Water: Pinch on Energy Development

ELECTRIC POWER RESEARCH INSTITUTE

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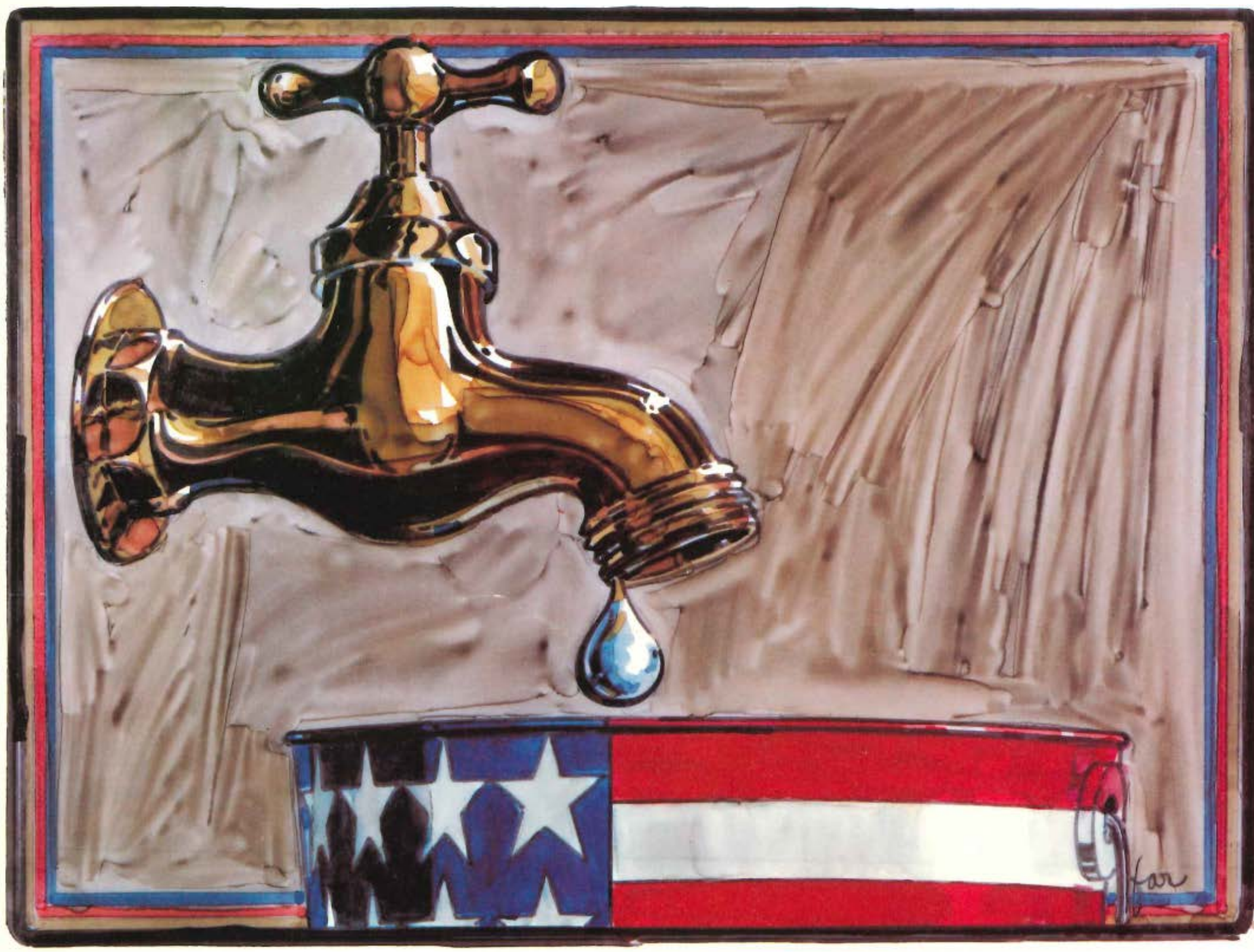

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Cover: The nation's water resources are
vast, but increasing use and competition are
creating pockets of thirst that will affect energy
development.

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Water Shortage: Real or Contrived?

Is there enough water? Is water a limit to growth? These questions are being raised with increasing frequency, particularly in discussions of energy supply. We read repeatedly that there is insufficient water to support accelerated development of our coal resources; that power production will divert water supplies from farms and thirsty cities; that water is too precious to waste on cooling power plants.

Is this a real issue or a contrived one? The nation has always been thought of as lush and water-rich, and the figures would seem to bear this out. The national average water precipitation on the conterminous 48 states is 30 inches a year—over 4200 billion (10^9) gallons a day. About 1200 billion gallons a day run off to the seas; groundwater reserves within 2500 feet of the surface are enormous; and total withdrawals average only 350 billion gallons a day.

However, averages are misleading; the facts are these. Based on detailed regional water balances, the U. S.Water Resources Council in the 1975 Water Assessment Report concludes that nearly two-thirds of the nation has consumptive water requirements exceeding 20% of current stream flows. These figures are based on average years; the actual situation in many years may be much worse. The 1975–1976 western drought brought home to suburbanites and city dwellers in a dramatic and personal way what farmers and ranchers have long known: mild perturbations in precipitation patterns, well within the range of the statistically probable, can quickly lead to a crisis.

The problem is not entirely a local or an ''arid West'' issue. Numerous locations in the East, including southern Florida, the eastern Carolinas, parts of Pennsylvania and the middle Atlantic states, the Ohio valley, and the Chicago area have potentially severe water supply problems stemming from temporal and geographic variability and lack of adequate storage.

What, then, are the implications for energy development and, more specifically, for the utility industry? Access to reliable water supply, primarily for cooling, has always been a siting constraint and, in most cases, will continue to be. Competition for water will increase, first and foremost in the West and Southwest, where growth is rapid, water is short, and coal is abundant. As water problems become part of conventional wisdom and hence a determinant factor in setting federal, state, and regional policy, the competition may well become more intense, the discussions more heated.

In order that sensible choices can be made, certain facts must be kept in mind. First, the energy sector is not the major consumer of water in our society, nor will it be in any of the nation's proposed energy development plans. Although the production of electricity accounts for approximately one-fourth of all U. S.water withdrawals, most of the water is returned. Consumption for power production accounts for only slightly over 1% of the total U. S.water consumption. Although the wider use of cooling towers and growing energy requirements will raise this percentage, even the most water-demanding energy plans project less than 10% of U.S. consumptive use going to the energy sector by the year 2000. While this represents a lot of water, it means that any water problems that arise will be largely independent of energy-related use.

Again, however, averages can be misleading. Power plants will have major effects on local water availability. A 1000-MW (e) power plant with a wet-cooling tower consumes approximately 10,000 gallons of water per minute. When this requirement is imposed on a region that already anticipates shortages for agricultural and municipal needs, it is clearly disruptive and a subject for controversy. When that same water requirement is coupled with the constraints of air quality regulations and proximity to fuel sources and load centers, an already difficult siting problem is exacerbated. A recent DOE study concludes that over one-third of projected utility coal use may be constrained by water availability problems.

Second, there is no technological panacea for energy's water supply problems. Whatever the mix of fuels and processes—more coal, more nuclear, solar, geothermal, or synfuels—the water requirements, if the systems are carefully designed, are broadly comparable. This is not to say that electric power plants and coal conversion facilities cannot or should not be designed to minimize water requirements. For example, most of the water in power plants is used for cooling, and dry cooling has the potential for major water savings at individual plants. Extensive research on advanced, lower-cost dry-cooling methods is under way at EPRI, DOE, and elsewhere. Similar conservation research should be vigorously pursued. However, even if successful, the water savings will only be measurable at the local level and will impose a penalty of lower plant efficiency and higher cost of electricity.

As a nation, we must conserve and extend our water supply, but to conserve water in the energy sector will increase the cost of energy. It is necessary to compare that economic penalty with the effect of similar conservation options in agriculture on the price of food, in manufacturing on the price of goods, or in municipal use on our daily routine. The energy sector cannot solve the problem alone. Even if it could, it would not be cost-effective to attempt to do so.

John Maulbetsch, Manager
Water Quality Control and Heat Rejection Program
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Authors and Articles

Technology R&D isn't entirely a hard pursuit governed by immutable laws of physics and chemistry. There are softer considerations of perception, policy, law, economics, and the strategies that can ultimately be built on them. These considerations are just as important; they can be just as knotty; and they are the points of departure for this month's *Journal* authors, who deal with utility water conservation, EPRI's R&D planning, research influences on economic productivity, and the benefits of thoughtful corporate listening.

■

For the planners and designers of steam-electric power plants, an evolving combination of water policies, priorities, laws, and economics underscores the competition that is gradually preempting utility access to traditional sources of cooling water. *Journal* feature writer Nadine Lihach documents this reality in "Water Water Everywhere But . . ." (page 6).

Drawing on the expertise of two EPRI research managers, Lihach also reviews efforts to develop cooling technology that will cut water consumption with the least adverse effect on electricity cost, and that should have the happy outcome of opening up more sites for power plants.

John Maulbetsch heads EPRI's program on water quality control and heat rejection, and John Bartz is a project manager who specializes in heat rejection mechanisms, processes, and equipment. Maulbetsch came to EPRI in August 1975 after eight years with Dynatech R/D Co. in Massachusetts, where he initiated and directed thermal engineering projects and ultimately became director of the company's energy technology center. Among his responsibilities was a two-year study for EPA on the technical and economic aspects of thermal pollution abatement in power plants. Maulbetsch earned BS, MS, and PhD degrees in mechanical engineering at MIT and was assistant professor there for three years.

John Bartz joined EPRI's staff in July 1978. He had been with the Linde Division of Union Carbide Corp. for three years, part of that time as manager of an EPRI-sponsored evaluation of an ammonia-based cooling cycle. Bartz is a mechanical engineering graduate of the State University of New York at Buffalo; he earned an MS degree at Ohio State University and returned to the State University of New York for further graduate work in physics. Later with Calspan Corp. for 13 years, he was heavily involved in methods of research test and evaluation, including experiments in gas dynamics and high-temperature non-equilibrium flows.

■

The EPRI Planning Staff deals every day with the soft side of utility R&D. "Strategic Planning for R&D" (page 14) reviews the mix of historical data, projections, and judgments used by R. L. Rudman, W. H. Esselman, F. S. Young, and their colleagues for planning and budgeting Institute R&D activity in five-year chunks. Right now, for example, the 1980–1984 plan recognizes energy shortfall as a possibility that is still advancing, not retreating. So between 50% and 60% of EPRI's total budget must be focused on relatively short-term research that will enable us to make or save more electricity with what are essentially the technologies now in use. The rest of the budget is spread over programs for new technologies that can be phased into use after 1990.

The three authors come to their collaboration with a variety of experience: nuclear reactor design, engineering computation, nuclear program management, strategic planning, and high-voltage transmission research. Rudman organized EPRI's Planning Staff in 1974 and has directed it ever since. A 1966 graduate of the University of California at Los Angeles, with an MS degree in nuclear engineering from the same school, Rudman worked in gas-cooled reactor design at Los Alamos Scientific Laboratory in the late 1960s. He later was associated with IBM for three years as a consultant in engineering computation, then became assistant to Chauncey Starr, EPRI's founding president, in March 1973.

