lowest failure probability but poor for the other groups. A perfect predictor of fuel failure probabilities would generate data points that (for statistical reasons) would be scattered within the shaded band.

Fortunately, while SPEAR's mechanistic model fails to adequately predict failures in the high-failure-probability regime, its empirical model is able to compensate for that shortcoming. Figure 3 compares the final SPEAR predictions, based on both mechanistic and empirical models, with the same data used in Figure 2. SPEAR predictions fall within the scatter band for high-failure-probability groups and only slightly outside the band for low-probability groups.

For comparison, Figure 4 shows the results of an EPRI evaluation of POSHO that used an almost identical data set. SPEAR's predictions are better than POSHO's by a factor of 2 in error magnitude. Perhaps more important, SPEAR predicts well for both BWR and PWR fuels; POSHO predicts well for BWR fuel but poorly for PWR fuel.

Considering how greatly SPEAR and POSHO differ in content, it is not surprising that they make different predictions. POSHO relates failure to relatively few factors, the most important of which is power shock, or the estimated magnitude of stress induced in cladding tubes during power ascensions; it does not take into account the effects of the rod's internal chemical environment. In contrast, SPEAR relates failure to a much larger number of factors, prominent among which are various aspects of the internal rod chemistry. SPEAR's empirical model finds in the data a fracture process in which the controlling step is a prolonged crack initiation phase dominated by internal rod chemistry and cladding plastic strain. Possibly it is only in the final crack propagation phase that the process is, as POSHO assumes, stress-controlled.

A first version of SPEAR, version alpha, is being evaluated by a working group of representatives from four utilities to ensure that the code can be readily mounted by utilities and that its documentation is clearly written. The data base against which the code has been tested will be expanded slightly. Workshops on effective use of the code will begin in May 1980. If the recommendation of the working group is positive, SPEAR should be available through the Electric Power Software Center by July 1980. *Project Manager: S. T. Oldberg*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP399-5	Feasibility Study for Turbine Missile Spin Tests	9 months	39.7	Southwest Research Institute *G. Sliter*
RP789-3	Development of Advanced Air Source Heat Pumps for Improved Performance and Reliability in Northern Climates	15 months	191.7	Carrier Corp. *R. Mauro*
RP1030-9	Chemical Comminution of Coal	6 months	56.0	Catalytic, Inc. *R. Sehgal*
RP1030-13	Dewatering of Fine Clean Coal and Refuse	2 years	149.5	University of California *R. Sehgal*
RP1162-3	Transient Density Measurements in Two-Phase Flow	3 months	14.2	Atomic Energy of Canada Ltd. *S. Pal Kalra*
RP1179-6	Evaluation of Fly Ash Recycle for Fluidized-Bed Combustion	3 months	11.9	General Atomic Co. *C. Aulisio*
RP1180-11	Evaluation of Emission Control and Combustion Control Devices and Related Technology	2 years	50.0	Kaiser Engineers, Inc. *O. Tassicker*
RP1219-4	Transportation Network Changes and Their Effects on Energy Supply	13 months	44.9	Russian Hill Associates *E. Altouney*
RP1260-17	Review of Models and Data for Predicting Performance and Evaporation from Cooling Ponds	6 months	37.5	Massachusetts Institute of Technology *J. Bartz*
RP1265-8	Failure Cause Analysis —Air Preheaters	1 year	76.6	KVB, Inc. *I. Diaz-Tous*
RP1282-2	High-Voltage Line Research Above ± 600 Volts	4 years	4361.5	General Electric Co. *J. Dunlap*
RP1393-3	Refueling Outage Improvement	2 years	753.8	General Electric Co. *T. Law*
RP1455-5	Performance Analysis of a Utility Boiler Firing Coal-Oil Mixture Fuel	18 months	303.1	Babcock & Wilcox Co. *S. Drenker*
RP1460-1	Protective Claddings for Utility Gas Turbines	30 months	741.3	General Electric Co. *J. Stringer*
RP1549-2	Probabilistic Analysis of Turbine Missile Risks	2 years	176.9	Research Triangle Institute, Inc. *B. Chu*
RP1584-1	Qualified Core Thermal Hydraulics Analysis Code for Utility Applications	16 months	248.9	Battelle, Pacific Northwest Laboratory *J. Naser*
RP1630-3	Western Regional Air Quality Studies	18 months	760.3	Dames & Moore *G. Hilst*
RP1646-2	Low Nitrogen Oxide Combustion Tests on Arapahoe Unit 4	13 months	137.1	KVB, Inc. *D. Giovanni*
RP1654-1	Plastic and Coking Behavior of Coals at Elevated Pressure	1 year	40.0	Pennsylvania State University *J. Yerushalmi*
RP1717-1	Transmission Line Mechanical Research Facility	5 months	206.5	Ebasco Services Inc. *R. Kennon*
RP1768-1	Development of an Alpha-Ionization Gas Density Monitor	7 months	49.7	Sigma Research, Inc. *V. Tahiliani*
T109-2	Qualification of Last-Pass Heat Sink Welding, Using Stagnant Water Cooling	5 months	244.5	Boston Edison Co. *M. Fox*
T119-1	Pipe Repair Replacement Design Study	14 months	90.0	MPR Associates, Inc. *J. Danko*