Esselman has also been instrumental in EPRI's five-year planning since it began. With Westinghouse Electric Corp. since 1939, he was loaned to EPRI in 1974, then joined the Planning Staff in August 1975 as director of R&D planning and assessment. Esselman's early Westinghouse work was in control systems, successively for elevators, naval ordnance directors, and the prototype reactor and propulsion system for the submarine *Nautilus.* Associated with Bettis Atomic Power Laboratory for nine years, he became its manager of advanced development and planning in 1955, then helped organize the Westinghouse Astronautics Laboratory in 1959 and worked in program management there until 1969. He later directed the Hanford Engineering Development Laboratory for Westinghouse, with responsibility for various breeder reactor and fast flux test facility programs. Between 1972 and 1974 he was director of strategic planning for the Westinghouse divisions involved in nuclear steam supply systems.

Young joined EPRI's Electrical Systems Division in September 1975, though he also had earlier worked for the Institute as a loaned employee from Westinghouse. A 1955 Stanford University graduate in electrical engineering, Young earned an MS degree at the University of Pittsburgh in 1962 during his early years with Westinghouse. Specializing in high-voltage transmission, he became manager of the Waltz Mill Underground Cable Test Facility in 1966 and in 1972 undertook design of a UHV technology center to conduct transmission research up to 1500 kV. Young became EPRI's manager of program plans in November 1977.

■

If communication is to be complete and if it is to be instructive for both parties, at least half of it must consist of listening. This premise applies to companies as well as to individuals, and it is the business of Walter Barlow, president of Research Strategies Corp. and a member of EPRI's Advisory Council. But Barlow did most of the talking in one recent interview; Jenny Hopkinson, *Journal* feature writer, did most of the listening, and the result is this month's profile, "Walter Barlow and the Science of Listening" (page 20).

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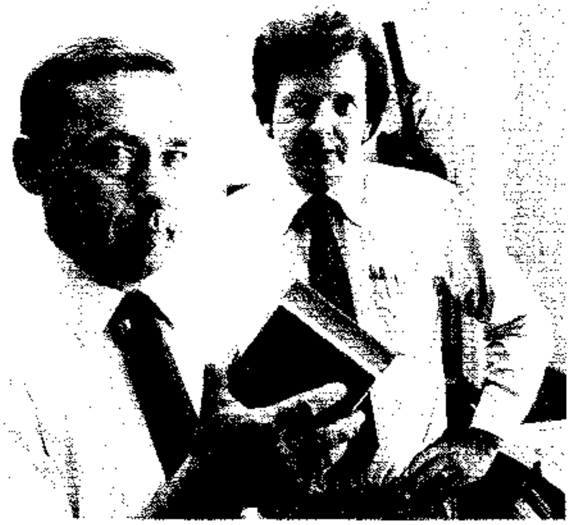
One item that concerns anybody in R&D planning is that national productivity growth is slackening. To find out why, economists have dissected the historical record, correlating data on R&D investments by type, time range, and level of risk with the apparent rates



Bartz Maulbetsch

Mansfield

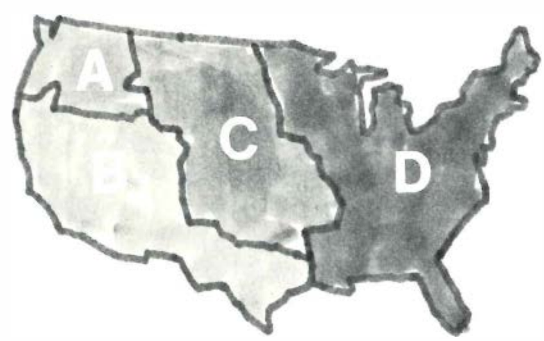
of return to companies and to society at large. The connection is both significant and direct, and Edwin Mansfield explains "How Research Pays Off in Productivity" (page 24). In the article, abstracted from his speech at the Edison Centennial Symposium in San Francisco last April, he also identifies some of the disincentives—real or perceived—that have combined with demographic changes in the labor force to slow productivity growth rates.

Mansfield is a professor of economics at the University of Pennsylvania, with faculty experience also at Carnegie-Mellon, Yale, and Harvard universities, and the California Institute of Technology. His own schooling was at Dartmouth College (BA) and Duke University (MS and PhD). Mansfield has consulted with the National Science Foundation, the Congressional Office of Technology Assessment, and the Rand Corp., and he is currently a member of NSF's Advisory Committee on Policy Research and Analysis.

Esselman Rudman Young

Water Water Everywhere

The nation's water resources are vast, but increasing use and competition among agricultural, industrial, domestic, and energy users are creating pockets of thirst—not only in the arid Southwest but also in the Midwest and East. Illustrated is the percent of surface water remaining after projected water requirements for all sectors—agriculture, industry, domestic, and energy—are met. The notation 100% would indicate the entire supply remains; 0%, requirements equal supply; and -100%, requirements are twice supply. The Southwest, region B, presently has a surface water deficit and must satisfy almost a third of its water requirements by such alternative means as groundwater pumping, wastewater reclamation, and dry systems. However, regional percentages illustrate only part of the problem. Even apparently water-wealthy regions (the East, region D, for example) contain areas that have shortages created by seasonal variation, lack of adequate storage, and increased use. Faced with difficult siting problems, the utility industry will turn more and more to recycle, reuse, and dry systems.



But...

Fuel and fire aren't the only essentials for electric power generation. Large amounts of water are necessary to cool thermal power plants. Smaller amounts of water are used for flue gas desulfurization and ash-sluicing operations in coal plants. And future fuel technologies—oil shale, coal gasification, coal liquefaction—will require process water.

Yet water availability is ebbing in many regions. While the United States has a national sufficiency of water from both surface and underground sources, there can be regional or local shortages of water because of uneven precipitation patterns. Water transfers between basins, often prohibitively expensive over long distances, can't make up the difference. In some areas, poor water quality can also restrict water use.

When there isn't enough water to go around, competition arises. "Competing off-stream uses of water for energy, agricultural, domestic, and industrial needs, coupled with environmental and instream flow uses, have resulted in basinwide and local problems throughout the United States," reports the U.S. Water Resources Council in its Second National

Water Assessment (December 1978). By 2000 the council forecasts a national increase in annual freshwater consumption, which will intensify the competition. By that year increasing shortages are expected in large regions of the country, including the Texas Gulf, Rio Grande, Upper and Lower Colorado, Great Basin, and California regions, where rainfall is low and irrigation is intensive. Even in the water-wealthy East, many waterways in densely populated, heavily industrialized areas are already burdened with allocations, as in the cases of the Susquehanna, Delaware, and Ohio river basins.

Hard times

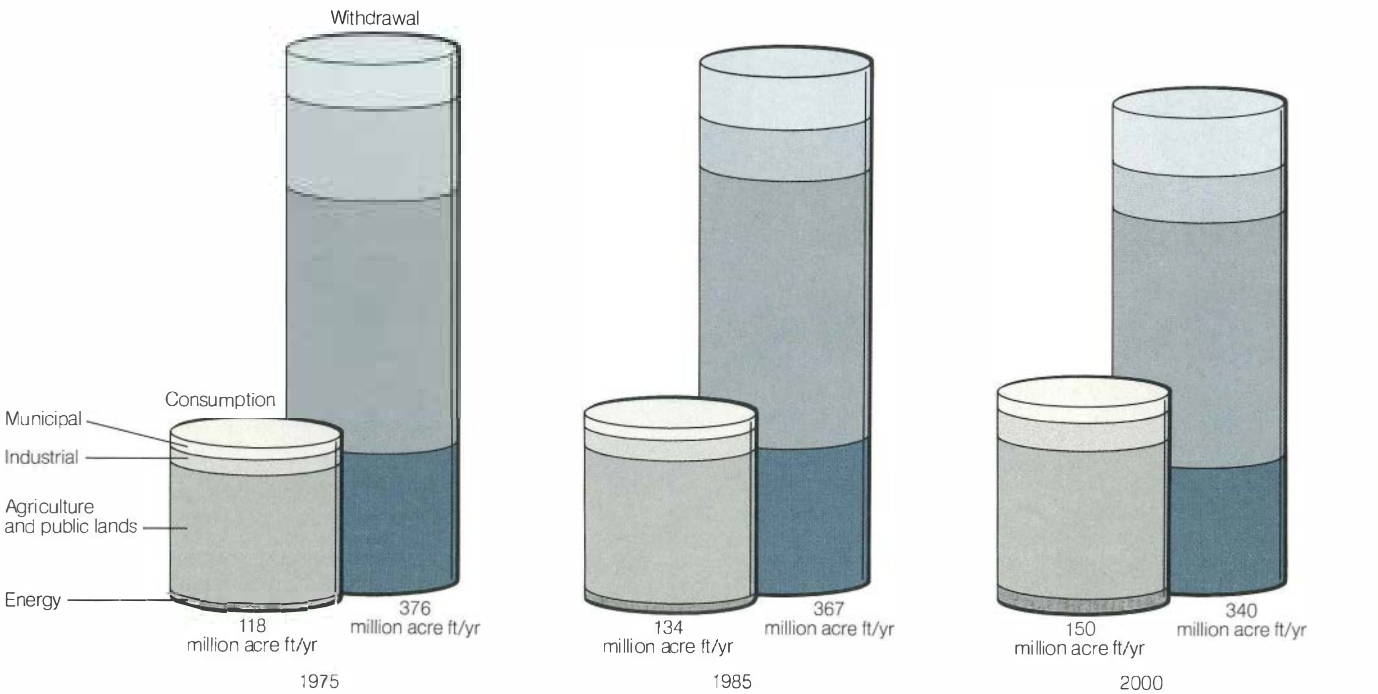
Electric utilities won't have an easy time coping with this shriveling water supply and stiffening competition. Although water supplies for established power plants are reasonably secure, the utility that attempts to site a new plant or expand generation at an existing facility may find itself unable to procure the water it needs to operate. Water may be physically unavailable, or it may be legally unavailable, explains John Maulbetsch, manager of EPRI's Water Quality Control and Heat Rejection Program. "In fact, availability could well become a legal or political question before it becomes a physical question in many parts of the country," advises Maulbetsch.

In the scramble for water, social pressure and legislative action may restrict water use to certain applications, with possible negative consequences for utilities. When a utility needs water for a new power plant or for expansion, it may first attempt to secure a right to a water resource. Failing that, a utility might buy land having rights to either irrigation or groundwater pumping. However, acquiring water may not be as simple as it sounds.

In every state, there are networks of laws applying to water supplies; these laws vary from state to state. A quick survey of some fundamental laws indicates how difficult it can be for a utility to know the extent of its future water supplies.

The riparian doctrine, prevalent in most eastern states, allows users holding property adjacent to a stream to withdraw water so long as the water flow for downstream uses is not affected. Reasonable withdrawal and consumption are

Comparison of the withdrawal and consumption patterns of the nation's water users. Withdrawal is defined as fresh water taken from a surface or groundwater source for offstream use; consumption is the part of water withdrawn for offstream use and not returned to a surface or groundwater source. Municipal use encompasses domestic and commercial applications; industrial use, manufacturing and mining. In the energy sector, where most of the water withdrawn is used for steam-electric generation, consumption is expected to increase largely due to the growing use of evaporative cooling. Withdrawals, on the other hand, are expected to decline, an indication of the diminishing popularity of once-through cooling. (Data from U.S. Water Resources Council, "The Nation's Water Resources, 1975–2000." Statistics for 1975 represent assumed average conditions.)



allowed in periods of adequate water supply. During water shortages, however, the amount available to any user may be restricted by established priorities of use and by the litigation of downstream users.

The appropriation doctrine applies in the western states, as well as in Delaware, Florida, and Mississippi. This doctrine holds that the right to use water is independent of land ownership and may be transferred from one user to another, given the approval of appropriate state officials. Approval usually depends on verification that the water will be applied to beneficial uses. This raises the question of what water uses are "beneficial." Utilities, farmers, manufacturers, sport fishermen, and speedboaters all have their opinions. Purchases can be restricted by legal constraints peculiar to each state.

Further possible curtailments to water availability include minimum-flow standards. These standards preserve specific water levels to support such in-stream uses as fish and wildlife, navigation, hydroelectric power, and outdoor recreation. The standards apply in only a few states now, yet could be adopted by others. Protection of certain rivers under the National Wild and Scenic Rivers Act of 1968 could further restrict the water supply available to utilities and other users.

In short, warns Maulbetsch, "A utility might be restricted by social pressure and by legislative action from using fresh water in water-short regions." Political requirements that water be used only in certain ways are anticipated in some, maybe all, states. Such requirements might turn off the freshwater supply to new power plants or hobble the licensing process so completely that the water is effectively unavailable.

The Supply Program in EPRI's Energy Analysis and Environment Division is helping to monitor water availability with a computerized data base system that describes existing water data. The data base, explains Edward Altouney, project manager, encompasses all states west of the Mississippi, and efforts are under way to provide nationwide coverage. Another EPRI project will enhance existing computerized energy models with water resource constraints for early identification of regional problems.

Conservation among those with water allocations is certainly possible and could loosen up the tight freshwater situation. Some industrial users, for example, are beginning to institute in-plant water recycling because of pollution control regulations on water discharge. Agricultural users, too, are trying water-conservative means of irrigation. Drip irrigation, for instance, delivers water straight to crops through synthetic tubes rather than through dirt furrows. However, for any major changes in national water management patterns to evolve, reallocation of water rights might be the only solution. Such action seems likely to be resisted by those currently holding water rights.

When fresh water is unavailable, a utility might consider using waste water reclaimed from municipal, agricultural, or industrial users. Wastewater reclamation for power plant purposes is still largely in developmental stages, although some utilities, such as Southwestern Public Service Co., already use it. Southwestern has been cooling several plants in Texas with municipal wastewater for some years now.

However, waste water is not always available in the quantities necessary to cool a power plant. For instance, a utility trying to locate a power plant in an arid, sparsely populated area with an abundance of coal may not be able to secure enough municipal, industrial, or agricultural waste water to suit its needs. For that reason, waste water is not the universal answer to water shortage problems. Waste water must also be treated to avert possible damage to power plant equipment (untreated industrial waste water, for example, may cause corrosion or scaling). This treatment can be both complicated and costly.

The technical options

Despite growing shortages, most electric utilities are now able to get the water they need for operations, if not always at a low price. However, as competition for water increases and as legislative and social pressures to restrict water use build, there will be more and more situations where utilities simply cannot obtain water for plant operations. In such cases, utilities have no choice but to use water-conserving systems.

Unfortunately, present-day power plant cooling technologies—the largest consumptive users of water at power plants—rely almost exclusively on water. This is true whether the power plant is coal-fired, oil-fired, gas-fired, nuclear, or geothermal. Once-through cooling, extensively used at older plants but in limited use in new installations because of thermal-pollution regulations, takes water from a waterway, cools the plant, then returns the now-heated water to the source. Although large amounts of water are withdrawn from the waterway for cooling, most of the cooling water is ultimately returned to the source. Evaporative cooling, generally accomplished with cooling towers, predominates at newer plants. Although evaporative cooling does not discharge large amounts of heat into waterways, it consumes more water through evaporation than does once-through cooling. A predicted jump in utility consumption of fresh water from 1.4 billion (10^9) gallons a day in 1975 to 4 billion gallons a day in 1985 (U.S. Water Resources Council) is largely due to the increasing use of evaporative cooling systems.

Dry-cooling systems that use air instead of water as the cooling medium would seem to be the most obvious technological alternative for the utility beset with water supply woes. There are two basic types of dry cooling. For dry cooling by direct condensation, the steam exhausted from generation turbines is condensed in cooling coils by ambient air. For indirect dry cooling, this steam is first condensed by water circulating in a closed circuit; the heated water is then channeled through the cooling coils, where it is cooled by ambient air. Cooling coils may be housed in either natural draft or mechanical draft towers.

The use of dry cooling instead of evaporative cooling would save over 7000 gallons of water a minute for a 1000-MW plant. The catch is that dry cooling is less efficient than wet cooling and much more expensive. With presently available technology, power from plants that use dry-cooling systems would cost 10–15% more than power from plants with wet-cooling towers and 15–20% more than power from plants with once-through cooling units. If water can be obtained by any means, asserts Maulbetsch, evaporative cooling would be preferred to dry cooling.

Today, dry cooling is resorted to only in isolated instances. For example, at the 330-MW, minemouth, coal-fired Wyodak power plant near Gillette, Wyoming, dry cooling was chosen because the cost of shipping the coal to a location with an adequate water supply exceeded the cost of dry cooling. The plant, built by Pacific Power & Light Co. and Black Hills Power and Light Co., is the largest dry-cooled power plant in the United States.

Yet Maulbetsch expects increasing numbers of water-conserving plants will be constructed in the coming years, particularly in the western states, where competition for water will be stiffest. One projection of water availability and demand, coupled with projections of requirements for new electric generating capacity, estimates that 24–44 GW of new capacity will require dry or hybrid dry-wet cooling by the year 2000. The projection, made in 1976 by Hanford Engineering Development Laboratories, indicates that most of this cooling will be needed in the West and Southwest.

Dry cooling might extricate utilities from a variety of other siting predicaments as well. Even in the eastern and midwestern regions, where water is relatively plentiful, the availability of an economical dry-cooling technology could markedly increase siting flexibility by eliminating proximity to a major water source as a primary constraint. For example, if a power plant does not have to be sited on waterfront property, it could locate near a railroad and benefit from lower coal-shipping costs. Or it might settle on less-expensive property, thereby saving real estate dollars.

Dry-cooling systems could also minimize certain environment-related licensing delays, as well as lower the cost of compliance with chemical and thermal discharge, solids disposal, and land-use regulations once a plant is in operation. Unlike once-through cooling, dry cooling discharges no heat into waterways. Nor do dry-cooling technologies produce the vapor plumes characteristic of evaporative cooling towers, plumes that some critics maintain can cause potentially dangerous ground fogs or icing of nearby highways and bridges. Dry cooling does not create drift, either: the tiny droplets of cooling water and dissolved water-treatment chemicals that blow downwind from an evaporative cooling tower and may damage vegetation. Water-conserving ash-sluicing and flue gas desulfurization systems could also shorten licensing delays and cut the costs of complying with environmental regulations.

Dry cooling can also reduce the freezing problems that evaporative cooling systems encounter in frigid climates. That was one of the reasons why dry cooling was selected for an oil-fired power plant constructed by Alyeska Pipeline Service Co. at Valdez, Alaska. In addition, dry cooling facilitated compliance with stringent environmental restrictions in that area.

Efficiency problems

Before utilities can use water-conserving systems widely—specifically dry-cooling systems—the price of those systems must be lowered closer to the price of wet cooling. EPRI and other research groups are attempting to accomplish just that. An underlying reason for the high cost of dry cooling is that the cooling medium, air, is a poor heat-transfer medium compared with water. In dry cooling, the plant's considerable reject heat—some two kilowatthours of heat for each kilowatthour of electricity generated—is transferred to the cooler ambient air by a sensible heat-transfer process. This exchange is much less efficient than the evaporation heat-transfer process that the evaporative cooling system relies on for up to 75% of its total heat transfer. In fact, evaporative cooling can reduce circulating-water temperature—and consequently, steam-condenser temperature—some 15–25°F below the temperatures dry cooling can achieve. And the cooler the steam condenser gets, says Maulbetsch, the more efficient the plant is. To keep pace with evaporative cooling systems, dry-cooling systems using commercially available technology require larger air volumes, air surfaces, and towers.

The difference between the cooling abilities of the wet and the dry technologies is most evident and most costly in hot summer weather. On a scorching day, a dry-cooling system can only cool the circulating water to a temperature approaching that of the hot outside air. This means that condenser temperature will be high, causing turbine back pressure and temperature to rise to undesirable levels. The plant loses efficiency and may even have to be derated just as it experiences the peak demands incurred by summer air conditioning. But if turbines designed to operate at high ambient temperatures are installed, the plant is burdened with higher heat rates during the rest of the year. Evaporative cooling, on the other hand, lowers the coolant to temperatures below that of the outside air, and thus maintains plant efficiency. Of course, not all regions experience summer peaks, and dry-cooling systems can operate more efficiently in those regions. Dry cooling is more common in Europe, for example, where winter rather than summer peaks are the norm.

Today researchers are chipping away at dry cooling's inefficiency and high price from a variety of angles. Some are developing improved heat exchanger surfaces; however, studies have shown that air-cooled heat exchangers contribute only 30–35% of the cost of these systems. The entire system—and not just the heat exchangers—must be overhauled for the price of dry cooling to drop significantly. Consequently, whole new approaches to heat transfer, such as a different heat-transfer fluid or augmented cooling during hot weather, are an important R&D focus.