New Technical Reports

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

Inquiries on technical content may be directed to the EPRI project manager named at the end of each summary: P.O. Box 10412, Palo Alto, California 94303; (415) 855-2000.

Requests for copies of specific reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 961-9043. There is no charge for reports requested by EPRI member utilities, government agencies (federal, state, local), or foreign organizations with which EPRI has an agreement for exchange of information. Others pay the listed price. Research Reports Center will send a catalog and price list on request.

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ADVANCED POWER SYSTEMS

Steam-Injected Gas Turbine Study: An Economic and Thermodynamic Appraisal

AF-1186 Final Report (TPS77-737); $3.50

A steam-injected gas turbine was compared with a simple-cycle gas turbine and a combined-cycle gas turbine for the cost of electricity produced, specific power, and efficiency. The results show that the steam-injected gas turbine would produce electricity at a lower cost than either the simple-cycle or the combined-cycle turbine over almost the whole range of applicable capacity factors. The system would require a redesigned turbine expander with a much larger flow capacity than that of a standard gas turbine. The contractor is General Electric Co. *EPRI Project Manager: Arthur Cohn*

Heat Rejection From Geothermal Power Plants

ER-1216 Final Report (RP927-1); $7.25

Comprehensive computer programs were developed to determine makeup-water requirements and electricity production costs associated with evaporative (wet) cooling and wet-dry cooling systems, which are the principal technologies for heat rejection in hydrothermal power plants. Parametric economic analyses were performed for both flashed-steam and binary-cycle conversion processes for various combinations of resource temperatures, climatic factors, hydrothermal fuel costs, and cooling-system makeup-water costs. Results are presented in curves showing busbar electricity costs as a function of makeup-water requirements. The contractor is R. W. Beck and Associates. *EPRI Project Manager: P. N. La Mori*

Electrode System Maintenance Processes in Slagging MHD Generators

AF-1223 Final Report (RP322-1); $8.75

The use of stable, flowing coal slag to protect cooled wall structures and to limit heat loss in the topping-cycle environment of a coal-fired, open-cycle magnetohydrodynamic (MHD) power generation process was studied. Data were obtained on mineral deposition, slag coating growth mechanisms and rates, and steady-state coating properties. Combinations of several exposed refractories and cooled metal substrates were evaluated as bonding surfaces for the slag coating. Flow and transport models were developed and compared with experimental results. The contractor is Avco Everett Research Laboratory, Inc. *EPRI Project Manager: P. S. Zygielbaum*

Coal to Methanol via New Processes Under Development: An Engineering and Economic Evaluation