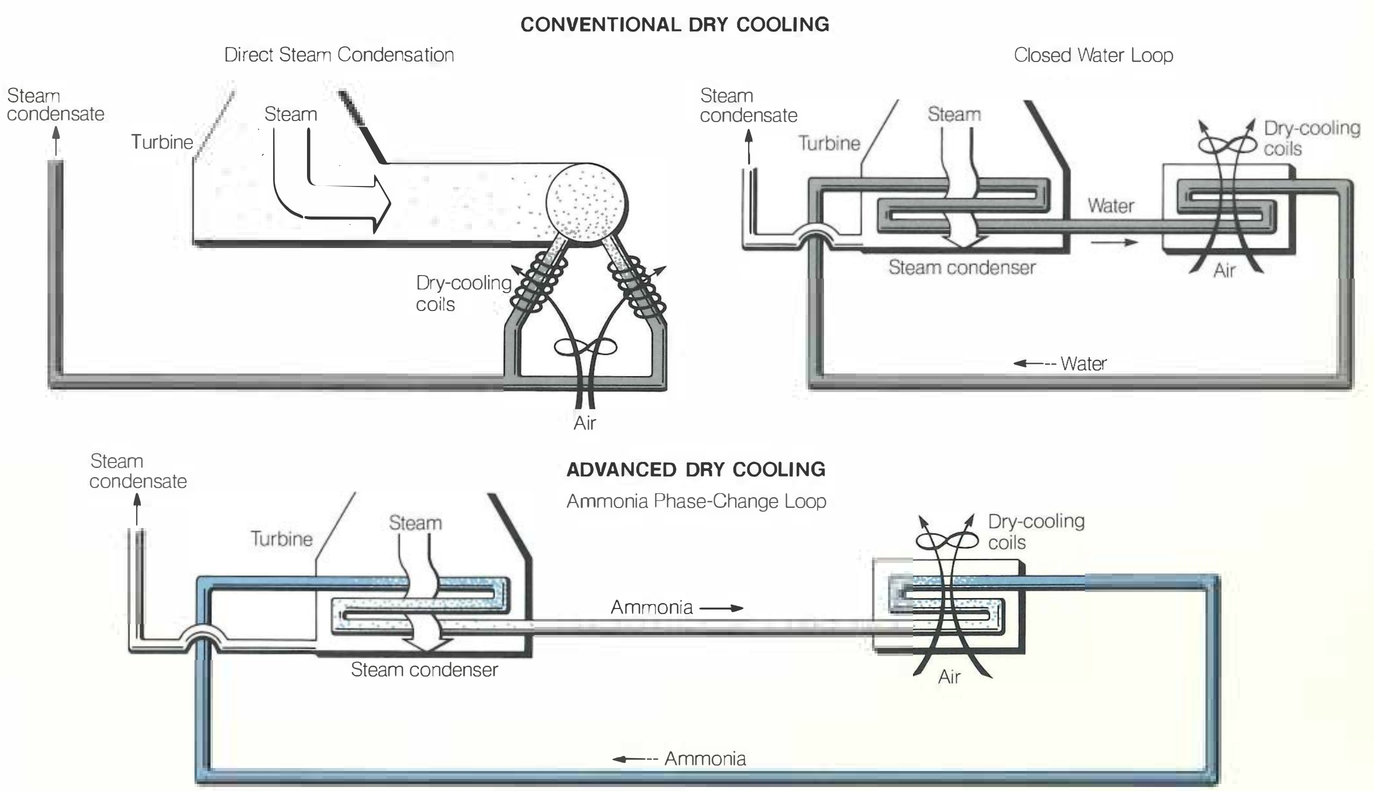
One of the most promising of these new approaches is the use of ammonia instead of water to transfer heat from condenser to cooling tower. Whereas conventional dry, closed-loop cooling systems use circulating water heated in the steam condenser and cooled in the tower, the advanced dry-cooling system evaporates ammonia in the steam condenser and condenses it in the tower. This phase-change system is nearly isothermal, which means the condensing-steam temperature can approach the cooling-air temperature closely and so reject heat more efficiently than can the closed water system.

Furthermore, ammonia's high heat of vaporization and high density mean it has a greater heat rejection capacity per unit volume than water, explains John Bartz, manager of EPRI's Heat Rejection Subprogram. Thus ammonia systems are on a more modest scale than water-based systems, reducing construction costs as well as pumping power requirements for the circulating loop. Ammonia also has a lower freezing point than does water, so freeze-protection devices are unnecessary. While ammonia itself is a toxic substance, ammonia-handling technology is well understood and much used in the refrigeration and chemical industries.

Another way to reduce the cost of dry cooling and increase its efficiency is to supplement it with wet cooling during spells of hot weather. If just a small

When a utility can't get enough water for wet cooling, dry cooling may be the answer. For direct steam condensation, the steam exhausted from generation turbines is condensed in dry-cooling coils by ambient air. For indirect dry cooling, this same steam is first condensed by water circulating through a closed loop: the heated water is then channeled through coils where it is cooled by ambient air. The cooled water returns to the steam condenser for reuse.

Unfortunately these conventional means of dry cooling are less efficient than wet cooling, and they are far more expensive. One promising advanced dry-cooling system would use ammonia instead of water to transfer heat from condenser to cooling tower. Ammonia condenses turbine exhaust steam and is itself vaporized in the process. The vaporized ammonia is then condensed in dry-cooling coils by ambient air and reused. This phase change is nearly isothermal, so the ammonia system can reject heat more efficiently than conventional dry-cooling systems. And because ammonia stores more energy per unit volume than water, smaller equipment and pipes are possible.



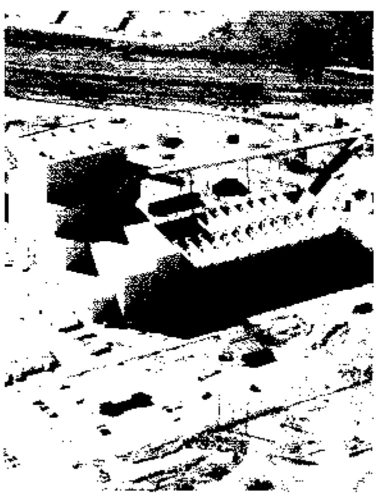
amount of water—say, 1–10% of the annual consumption of a wet-cooling system—is available to bolster dry-tower performance on the hottest days, cost reductions of 10–20% over all-dry systems can be achieved.

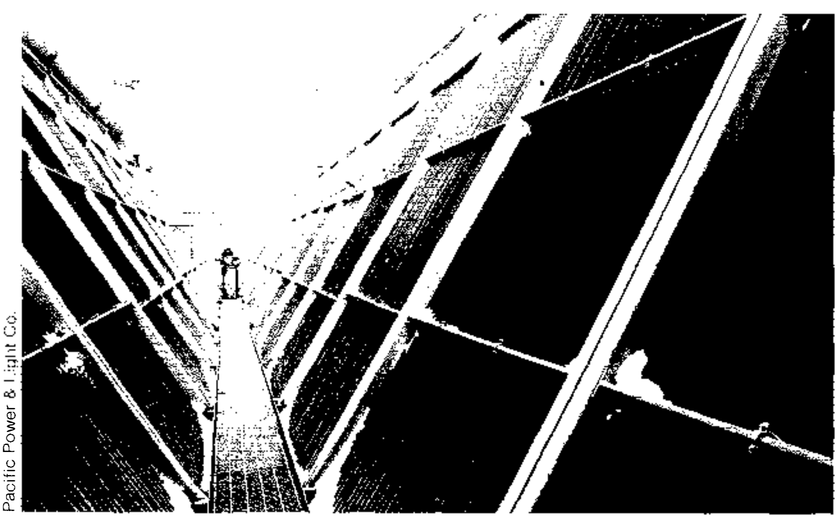
In California a demonstration of dry-wet cooling is nearing completion at Southern California Edison Co.'s San Bernardino plant. The upper part of the system's cooling tower is dry, with water coolant circulating through tubes. As the coolant descends through the tower, it splashes through a conventional wet-tower arrangement. Near Farmington, New Mexico, one of the largest dry-wet cooled power plants in the nation is approaching completion. The 466-MW plant, San Juan III, is expected to go on-line later this year. The owners are Public Service Company of New Mexico and Tucson Electric Power Company.

Innovative concepts

Dry-wet cooling can be teamed with ammonia dry cooling for still greater efficiencies. Two dry-wet cooling concepts, both adaptable to the ammonia system, have provoked considerable interest among research communities. One is the deluge method, so called because the fins of a dry-cooled heat exchanger are flooded directly with water, explains Bartz. The Hoterv Institute in Hungary developed this system for power plant cooling. The second dry-wet system uses an air-cooled ammonia condenser on ordinary days. On hot days, any ammonia vapor that cannot be condensed by the ambient air—perhaps 20% of the total cooling load—is transferred to a water-cooled condenser.

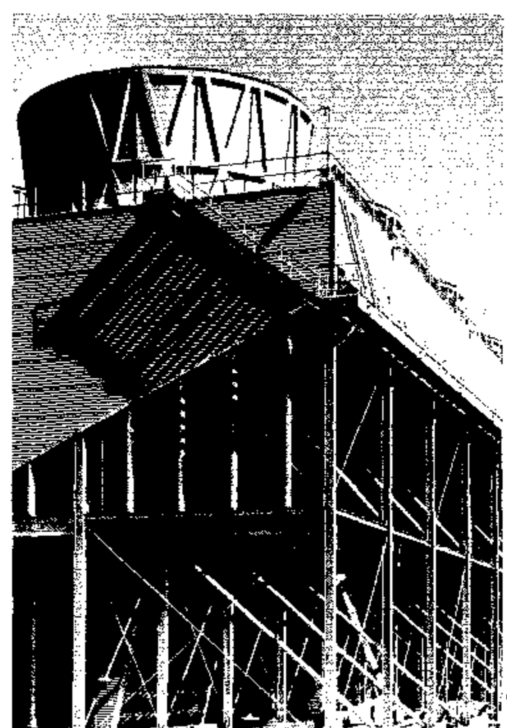
Dry and dry-wet cooling technologies will both be evaluated at an $8.4 million demonstration facility at Pacific Gas and Electric Co.'s Kern power plant in Bakersfield, California. Ammonia will be used as the coolant. EPRI is funding construction of the facility, scheduled to begin in 1980. The facility will begin operation sometime in 1981. Tests will be conducted on a 10-MW house turbine; test sponsors include DOE, EPRI, EPA, PG&E, and other utilities. Battelle,





Pacific Power & Light Co.

Dry cooling is already providing solutions to utility water supply problems. At the 330-MW, minemouth Wyodak power plant near Gillette, Wyoming (left), dry cooling was chosen because the cost of shipping the coal to a location with an adequate water supply exceeded the cost of dry cooling. Wyodak was built by Pacific Power & Light Co. and Black Hills Power and Light Co. The 466-MW, minemouth San Juan III near Farmington, New Mexico (right), to go on-line later this year, will use dry-wet cooling for similar reasons. Public Service Co. of New Mexico and Tucson Electric Power Co. are the owners.



Public Service Co. of New Mexico

Pacific Northwest Laboratories is project manager.

Another way to increase the efficiency of ammonia systems will be tested at a demonstration facility being built by Electricité de France (EDF) near Paris. An ammonia turbine, situated between the facility's steam condenser and dry-cooling tower, will extract energy by expanding ammonia vapor during periods of low ambient temperature. This system will be a particular advantage in France, which has a winter peak, explains Bartz.

Meanwhile, work progresses on improved air-cooled heat exchanger surfaces for dry and dry-wet processes. A design developed by Curtiss-Wright Corp., for example, features an aluminum surface which is skived, or shaved in thin layers. The increased surface area of the metal boosts thermal performance. Another example is plastic cooling tubes, an Italian concept. These are expected to offer low purchase and installation costs, although tube life is uncertain. A 30-MW demonstration in Italy is planned.

Research is also under way to improve the heat-transfer surfaces of steam condensers in ammonia-based systems. Linde Division, Union Carbide Corp., for example, has come up with steam-condenser tubes equipped with heat-transfer enhancements on both the ammonia-boiling and steam-condensing sides. These tubes will be used at the Kern facility.

Because cooling water constitutes 75–80% of the utility industry's water consumption, dry/dry-wet cooling technologies provide the greatest opportunity for water conservation. Yet there is also room for water conservation in other plant operations. After cooling, ash-sluicing and flue gas desulfurization (FGD) processes at coal-fired power plants are the utility industry's biggest water consumers.

In most cases, water is used to flush the bottom ash out of boilers and into hoppers. This technique has been preferred because water does a good job of breaking up the molten ash. Dry technologies for bottom ash removal exist, but are in limited use. The fly ash that collects in electrostatic precipitators is removed by either wet or dry techniques, with about half the removal accomplished by wet means.

Most FGD systems in use today are wet systems. A reagent is mixed with water and sprayed into flue gases; the resulting by-product is made up of about 55% solids, 45% water. The process requires about 1.2 gallons a minute ($75.7 \text{ cm}^3/\text{s}$) per megawatt. Scrubber systems designed to produce a gypsum product rather than a sludge are being investigated; these systems might reduce the by-product to 95% solids, 5% water.

Two other developing FGD systems are also water-conserving. In one, the desulfurization reagent is mixed with water and sprayed into the flue gases. The water evaporates, leaving a dry by-product. This process uses 0.8 gallon of water a minute ($50.5 \text{ cm}^3/\text{s}$) per megawatt. In the second system—entirely dry—a dry reagent is directly injected into the flue gases. The result is a dry SO_2 by-product, collected in baghouses.

Until now, water conservation has not been a driving force in the development of dry ash-sluicing and FGD systems. Rather, the dry product is easier to handle, transport, and dispose of. But these technologies save water nevertheless. Recycled plant water could also satisfy at least part of the water requirements of these operations.

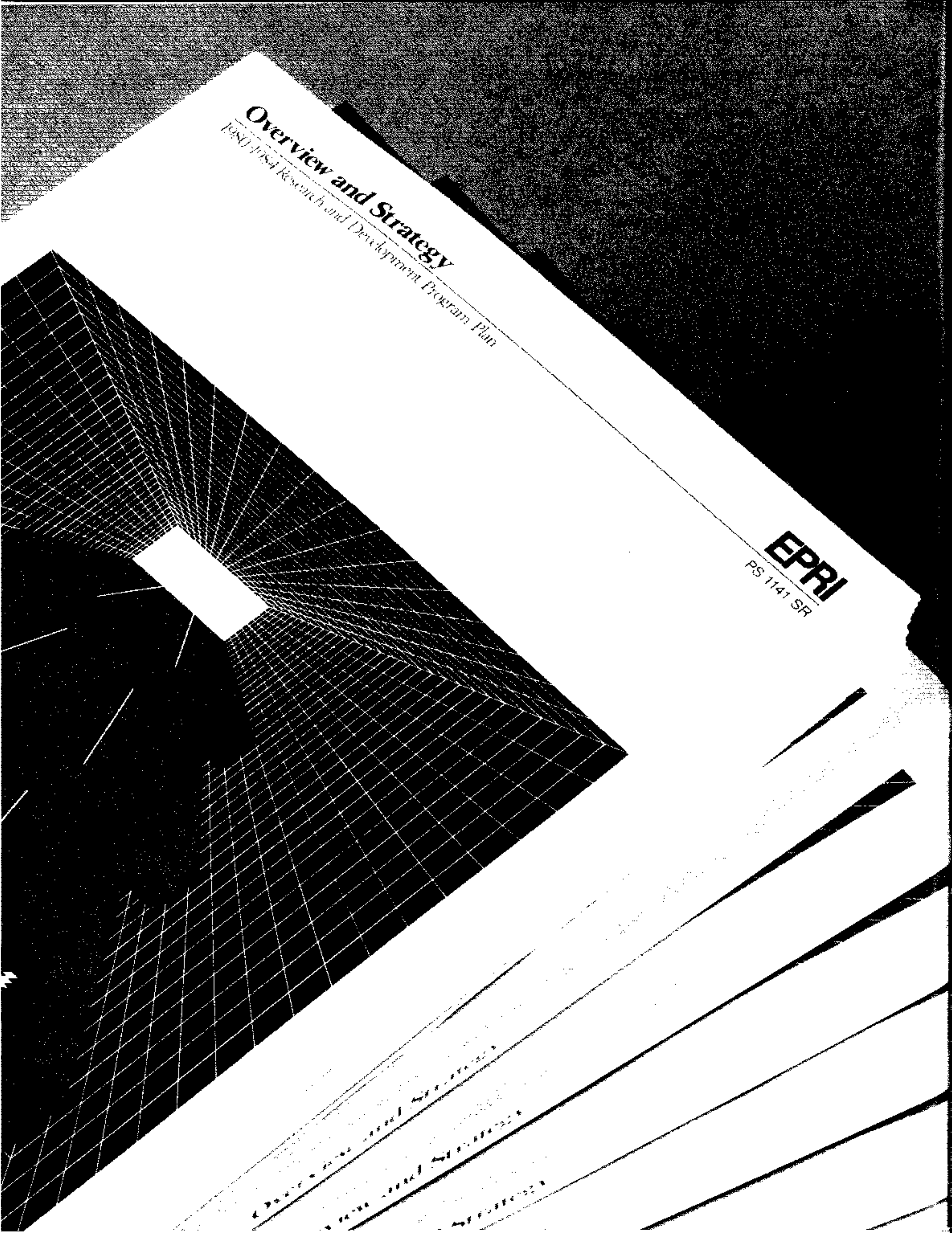
The future

While researchers grapple with ways to get along without water at conventional power plants, they also look to the future for alternative sources of energy and future options for electric power generation. Considerations center on reduced dependence on imported oil, uncertainty over the installation of new nuclear capacity, increased reliance on coal and coal-derived fuels, and the viability of new energy sources, such as solar and geothermal. "From the standpoint of water requirements," says Maulbetsch, "none of these options provides much relief."

Conventional power generation, whether fossil or nuclear, requires essentially the same amount of water. While nuclear has higher cooling-water requirements, coal plants need extra water for ash sluicing and FGD. Advanced coal options, to the extent that their generation mode replaces the steam cycle, as in gasification–combined-cycle plants or gas turbines, have the potential for reducing cooling-water requirements. An equivalent gasification–combined-cycle plant may require only two-thirds the cooling water of a conventional coal-fired plant. However, necessary water quantities are still large, and the increased use of coal will still present substantial water needs, not only for power cycle and conversion process cooling, cleaning, and ash handling, but for land reclamation as well. Similar needs exist for the development of the nation's massive shale-oil reserves.

Geothermal plants, with inherently higher heat rates, have very large cooling requirements. Sometimes, the geothermal resource itself can provide the necessary cooling water. In cases where that water must be returned to the reservoir for groundwater subsidence control, however, water requirements many times greater than conventional plant requirements will have to be met. Solar-electric, if implemented with an air cycle for power generation, has the potential of substantial water savings because heat rejection temperatures are high and air cooling can be easily applied; if combined with a steam cycle, the cooling requirements are comparable to conventional plants.

"There are no easy outs to the water supply dilemma," concludes Maulbetsch. As the problem becomes more acute, the utility industry, together with all the other major water-using sectors of society, must innovate and conserve to make optimal use of the nation's finite water resources. ■



Overview and Strategy
Research and Development Program Plan
EPRI
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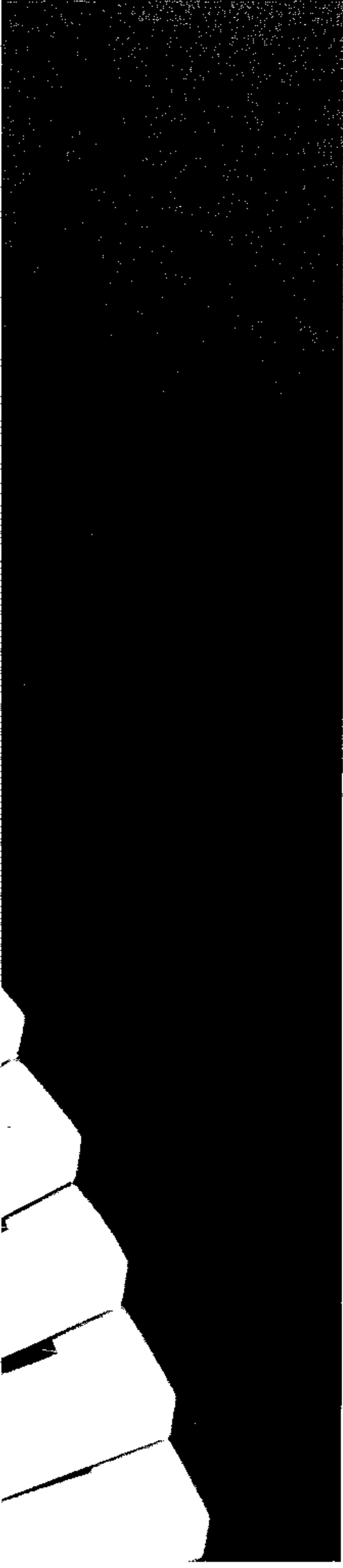


Strategic Planning for R&D

by R. L. Rudman, W. H. Esselman, and F. S. Young

As we analyze the elements of our common future, we perceive that the United States is rapidly running out of time to make decisions needed to reduce the possibility of an energy shortfall. EPRI's "Overview and Strategy Plan for 1980–1984," highlighted here, analyzes the issues and sets forth EPRI's R&D objectives.

The American, by nature," said President John F. Kennedy nearly two decades ago, "is optimistic. He is experimental, an inventor, and a builder who builds best when called upon to build greatly. Arouse his will to believe in himself, give him a great goal to believe in, and he will create the means to reach it. This trait of the American character is our greatest single national asset."

As we survey America's energy picture today and draw EPRI's five-year plan and strategy for R&D to meet the nation's future needs, that single statement could stand as well as any for what should be the basic objective of our many R&D programs. The need for optimism and inventiveness will be as important as our scientific and technical striving, for time and options are fast running out.

This urgency was reflected in the passage of the National Energy Act of 1978 and in President Carter's drive, beginning with his speech of July 15 this year when he called for a mobilization of the nation's efforts to develop our national energy resources and to reduce dependence on foreign oil. In broad principles the EPRI plan is consistent with these national efforts.

In formulating the EPRI plan, we lay out an R&D strategy for the near term (next 10 years), the midterm (10–25 years), and the long term (25 years and beyond). Because our budget is finite, we must also look at what other organizations and the federal government are doing in energy R&D so as to define what our proper role should be, whether as a major participant, a principal sponsor, or a selective participant. And in setting our priorities of R&D programs, we draw heavily on the counsel of all our advisory groups. EPRI's strategy plan, highlighted in this article, thus embodies our analyses and our collective wisdom in trying to see what may lie ahead.

National situation

Since 1974 there have been perturbations in total energy requirements resulting from price increases in oil. Although the need for electricity has undergone less violent fluctuations than the need for total energy, we must look (and build) for an uncertain future. By the year 2000 electricity may constitute 45% of our total energy budget, in contrast to 30% today; thus in our planning R&D we must be sure that alternatives are available to provide future capacity expansion requirements. We do this so that electricity does not act as a constraint on our national economy.

Our nation faces potential shortages of electric energy that could become prevalent in the next decade and could lead to difficult social problems. Unless we can speed the use of systems and

R. L. Rudman is director of EPRI's Planning Staff; W. H. Esselman is director of the R&D Planning and Assessment Department; and F. S. Young is manager of the Program Plans Section.

The factor
analyzes in it

TOTAL U.S. ENERGY NEEDS

Average annual growth rate for total energy consumption during the next two decades will be between 1.5 and 2.8%. In the year 2000, U.S. demand for all primary energy resources—oil, gas, coal, uranium, solar, geothermal, hydropower—will be between 107 and 145 quadrillion (10^{15}) Btu. The base case projection estimates that energy demand will grow at an annual rate of 2.5% between now and the end of the century and that the energy requirements in the year 2000 will be 130 quadrillion Btu.