AF-1227 Final Report (RP832-1); $5.25

This report presents an engineering and economic evaluation of two coal-to-methanol production schemes. The two coal conversion complexes described are designed to produce, per day, a quantity of storable liquid fuels with a heating value equivalent to that of 50,000 barrels of crude oil distillate. Two coals were investigated in two different plant configurations: Illinois No. 6 coal in an all-methanol scheme and Wyodak subbituminous coal in a methanol and distillate fuel oil coproduction scheme. The contractor is C F Braun & Co. *EPRI Project Manager: Nandor Herskovits*

Open-Cycle MHD Systems Analysis

AF-1230 Final Report (RP640-2); $6.50

This study investigated the performance and economic characteristics of six open-cycle magnetohydrodynamic (MHD) power plant options: four with directly fired air preheaters, one with separately fired air preheaters, and one with oxygen enrichment. For the directly fired options, the study compared the effects of high-sulfur eastern coal and low-sulfur western coal, sulfur emissions control by seed regeneration and by wet limestone scrubbers, and slag removal performance in the MHD combustor unit. Critical components requiring further development were identified. The contractor is STD Research Corp. *EPRI Project Manager: Andrew Lowenstein*

Catalyst Development for Coal Liquefaction

AF-1233 Final Report (RP408-1, RP408-2); $13.50

Research to develop improved catalysts for use in the H-Coal liquefaction process is summarized. Part 1 describes slurry oil production and the development and application of catalysts for liquefaction of various eastern and western coals. Part 2 describes preparation of 500 lb of one experimental catalyst, Amocat 1A, to evaluate its commercial feasibility. Preliminary bench-scale evaluation of the catalyst is discussed. The contractors are Amoco Oil Co. and W. R. Grace & Co. *EPRI Project Manager: W. C. Rovesti*

Proceedings of the Third Annual Geothermal Conference and Workshop

WS-79-166 Workshop Proceedings; $8.75

This is a compilation of papers presented at the Third Annual Geothermal Conference, held in Monterey, California, in June 1979. Included are reports on EPRI geothermal projects and utility projects and plans, as well as summaries of the workshop panel discussions on the next generation of geothermal power systems. The contractor is Altas Corp. *EPRI Program Manager: Vasel Roberts*

COAL COMBUSTION SYSTEMS

Nuclear Assay of Coal: Coal Btu Measurement Study—Monitoring of Moisture in Coal

FP-989 Final Report, Vol. 5 (RP1048-7); $4.50

Two electromagnetic techniques, capacitance response and microwave absorption, were investigated for on-line moisture monitoring of coal. Instruments using these techniques were tested on a representative range of U. S. coal types and moisture levels. Uncertainties in moisture determination of less than 5% were obtained with both techniques. However, microwave interrogation was judged better for on-line application because it is both accurate and unobtrusive. In such applications, this technique will allow the coal's Btu value to be deduced to accuracies of 2% or better. The contractor is Science Applications, Inc. *EPRI Project Manager: C. J. Frank*

Conceptual Design of a Gulf Coast Lignite-Fired Atmospheric Fluidized-Bed Power Plant

FP-1173 Final Report (RP1179-1, RP1180-1); $9.50

This report compares the design and the capital and busbar power cost estimates for an atmospheric fluidized-bed combustion (AFBC) plant with those for a conventional power plant that uses wet SO_2 scrubbers. The comparison was based on the combustion of a low-grade Texas lignite. According to the cost and performance estimates developed, the AFBC plant can be expected to yield a cost savings of 10–15% in both capital investment and levelized busbar cost of electricity for this type of fuel. The contractor is Burns and Roe, Inc. *EPRI Project Manager: C. R. McGowin*

Evaluation of Flood Levels for Solid-Waste Disposal Areas

FP-1205 Final Report (RP1260-9); $7.25

The potential impact on the utility industry of EPA regulations that restrict the disposal of solid wastes in floodplains are examined. Locations of present and future coal-fired plants with respect to riverine and coastal floodplains were surveyed, and a plant-by-plant computer listing of the survey results is included. Federal Insurance Administration methods of flood mapping, used to enforce EPA solid-waste regulations, are assessed, and preliminary guidelines for responding to EPA flood-level regulations are given. The contractor is Hydrocomp, Inc. *EPRI Project Manager: D. M. Golden*