ELECTRICITY GENERATION

Average annual growth rate in electricity generation is projected to be between 3.8 and 5.6% from 1977 to 2000 and a lower growth rate—between 2.5 and 3.5%—between 2000 and 2020. R&D planning target for 2000 will be 6.1 trillion (10^{12}) kWh (compared with actual use of 2.2 trillion kWh in 1978). This planning target corresponds to an average annual growth rate in electricity demand of 4.7% between 1979 and 2000. Generating capacity equal to 1300 GW will be needed to supply this requirement for electric energy (compared with an installed capacity use of 560 GW in 1979).

ENERGY CONSERVATION

The nation must continue to make even more productive use of energy as demand continues to grow. The EPRI base case projection of 6.1 trillion (10^{12}) kWh in 2000 is consistent with an average reduction of about 20% from the historical growth of electricity. A managed effort to improve the efficiency of utility systems, industrial equipment, and consumer appliances will aid in achieving a reduction in energy and conserve resources.

ELECTRICITY SUPPLY

If electricity supply does not meet projected needs, national economic growth could be limited to less than 3% per year. Unless nuclear and coal expansion is rapid, shortfalls and disruptions of service could occur in many regions by the mid-1990s. For the utility industry, natural gas and oil will be severely restricted during the latter part of this century. Coal production by the year 2000 must be three times the current level, an expansion that appears difficult. A key question is how many nuclear plants can reasonably be expected to be in service by the year 2000.

EFFECT OF LOAD PROFILE

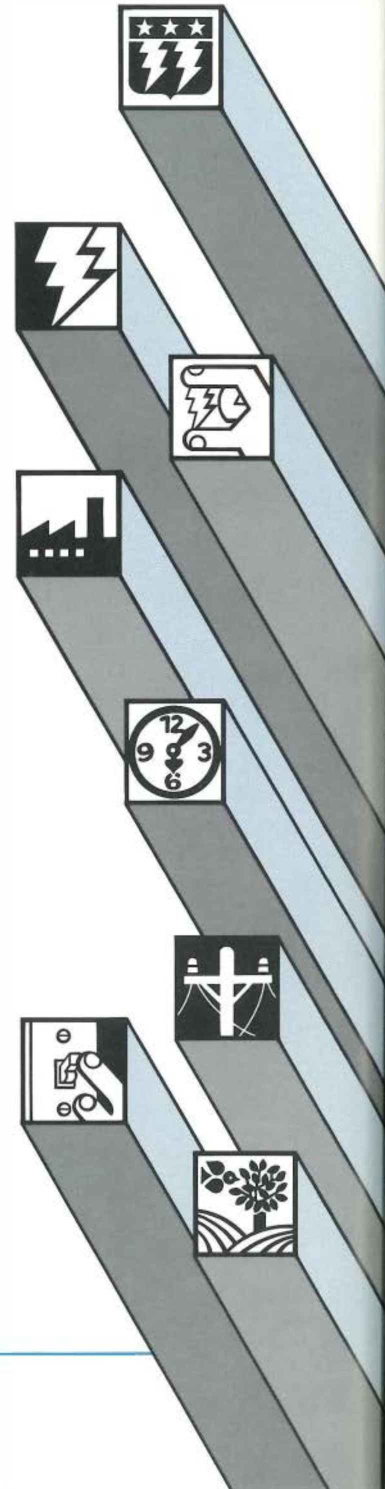
Efforts need to be made to reverse the historical decline in load factor and to provide better means of supplying peak loads through load management and supply management. New technologies now in development, such as reliable combustion turbines, combined-cycle power plants, coal-derived liquids and gases, and central energy storage, will assist utilities in supplying peak load. Load management options include rate design (such as time-of-day pricing) and direct load control (such as emergency water heater control). But studies show that no one method of load management will satisfy all the country's needs. The National Energy Act of 1978 encourages each utility to evaluate consumer load management techniques to see that they are practicable, cost-effective, and reliable and that they provide useful capacity management advantages to the utility.

DELIVERY OF ELECTRICITY

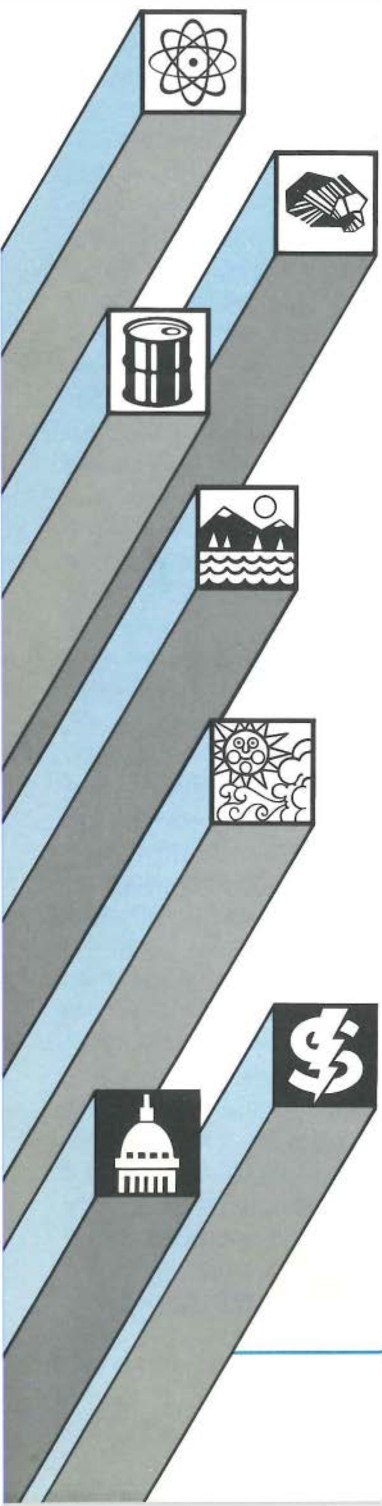
Despite much research, no revolutionary concepts appear on the horizon to change the basic way to deliver electricity. Although transmission and distribution costs, in real terms, have declined relative to generation costs, they are still significant, especially in view of the projection that average distances from new generation to load center will increase 50 to 100% by 1990. Competition for land and capital resources will increasingly affect transmission system design and pressures will increase to place circuits underground. Judicious installation of 765-kV or 1200-kV ac lines and long-distance dc lines may prove one of the most effective energy conservation measures utilities can take between now and 2000, if such lines will be permitted.

RELIABILITY

Because of the high costs for new electric utility facilities, their increasing complexity, and the growing vulnerability of society to costly disruptions of electric service, the reliability and availability of existing systems are becoming crucial areas of concern. Also, because electric generation from the most plentiful, least-expensive indigenous fuels requires the most complex and



that EPRI strategic planning



sophisticated power plants, building of new capacity may be deferred. Thus older plants must be able to extend their useful life. R&D must focus on improving the reliability of system components and improving the methods of evaluating the cost of decisions relating to system improvements.

PRIMARY ENERGY RESOURCES

Availability of primary energy resources is the dominant issue in research planning, for fuel needed for electricity generation must compete with other national energy demands. About 81% of electricity used in 2000 is expected to be generated from uranium and coal (compared with 62% in 1978) because domestic oil and gas will be neither sufficient nor available for generation after 1990. Therefore, coal production must be more than 2 billion (10^9) tons annually by 2000, a growth rate for that industry of 4.7% per year, compared with its historical growth of 1.5% per year. The coal mining and transportation industries thus face a monumental challenge. Considering the uncertainties in oil supplies, and with new Mexican discoveries extending world supply by only six or seven years, the development of substitute liquid and gaseous fuels from coal and shale is not only prudent but absolutely necessary. The nuclear fuel cycle is essential, but the issue of highest priority is whether construction of nuclear plants can continue in an orderly manner without further delay.

LAND, WATER, AND CRITICAL RESOURCES

Siting of power plants and line rights-of-way will be further constrained by land and water problems; yet to meet electricity needs, more than 3 million acres of land for new plants and lines will be required by 2000. Power plant water consumption is expected to increase, while certain areas of the nation will face critical water-related energy problems beginning in the 1990s. Technologies such as wet-dry and dry-cooling towers are being developed to reduce water use. Technologies such as regenerative flue gas desulfurization, coal gasification, and clean coal-derived synthetic fuels are expected to reduce land use at generation sites, while UHV, dc, underground, and compact transmission are aimed at reducing land use for transmission. Mineral resources are adequate at least for the next 50 years.

RENEWABLE ENERGY RESOURCES

Solar, geothermal, wind, biomass, fusion are all regarded as important renewable resources in the future, but early applications of cost-effective versions appear unlikely. Continuous support for 30 or 40 years may be required before a significant amount of energy for electricity generation becomes available from these sources. An estimate of a 25-GW capacity from these sources in the year 2000 (as part of the 1300 GW that will be required) should be regarded as optimistic. An additional 21 GW may also be forthcoming from existing hydroelectric systems through the installation of larger generators and more efficient turbines.

ECONOMIC AND FINANCIAL ISSUES

In the 1960s the historical trend of ever-decreasing costs per unit of electric output was reversed as a plateau in plant sizes was reached, as licensing and construction delays lengthened, and as interest charges increased. It is projected that the costs of electricity will continue to increase as fuel costs and additional capital costs (caused by environmental controls) are incurred. New capacity required for future electricity generation, transmission, and distribution will impose a significant capital burden on the utility industry.

ENVIRONMENTAL REQUIREMENTS

The national trend toward more stringent environmental controls to limit emissions from utility plants can be expected to continue. Control costs are certain to rise as utilities move toward compliance and as new regulations come into effect. Capital costs of compliance, now about $3 billion per year, are expected to double by 1985 and could go even higher if solid wastes, such as ash, are declared hazardous.

REGULATORY ISSUES AND GOVERNMENT POLICY

The electric utility system is being shaped more and more by actions of the federal government and state regulatory agencies. Those actions, along with existing environmental regulations, will continue to have a major effect on EPRI R&D, particularly on fossil fuel technologies. Nuclear regulatory requirements, brought into sharper focus by the accident at Three Mile Island, will necessitate increased attention to nuclear safety, fuel processing, and waste management.

technologies we already understand and accelerate new systems and new technologies toward actual operation, the future energy problems predicted not long ago could likely be with us in the near term.

During the past year the public has begun to perceive that our nation is no longer engaged simply in an interesting debate about energy options but that hard and definite decisions are now upon us. Each decision must ultimately lead to the production of more electricity or the means of saving it.

It is important to recognize that coal and nuclear power represent the only proved and domestically abundant energy options that can be relied on to meet growing electricity demands during the next several decades. These technologies, in concert with active conservation programs and strong support of a broadly based energy R&D program, form the foundation of the nation's energy future. In addition to effective conservation, as soon as possible we must have pulverized-coal plants with reliable flue gas desulfurization systems, public acceptance of nuclear reactor systems, coal gasification, coal-derived liquids, and a host of other technologies. Support for these major options is at the heart of EPRI's "Overview and Strategy Plan for 1980–1984."