Disposal of Polychlorinated Biphenyls and PCB-Contaminated Materials

FP-1207 Final Report, Vol. 1 (RP1263-1); $13.50

Results of a study on the disposal management of polychlorinated biphenyls (PCBs) and PCB-contaminated materials are reported. A PCB disposal data base is presented, which includes information on PCB production and use, PCB disposal regulations, projected regional PCB disposal requirements, available PCB incineration technology and proposed commercial facilities, and PCB landfill design and available commercial facilities. Industrywide and utility-specific PCB disposal guidelines and recommendations are given. The contractor is SCS Engineers. *EPRI Project Manager: D. M. Golden*

Disposal of Polychlorinated Biphenyls and PCB-Contaminated Materials: Suggested Procedure for Development of PCB Spill Prevention Control and Countermeasure Plans

FP-1207 Final Report, Vol. 2 (RP1263-1); $5.75

This volume provides specific guidelines for preparing spill prevention control and countermeasure plans for activities involving polychlorinated biphenyls (PCBs). It reflects regulatory requirements as of May 31, 1979. Included are instructions relevant to plan preparation, sample and optional blank forms for meeting requirements and documenting spill prevention and control at the facility level, examples of response and cleanup procedures, and a discussion of specific regulatory requirements. Also included are forms that focus on individual facilities where PCB control may be important. The contractor is SCS Engineers. *EPRI Project Manager: D. M. Golden*

Pulverizer Failure Cause Analysis

FP-1226 Final Report (RP1265-1); $5.75

This study examined the problem of pulverizer outages and identified root-cause failure modes for the major mill types currently in service. A data base of 469 pulverizers was compiled and analyzed to identify both design and operating problems. Five problem areas were established and evaluated: drive components, grinding zone, air system, mill fires and explosions, and boiler problems associated with the pulverizer. Recommended solutions to some of the more common problems are given. The contractor is KVB, Inc. *EPRI Project Manager: I. A. Diaz-Tous*

Mössbauer-Effect Spectroscopic Study of Pyritic Sulfur in Coal

FP-1228 Final Report (RP267-2); $3.50

This report describes the adaptation of the Mössbauer spectroscopic technique for use in measuring the percentage of sulfur in coal samples. It reviews the method's salient features, outlines optimal experimental techniques and required equipment, compares the method with ASTM wet chemical procedures, and analyzes experimental error sources and measurement time requirements. The contractor is General Electric Co. *EPRI Project Manager: W. W. Slaughter*

Prediction of the Impact of Screening on Refuse-Derived Fuel Quality

FP-1249 Final Report (RP1180-6); $4.50

Systems for recovering refuse-derived fuel (RDF) from municipal solid waste, as well as means of predicting and evaluating the performance of these systems, were investigated. Models were developed for four unit processes: size reduction, air classification, magnetic separation, and pretrommeling. Results show that screening either the unshredded raw refuse or the product RDF stream improves the combustion properties of the RDF by reducing its ash, glass, and moisture content. The contractors are Cal Recovery Systems, Inc., and Midwest Research Institute. *EPRI Project Manager: C. R. McGowin*

Plant Performance Testing and Evaluation Workshop

WS-78-134 Workshop Proceedings; $11.25

A utility-vendor workshop on plant testing methods and their evaluation, held in Houston, Texas, was sponsored by Houston Lighting & Power Co. and EPRI in November 1978. This report contains the papers presented, a summary of the working group sessions, and the results of a questionnaire on plant testing. The papers cover a wide spectrum of topics, including detailed plant modeling, in-plant experience with boiler and turbine testing, and proper application of instrumentation and data acquisition systems. The contractor is Science Applications, Inc. *EPRI Project Manager: David Poole*

ENERGY ANALYSIS AND ENVIRONMENT

Evaluation of a Cooling-Lake Fishery: Lake Sangchris Ecosystem Modeling

EA-1148 Final Report, Vol. 2 (RP573); $8.75

This volume describes the theories, supporting data, and mathematical formulations used in developing models of the ecosystem of Lake Sangchris, a cooling lake. The structure and function of each of the two major models developed—a physical model (TEMP) and a primarily biological cooling-lake ecosystem model (CLEM)—are fully documented. The contractor is the Illinois Natural History Survey. *EPRI Project Manager: J. Z. Reynolds*

Correction of End Effects in Energy Planning Models

EA-1231 Final Report (TPS77-727); $3.50

This report analyzes three procedures to mitigate end effects (i.e., distortions) in planning-model outputs that result from planning over a fixed time span rather than the indefinite future. The procedures—the truncation, salvage or bequest value, and dual equilibrium methods—were compared in terms of simplicity, computation difficulty, generality, and flexibility and then tested in calculations using an energy planning model. The dual equilibrium method was superior on the basis of both theoretical and numerical considerations. The contractor is the University of California at Berkeley. *EPRI Project Managers: J. J. Karaganis and R. G. Richels*

Methodology for Assessing Population and Ecosystem Level Effects Related to Intake of Cooling Waters

EA-1238 Final Report (RP876); $7.25

This report presents available methods for assessing population and ecosystem effects of the impingement and entrainment of major fish and invertebrate species. It describes quantitative techniques for determining the effects of power plant intake and water withdrawal on marine mortality, and presents a framework for using these techniques that relies on the investigator's judgment. It also provides guidance in the interpretation of calculated or measured effects. The contractor is Lawler, Matusky & Skelly Engineers. *EPRI Project Manager: J. Z. Reynolds*

Power Shortage Costs and Efforts to Minimize: An Example

EA-1241 Interim Report (RP1104-1); $3.50

Estimates of the costs of a prolonged electric power shortage in Key West, Florida, during the summer of 1978 are given. During this shortage, users were periodically disconnected over a 26-day interval. Willingness-to-pay estimates are presented and discussed for residential and nonresidential users. Also included is a discussion of shortage preplanning. The contractor is Jack Faucett Associates, Inc. *EPRI Project Manager: A. N. Halter*

Workshop Proceedings: Integration of Environmental Considerations Into Energy-Economic System Models

WS-78-95 Workshop Proceedings; $10.50

An advisory workshop on integrating environmental considerations into energy-economic system models was held at Eastbound, Washington, in October 1978. These proceedings include a discussion of integrated assessment modeling, the papers presented at the workshop, summaries of the workshop discussions, and research recommendations. The appendixes present supplementary materials and a list of participants. The contractor is Sigma Research, Inc. *EPRI Project Manager: Ronald Wyzga*

ENERGY MANAGEMENT AND UTILIZATION

Detailed Designs and Construction: Individual Load Center—Solar Heating and Cooling Residential Project

ER-1206-SY Summary Report (RP549); $3.50

This report summarizes the design, construction, and instrumentation of 10 experimental load-managed solar residences. It outlines the design and procurement approach for the experimental subsystems (solar, load management, heat pump, and instrumentation and control) and describes the information-processing procedure. A series of pictures shows the construction process, the integration of solar collectors into houses of different architectural styles, and the solar and load management systems. The contractor is Arthur D. Little, Inc. *EPRI Project Manager: Gary Purcell*

Thermal Energy Storage for Steam Power Plants

EM-1218 Final Report (RP1082-1); $12.50

The selection of four systems that integrate thermal energy storage (TES) with central-station steam power plants is discussed. Results of recent work, detailed conceptual designs, performance predictions, and cost estimates are presented for each of the four systems. Also included is a cost-value analysis (based on utility economics) that compares the best of the TES-power plant systems with conventional generation alternatives. Results show that in terms of performance and costs, even the best of these systems could not compete in near-term utility applications with cycling coal plants and typical gas turbines available for peaking power. The contractor is General Electric Co. *EPRI Project Manager: W. A. Stevens*