A unique aspect of this year's R&D plan is that it articulates the strategy that underlies all EPRI's programs and projects. EPRI's project bin is overflowing, so there is also a pressing need to prune and select. EPRI's management must continually monitor the reality and usefulness of each program and see that each fits sensibly and practically into the overall strategy so EPRI can meet the needs of the nation. Thus the strategy statement provides benchmarks and guidelines for use by both EPRI management and utility industry decision makers.

EPRI has had, in fact, a strategy for its R&D programs from 1973 on, which has progressively evolved as the Institute has grown, as its many R&D programs have matured, and as its connections and understanding of utility industry needs and problems have widened and deepened. Because of recent events and trends, it has now become clear that EPRI must deal urgently with evolutionary improvements in current technologies so as to make existing systems more reliable. In fact, EPRI's current allocations on near-term R&D constitute between 50 and 60% of the budget.

Factors in planning R&D

It is hardly necessary to prove that the following trends are having and will have a substantial impact on the way we meet the future: increasing fuel costs; continuing economic inflation; ever more stringent environmental, safety, regulatory, and licensing concerns; increasing population; decreasing load factor; and slackening of national productivity and innovation, accompanied by a seeming weakening of our national scientific and technological zest.

Likewise, new factors and events—President Carter's pledge to cut back our oil imports, the National Energy Act, the discovery of greater reserves of oil and gas in Mexico, the Three Mile Island accident, the emergent possibility that solid wastes from fossil fuels may be classified as toxic substances, the mystery of acid rain, the gasoline shortage—raise both problems and opportunities for the electric utility industry that must be continually monitored and weighed. The hard pressures of conflicting demands and eroded resources are tightening and will force difficult decisions.

In our planning, 13 basic planning factors form the backbone of analysis. For the utility industry and its R&D programs, these factors constitute the fundamental dimensions of a dynamic social-economic-technological matrix. They are time-proven indicators—like the well-known indicators of the economist—which, through monitoring and analysis, allow us to infer the most likely patterns of future development. For instance, there is a coupling between total energy use and our gross national product. We have seen in the past that if the GNP goes up, energy use goes up, and if GNP goes down, energy use goes down. On the other hand, the energy-GNP ratio has slowly declined over time and should continue to decline in the future as additional conservation measures take effect. A radical change in the trend of this indicator is not expected in the short term; thus it gives us a rather reliable rule of thumb.

Buried in these basic planning factors are many other variables and parameters, such as population growth, relative size and composition of the workforce, its productivity, and the elasticity of electricity pricing. The planner's task of providing a reasonable view of future events is therefore still more of an art than a science. Reasonable and prudent estimates are needed. They give guidance to shape our R&D programs. In general, our confidence in these projections and R&D needs is highest in the near term, and it diminishes the further out in the future we attempt to see.

The EPRI plan is more sensitive to changes in certain factors than others. Of the 13 basic planning factors, for instance, those that have the potential to alter EPRI's present R&D strategy most strongly are the relative availability of primary energy resources (coal, gas, oil, and uranium), environmental and public health issues, and the availability of land and water resources. Resolving the many dilemmas surrounding the availability and relative mix of these resources will pose some difficult choices for the nation.

Given this reality, we have added a new factor to our list: reliability. With higher fuel costs, longer construction times, greater drain on capital resources, slightly lower growth rate, and the multiple pressures and turn of events of the past year, we now believe it is becoming more important to stretch out the life and improve the performance of existing equipment and technologies. New ways and means must be found to do so. Thus EPRI R&D programs will be placing more stress on enhancing reliability in the near term and finding evolutionary improvements that can be retrofitted.

From an analysis of the planning factors that enumerate the critical requirements facing the utility industry, we have identified eight major premises—our basic assumptions about what the future will demand of us. We assume, for instance, that our nation will maintain its economic growth, that its need for both total energy and electricity will grow, that electricity production should not become a strain on growth, and that capital requirements to sustain such growth will challenge the resources of the utility industry. Because long lead times are involved in developing new resource technologies, such options must be undertaken decades in advance of projected need, and current technologies must be made as reliable as possible in the interim.

To do all this, and more, it appears we must depend on domestic coal and uranium as our principal energy resources for at least the next several decades. This premise is the basis for EPRI's strategy in developing its R&D programs. Basically, what we must do is to stretch out the useful life of our resources through conservation; develop more efficient use of our electricity supply; protect the environment, while keeping the costs of electricity for consumers at competitive levels; and work as aggressively as possible to free our nation from dependence on foreign energy resources. At the same time EPRI, working in concert with the federal energy program, is attempting to accelerate the development of renewable energy options.

Program strategies

Those who have studied EPRI's R&D plan in previous years will be interested in the specific program strategies that have now been evolved. Among the evolutionary improvements in the near term (transition period) are some of the following. For pulverized-coal–steam plants, which are expected to become the dominant supplier of electricity over the next two decades, major emphasis will be on developing environmental control technologies, such as flue gas desulfurization (including regenerative and sulfate producing systems); NO_x control; particulate control; water quality and use; and plant reliability. For environmental R&D, EPRI's strategy will be to concentrate on the development of data that will be useful in the near and midterm.

For the nuclear option, work will be aimed at improving the availability and reducing the costs of light water reactors, assuring the safety of nuclear plants, and producing experimental and analytic results that can assist in improving nuclear power plant operations.

The strategy for electrical systems will be to maintain a strong and balanced program of R&D in all aspects related to the delivery of electric energy to the ultimate customers. EPRI will act as a principal sponsor of such R&D because of the utility industry's expertise in this area.

R&D in conservation will be strengthened and will be directed at work on improved efficiency of electric energy use (e.g., heat pumps), improved electric load management technology (e.g., heat storage), expanded cogeneration options, and the efficient substitution for scarce fuels. Energy analysis research will aim at improving the utility industry's ability to project future changes in electricity requirements and to provide a safe and economical fuel supply in the energy resource mix.

For the next-generation technologies, EPRI's strategy for the coal option will give the highest priority to R&D on gasification–combined-cycle for baseload applications in the 1990s. In addition, it will stress work that ensures a supply of economic and environmentally acceptable liquids from coal; it will push toward the design of utility-scale fluidized-bed systems; and it will continue active research on fuel cells based on coal-derived gas or liquid. Work in electrical systems will aim at higher-capacity transmission and distribution systems, such as UHV lines and compact substations. The environmental assessment strategy will focus on a thorough analysis of the effects of alternative fuel technologies, such as coal gasification and coal-derived liquids. In storage and energy management, EPRI's program will aim at resolving technical uncertainties in compressed-air storage and underground pumped hydroelectric systems.

Looking to the next century, EPRI's strategy will be to place an appropriate but lesser amount of effort (recognizing the large federal programs in all these areas) on emerging technologies and on exploratory research. EPRI has active and important research support programs in solar-thermal electric, photovoltaics, wind, and various fusion concepts.

Planning flexibility

The R&D process must be dynamic and flexible in order to respond to emerging national concerns. For instance, during the past year, at the request of the electric utility industry, EPRI established the Nuclear Safety Analysis Center to respond to issues arising from the Three Mile Island accident and is giving greater attention to the seemingly well-established components of nuclear plants (pumps, release valves, and so on). EPRI has established new environmental and control technology projects on the hazards of solid wastes from fossil fuel plants and a project on acid rain.

R&D is the key to a vigorous growth in our nation's capacity to provide energy. With the strategy guidelines laid out in this year's plan, we expect to have the flexibility to respond to unforeseen technical developments as they occur. But R&D strategies alone cannot provide the total answer. The challenge of long lead times, licensing delays, construction problems, and a myriad of other institutional issues must be resolved by the United States in the next few years if a major energy shortfall is to be avoided. It is up to industry and the nation to build together. ■

Walter Barlow and the Science of Listening

A member of EPRI's Advisory Council, who is a listener by profession, takes the speaker's chair for a change in his New York office.

Communication is a two-way process, but most businesses and organizations hold a monologue. As Walter Barlow, EPRI Advisory Council member, explains, "Corporations spend massive amounts of money talking to people, at people. They don't do very much in the way of listening, so they never know quite what people are thinking about them. This is oversimplified, but the whole process of opinion research—the kind I am involved in—is aimed at closing the loop. It is to help institutions and groups of people to listen to their constituencies scientifically."

As a scientific listener himself, Barlow counsels companies on the ways they can use opinion surveys to better meet the needs of their customers, employees, and shareholders. He has valuable ideas to contribute to EPRI's Advisory Council, which itself reflects people's attitudes toward the utility industry. Public needs are communicated to EPRI's Board of Directors through the 27 or so Advisory Council members, who include public utility commissioners, university professors, economists, and lawyers.

Barlow's professional career included the listening function right from the start. After graduating from Cornell University in 1939 with a triple major in philosophy, political theory, and English history and following five years in the Army, Barlow encountered Claude Robinson, who had founded Opinion Research Corp. in Princeton, New Jersey. Robinson had designed his company to assist businesses and trade associations in weathering the forces of public attitude "that were buffeting business during and after the war."

Because most large corporations suffered from similar difficulties—government regulations on capital formation and adverse attitudes toward big business generally, including its leadership—Robinson put together a business service package, the Public Opinion Index for Industry, to help companies overcome these problems. Barlow describes the way Robinson mobilized this service. "He used the same survey, wrote reports, syndicated them, then personalized the results for the companies by putting on presentations for them. When I came along he was looking for some people to help him build that service. That's how I started to work for Opinion Research. I stayed there—I began in February 1946, and I left when Robinson died in 1965. For the last six years I was president."

In the year after he left Opinion Research, Barlow founded his own company, Research Strategies Corp. This allowed him not only to fulfill a lifelong wish to run his own business but also to put his energies into helping clients plan, manage, and then use research in their decision making, rather than just selling and delivering information itself.

Wider spheres

The science of listening, as practiced by Barlow, has also found its way into other walks of his life. He has served for years on boards of the United Presbyterian Church in the United States, on the Cornell University Board of Trustees, and on the Board of Public Welfare of the state of New Jersey. In addition, he has been a director and national president of the Family Service Association and is now a director of A. D. Publications, Inc., a publishing company affiliated with the United Presbyterian Church.

His strong tie with the church came naturally; his father was a Presbyterian minister. "But," Barlow recalls, "what really got me involved in Presbyterian affairs was that back in 1963 or 1964 I was asked to go on the board of what was then *Presbyterian Life* magazine, and I stayed with them for years, through the period of merging *Presbyterian Life* and the United Church *Herald* into the magazine that now serves the two churches—*A. D.*"

Through his Presbyterian affiliation, Barlow helped found the research division within the church's Support Agency and he has counseled on Presbyterian Church research projects, as well as on projects designed to assist *A. D.* magazine itself. "*A. D.* makes no major decisions now without carefully researching them in advance," Barlow noted.

In 1965 Barlow again began to take part in the life of his alma mater, Cornell University. He picks up the story, "You may remember the front cover of *Time* magazine showing the black students coming out, holding their guns in the air. There wasn't a shot fired in anger. Aside from a few fisticuffs, no violence resulted at all. But Cornell had to face up to the fact that it had been trembling on the edge of violence." He continues, "I had just been elected an alumni trustee on a board that had representation from a wide variety of fields, and they put together a seven-person commission with power to call anybody to testify. We sat week after week after week, trying to analyze what had happened and why, with the idea of developing recommendations to the board of the university.