NUCLEAR POWER

UO_2 Pellet Fragment Relocation: Kinetics and Mechanics

NP-1106 Final Report (RP508-1, RP508-2); $4.50

This report describes tests that provided data on the complex behavior of uranium oxide fuel pellets under power. An experimental out-of-reactor apparatus was constructed that is capable of heating a pellet column to operating temperatures. Power was provided by direct electric resistance heating of the pellet material itself, and heat was removed by a recirculating helium loop. A variety of sensors monitored the response to power cycling of both clad and unclad pellet stacks. Statistical analyses of the 13,000-event data base are presented. The contractors are Argonne National Laboratory and Entropy Limited. *EPRI Project Manager: S. T. Oldberg*

Human Factors Methods for Nuclear Control Room Design: Human Factors Enhancement of Existing Nuclear Control Rooms

NP-1118 Final Report, Vol. 1 (RP501-3); $3.50

Human factors engineering concepts were applied to the design of control boards in nuclear power plants that are operational or near operational. Two levels of board enhancement were considered: surface modifications that could be made without interruption of plant operation and more substantial reworking that could be accomplished during anticipated or scheduled shutdowns. The contractor is Lockheed Missiles & Space Co., Inc. *EPRI Project Managers: R. W. Pack and H. L. Parris*

Computational Method to Perform the Flaw Evaluation Procedure as Specified in the ASME Code, Section XI, Appendix A: General Description and Background

NP-1181 Key Phase Report, Part 1 (RP700-1); $4.50

This report presents the background, general description, capabilities, and restrictions of the computer program FACET, which is designed to perform quickly and accurately the flaw evaluation specified in Appendix A of Section XI of the ASME Code. The contractor is Failure Analysis Associates. *EPRI Project Manager: F. E. Gelhaus*

Water as a Means of Cable Fire Protection: Operational Effects Experience

NP-1193 Final Report (TPS77-745); $4.50

Cases of fire loss involving plant cable systems, switchgear, relays, and equipment rooms are documented. The use of water on cable fires and the effects of water on electrical switching and control equipment are discussed. The study concludes that the most effective way to extinguish cable fires is with the rapid application of water, except for fires located where water would cause damage to switchgear and control equipment and thus increase the fire hazard. A list of criteria for the application of water is included. The contractor is Factory Mutual Research Corp. *EPRI Project Manager: Roy Swanson*

Review of the PBF Program as a Source of Data for Qualification of Fuel Behavior Codes

NP-1202 Final Report (RP694); $4.50

NRC's Power Burst Facility (PBF) test program was evaluated in terms of its usefulness in the qualification of fuel behavior codes employed in the licensing of nuclear power plants. Fuel performance parameter ranges from selected design-basis events were compared with experimental conditions. Data adequacy was judged on the basis of completeness and required accuracy for use in transient fuel behavior code assessment. The contractor is Intermountain Technologies Inc. *EPRI Project Manager: R. N. Oehlberg*

Comparison of Experimental Results With Analytic Predictions for LOFT L2-2

NP-1204 Interim Report (RP496-1); $7.25

In this report, analytic predictions of the first loss-of-fluid test (LOFT L2-2) are compared with actual test results. The predictions were made with the RETRAN thermal-hydraulic computer code. LOFT L2-2 was a full-area, double-ended, cold leg break simulation, with the core operating at 24.88 MW (maximum linear heat generation of 27.37 kW/m). The validity and usefulness of the experimental results are also reviewed. The contractor is Intermountain Technologies Inc. *EPRI Project Manager: L. J. Agee*

Analysis of Pipe Whip

NP-1208 Final Report (RP1324-1); $4.50

This is a state-of-the-art assessment of the analysis of structural response to postulated pipe breaks. The work focused on the structural response of the broken pipe and of the restraints and other structures with which it interacts. Practical techniques are suggested for modeling the dominant phenomena involved in pipe whip: large motions of beam-type structures, rate-dependent elastic-plastic material behavior, dynamic response, and impact. The contractor is Hibbitt & Karlsson, Inc. *EPRI Project Manager: H. T. Tang*

Measurement of the Thickness of Liquid Film by the Capacitance Method

NP-1212 Interim Report (RP1379); $3.50

A technique was developed for measuring water film thickness in a two-phase annular flow system by the capacitance method. Theoretical principles were applied to estimate the capacitance value as a function of the film thickness. An experimental model of the flow system was constructed, with two types of electrodes mounted on the inner wall of a cylindrical tube. The ability of the apparatus to detect fluctuations and wave motions in the water film passing over the electrodes was evaluated. The contractor is Lawrence Berkeley Laboratory. *EPRI Project Manager: J. P. Sursock*

Improvement of Nuclear Castings by Application of Hot Isostatic Pressing

NP-1213 Final Report (RP1249-1); $5.75

Hot isostatic pressing (HIP) was investigated as a means of healing subsurface pore defects and tears in cast stainless steel valve components for nuclear power plants. When the internal defects were not connected to the surface of the casting by a gas path, HIP was effective in healing porosity (even when oxidized surfaces were present) and in restoring material with hot tears to normal property levels. Defects connected to the surface by gas paths could not be healed unless the component was enclosed in an impermeable membrane. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: J. T. A. Roberts*

Fort St. Vrain Experience: Phase 4, Follow-On Studies

NP-1214 Final Report (RP457-1); $5.75

This report examines various aspects of the start-up of the first large high-temperature gas-cooled reactor and its initial operation at power levels from 30% to 70% of rated reactor power. Five specific topics are covered: resolution of core flux instrumentation decalibration questions, steam generator system thermal performance, overall performance of plant control and protection systems, heat load distribution in the liner-cooling system of the prestressed concrete reactor vessel, and primary-system temperature oscillations. The contractor is The S. M. Stoller Corp. *EPRI Project Manager: James Kendall*

Local Response of Reinforced Concrete to Missile Impact

NP-1217 Final Report (RP393-1); $8.75

An experimental and analytic study was conducted to determine the response of reinforced concrete to impacts from tornado debris and other missiles considered in nuclear plant design. The study included laboratory-scale missile impacts, experiments to measure material properties, computational model development, and two-dimensional simulations of missile impacts. Recommendations for model refinement and extension to other impact conditions are given. The contractor is SRI International. *EPRI Project Manager: G. E. Sliter*

Preliminary Design: Duplex Tube Low-Pressure Saturated-Steam Generator for Large LMFBR Plants

NP-1219 Final Report (RP620-29); $9.50

The preliminary design was completed for a large duplex tube steam generator module suitable for an LMFBR plant operating with a saturated-steam cycle. The study identified areas of concern that must be resolved by development tests before a commitment to the detail design can be made. The work scope of these development tests was defined. The contractor is Foster Wheeler Energy Corp. *EPRI Project Manager: J. G. Duffy*

A Review of Seismic Isolation for Nuclear Structures

NP-1220-SR Special Report; $5.25

This is a state-of-the-art survey of seismic isolation techniques and an assessment of the feasibility, potential benefits, and possible problems associated with the use of seismic isolation devices in the nuclear industry. It concludes that isolation devices that make use of springs, hysteretic dampers, friction plates, and floating platforms are feasible for nuclear applications. Recommendations for further research are included. The contractor is Dames & Moore. *EPRI Project Manager: Conway Chan*

Evaluation of Near-Term BWR Pipe Remedies

NP-1222 Final Report (RP701-1); Vol. 1, $2.75; Vol. 2, $12.00

This project is one of several that are examining the phenomenon of intergranular stress corrosion cracking (IGSCC) in welded type-304 stainless steel BWR piping. Volume 1 contains a brief summary of the significant technical data generated in an evaluation of near-term remedies, including postweld solution heat treatment, application of a corrosion-resistant cladding to the weld-heat-affected zone, and heat sink welding. It describes the rationale for each remedy and the procedures involved in applying it. Volume 2 describes in detail (1) full-size welded-pipe screening tests conducted to determine the susceptibility of reference type-304 stainless steel to IGSCC and to assess candidate remedies and protection methods, (2) a statistical evaluation of the most promising remedies and protection methods, (3) electrochemical studies of corrosion and oxidation potential, conducted both in the laboratory and in an operating BWR, and (4) a study of the effect of ferrite on the intergranular stress corrosion behavior of type-308 stainless steel. The contractor is General Electric Co. *EPRI Project Manager: J. C. Danko*

Feasibility Study for a Plasticity Model to Describe the Transient Thermomechanical Behavior of Zircaloy

NP-1224 Final Report (RP1321); $3.50

This study assessed the feasibility of applying the endochronic theory of plasticity to the transient thermomechanical behavior of Zircaloy. Advantages are the simplicity of the physical basis of the theory and the unified manner in which it could account for effects of deformation history, temperature, and neutron irradiation. Computational comparisons of three constitutive models for Zircaloy were made. The contractor is Systems, Science & Software. *EPRI Project Manager: R. N. Oehlberg*

Crack Arrest Studies

NP-1225 Final Report (RP303-1); $4.50

This report describes crack arrest studies that addressed the issue of whether a simple procedure that uses linear elastic fracture mechanics and static stress calculation is adequate for dealing with crack propagation and arrest in reactor vessels. The report discusses the significance of crack arrest toughness testing, compares crack arrest methodologies, and considers crack arrest in a simulated loss-of-coolant accident. The codified procedures for treating crack arrest were demonstrated to be adequate. The contractor is Materials Research Laboratory, Inc. *EPRI Project Manager: T. U. Marston*

Development of an Ultrasonic Imaging System for the Inspection of Nuclear Reactor Pressure Vessels

NP-1229 Final Report (RP606-1); $6.50

This report describes the development of an experimental model of an ultrasonic linear-array system for the inspection of weldments in nuclear reactor pressure vessels. The imaging system is designed to operate in both pulse-echo and holographic modes. It uses a sequentially pulsed, phase-steered linear array to develop pulse-echo images and a line-focused illuminating transducer in conjunction with a linear receiver array to develop reconstructed holographic images. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: J. R. Quinn*

Nondestructive Evaluation Program: Progress in 1979

NP-1234-SR Special Report; $16.00

This is a comprehensive review of EPRI's Nondestructive Evaluation Program. The major portion consists of contractor-supplied descriptions of current projects, which summarize progress and define project significance. An organizational overview of the program is also presented. *EPRI Project Manager: G. J. Dau*

Core Performance Benchmarking: Edwin I. Hatch Nuclear Plant, Unit 1, Cycle 1

NP-1235 Final Report (RP1178-1); $8.75

The first combined application of CASMO, an assembly analysis code, and SIMULATE, an advanced nodal core code, to BWR benchmarking is discussed. The codes were used to model cycle 1 of Hatch-1. The SIMULATE results were compared with gamma scan measurements at the end of cycle 1 and with the process computer data at selected points throughout the cycle to evaluate that code's ability to predict power distributions and reactivity in an operating BWR. The contractor is Southern Company Services, Inc. *EPRI Project Manager: W. J. Eich*

Value-Impact Analysis

NP-1237 Final Report (RP1233-4); $5.25

This report reviews the state of the art of value-impact (benefit-cost) analysis and takes a first step in developing a comprehensive value-impact methodology for application in the nuclear industry. Various methods of value-impact analysis are presented, and their usefulness in a particular nuclear licensing problem (anticipated transients without scram) is assessed. Recommendations for future development work are made. The contractor is Science Applications, Inc. *EPRI Project Manager: G. S. Lellouche*

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