"This Robertson Commission, as it was called, uncovered the fact that communications between the university, its alumni, and particularly its students and faculty were really far from satisfactory. We had a set of definite recommendations about starting a publication based on information gathered in some very significant surveys. Bit by bit, most of those recommendations were accepted, and we now have a very good communications program." The result was the founding of the *Cornell Chronicle,* now the official publication of the university. In newspaper format, the *Chronicle* tells faculty, students, alumni, and the Cornell community what is going on at Cornell and why. "It has proved to be a vital link in the university's communications system," Barlow says.

Ways of listening

The Cornell surveys in which Barlow had a supervisory hand laid the foundation for what has become the present-day internal communications audit, a survey used in learning about employees' knowledge and perceptions of their company. To Barlow, the audit is a touchstone for communication planning.

But the opinions that a company does well to hear are those not only of its own employees but of people in the community—customers, stockholders, the media, nearby residents. Each of these groups has different information needs and interests. Although a corporation cannot be all things to all people, it has certain basic impressions about itself that it wants everyone to share. But the way it discusses them with one constituency will differ from the way it discusses them with another. Barlow details some examples. "We have a great problem in this country (and certainly the utility industry knows it) of getting enough money to expand because we have cut the capital formation incentives so low. Well, you talk to the stockholder constituency within a different context because you are talking their direct self-interest, whereas with employees and managers you talk about a longer-term interest—

productivity. If the plant is more productive and more profitable, it is easier for it to get the needed capital, so you end up talking about capital formation. But it is quite different from one group to another."

Utilities and their constituencies

Two electric utilities that Barlow advises are Pacific Gas and Electric Co., San Francisco, California, and Consumers Power Co., Jackson, Michigan. Since the 1950s PG&E has had Opinion Research and, more recently, Research Strategies take a customer attitude survey every two years. As Barlow describes it, "We ask a number of questions about people's perceptions, whether they believe the company's information and a number of things that have been standard. We watch the trends over the years.

"As the issues change—conservation, nuclear power, environmental pollution—relevant questions are gradually built in. So every two years PG&E has had a photograph of itself through the eyes of its customers, and a big enough sample is surveyed so we can look at its five major geographic subdivisions." As a result, decisions on what information should be communicated to customers and what means should be selected have been based on thorough knowledge about what PG&E's customers know, think, and want to know more about.

Consumers Power is having Research Strategies carry out a systematic survey of its major constituencies. Says Barlow, "We have been to their customers on a systemwide basis, similar to the PG&E survey. We added a sampling of influential, or 'thought leader,' types. We have surveyed the top media people—radio, television, newspapers—statewide. The communicators at Consumers Power wanted a good look at themselves through the eyes of one of their principal 'markets,' namely the media.

"A year ago we completed a survey of security analysts, portfolio managers, people in the financial community. We are just now tabulating a scientific survey of their stockholders. And this is part of an ongoing program, periodically looking through the eyes of the major constituencies the utility serves and with whom, of course, it has to communicate."

A question that seems to be important is the cost of such scientific listening services. Barlow replies, "You don't have to be big, in terms of utilities, to do this kind of research. When someone asks me, 'How much should our research budget be?' I say, 'Well, what is your total outgoing communications budget? If it is $50 million, on the theory that good interpersonal communications is a 50/50 proposition you either ought to cut your budget to $25 million and spend $25 million listening or spend an additional $50 million on listening.' People always laugh, but the point is that to listen adequately, you have to spend money. So any utility can do this kind of research; it just has to put the spending in the perspective of what it actually spends on communications. Any company that wants to do it will find a way to shave its communications budget for a year or two to fit it in. But the resulting insights should more than make up for the research expenditures in increased communications efficiency."

"I don't know whether we're moving into a more listening and accommodating era. I have a hunch we are; but that hunch could be a creature of hope."

Changing attitudes

Public opinion shifts faster today than it used to, according to Barlow. One of the reasons, he claims, is that we have enormously speeded up media time. For instance, energy crisis attitudes have changed rapidly in the last six to nine months.

"For years," says Barlow, "the prevailing public opinion was favorable toward nuclear power generation. Furthermore, survey after survey showed that people living near nuclear reactors were even more favorable in their attitudes than those living elsewhere. Their reasons were that the reactors were clean, there was no smoke, and there was plenty of power. Well, now what's happened is that that particular relationship—namely, that the closer you live to the reactor, the more favorable you are—has undergone some change, because people now have concerns as a result of Three Mile Island. But coming along is that trade-off situation where people will say, 'At what point am I willing to continue paying for safety? To what point am I willing to require environmental costs and run the danger of not having power?' I won't predict how people will react, other than I think they want their lights on and their homes heated and the elevators to work."

This last remark about prediction, or the lack of it, points up the fact that even though the information produced by surveys is powerful, it is not a substitute for judgment. Barlow insists, "Insofar as surveys are constantly kept in the perspective of being an assistance to the decision maker but not in any way, shape, or form making his decision, then this kind of research is as it should be: an aid to judgment."

Extending his argument, Barlow refers to EPRI's research in the same vein. "It's one thing for EPRI to do the scientific research. It's another for decision makers to say whether or not we open the throttle or bring it back toward zero. The information becomes the power that somebody has to use.

"Now there are those who say we have to go back toward zero growth. There are those who say we ought to be struggling to increase exponentially our energy supplies, and hence the utilities' growth. But that kind of a discussion is not one in which EPRI partakes. It scrupulously avoids taking sides.

"EPRI has a manifest destiny. Its Board says, 'Here are the funds; develop the process.' Once it's developed, somebody else has to say, 'Are we going to finance the process further and use it?' The heads of the major power companies and the leadership of our national groups who make the decisions whether to spend money on programs or not—those are the people who have to have a philosophy. EPRI was not set up as a school of philosophy. It was set up to bring together the finest aggregation of scientific talent that collectively and most efficiently, and in a cost-benefit way, could do the research that the industry wanted to be done."

Energy and costs

Barlow is enthusiastically committed to the idea of the expansion of energy sources and production but only if it is accompanied by a real understanding of the environmental implications of releasing energy for human use. However, in agreeing that we have to protect the environment, he also warns, "We can overreact in terms of controls; somewhere, someplace, someone has to say, 'The trade-off between escalating costs of controls and possible risk is one that we are legitimately willing to take.'"

Mention of escalating costs leads Barlow to comment on the gasoline crisis. "In the last 50 years we've become accustomed in this country to artificially priced gasoline. The rest of the world has been paying a true market price . . . we haven't, because we've made the arbitrary decision as a people that we're going to subsidize the price of gasoline. Now those subsidies are no longer under our control because OPEC is gradually sucking our blood dry. We literally have to find a way to begin to pay for gasoline at a price in keeping with its true cost."

This particular truth is a painful one in Barlow's view. "I think people will pay whatever is necessary for their gasoline. But at this point they're going through the absolute tortures of realizing that they may not be able to get it even at a price they're griping about paying. It's really put a finger on our emotional jugular." At this point the American people feel threatened by the limits imposed on their gasoline supply. Barlow continues, "They blame the oil companies because they have to have somebody to blame. They are beginning to blame the government more. But the real root problem is this: the automobile and the mobility it gives are about as deeply rooted and as unalienable a right in people's minds as we've got in this country. I would paraphrase the public's view as: 'I have a right to move when I want, where I want, and in my automobile.' What they see is something threatening that personal freedom; it impinges upon their control of their lives, and people rebel."

"I won't predict how people will react, other than I think they want their lights on and their homes heated and the elevators to work."

When people are not informed of the reason for a problem, particularly when it relates to a vital part of their lives, such as their car and their mobility, their job and their recreation, they begin to lose confidence in their leaders and in themselves. Their morale drops and a feeling of helplessness develops. With this lack of vigor comes a lessening of effectiveness and productivity.

To rebuild effectiveness and to recharge productivity require the opportunity for people to give their opinions, to put forward their ideas and suggestions, and to present their questions and concerns—all grist for the mill of the scientific listener.

Effectiveness of energy policies may well depend on the confidence people have in decision makers. Confidence in decision making is only likely to result from self-confidence, which is itself a faith in good judgment that comes from a sense of interdependence, even, as Barlow expresses it, a collective morality. This is where the science of listening plays its part.

From Barlow's point of view, "The last 20 years have seen a polarization where people take hard positions and say, 'You're going to come to my side; I'm not going to come to your side.' So then the only strategy is how to knock the other person off, not how to accommodate and find the common middle ground. I don't know whether we're moving into a more listening and accommodating era. I have a hunch we are; but that hunch could be a creature of hope."

The hope is that the advent of a listening and accommodating era could effectively support an era of economic growth and establish a steadying influence on energy policy. ■

Resting on a mix of basic and applied research, technology lifts our society to new levels of productivity and economic development.

How Research Pays Off in Productivity

by Edwin Mansfield

Many great economists of the past were pessimistic about how much per capita output could be increased. In their view, population would expand whenever the standard of living poked its head above the subsistence level, with the result that more and more people would be working a relatively fixed amount of land. Given the law of diminishing marginal returns, it appeared certain that per capita output (the basic measure of economic growth) would eventually fall.

Obviously, this has not occurred, at least for the industrialized nations. Because of the power of technological change, a flood of innovation has offset the dreaded law of diminishing returns and allowed food supplies to more than keep pace with increases in population.

Economists of today, although their understanding of the determinants of growth is still far from complete, are much more aware of the importance of technological change. Now it appears that economic growth is due largely to increased productivity (output per unit of input) and that the rate of productivity growth depends heavily on the rate of technological change. However informal or structured it may be, research and development produces that change. So I shall first summarize what economists think they know about the relationship between R&D and the rate of productivity growth. Second, I shall present some new empirical findings concerning the relationship between basic research and the rate of productivity growth. Third, I shall discuss why the rate of U.S. productivity growth has faltered, as well as some of the steps taken recently by the federal government to examine our policies influencing technology.

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Productivity from R&D

During the past 20 years a number of studies have investigated the relationship between the amount spent by an industry or firm on R&D and that industry's or firm's rate of productivity increase. For the industries and time periods studied in the 1960s, R&D seemed to have a very significant effect. In chemicals, for example, a firm's rate of productivity increase was directly related to R&D, the marginal rate of return (i.e., the rate of return from each additional R&D dollar) being about 50%. In petroleum, the marginal rate of return was about 40%. And in agriculture, with other inputs held constant and a six-year lag assumed between research input and its return, the marginal rate of return was estimated to be 53%.

During the 1970s several additional studies of this kind were carried out. One study, using data from almost 900 manufacturing firms, found that the private rate of return from R&D was about 17%. The rate was much higher than this in chemicals and petroleum and much lower in aircraft and electrical equipment. Also, the return was generally lower in industries where much R&D is federally financed.

It is important to distinguish between *private* rate of return and *social* rate of return. The private rate of return is the rate of return to the firm carrying out the R&D; the social rate of return is the rate of return to society as a whole. Since a firm frequently cannot appropriate many of the benefits of its own R&D, the social rate of return may be considerably higher.

A 1974 study analyzed the effects of R&D expenditure on productivity change in 33 manufacturing and nonmanufacturing industries throughout the period 1948–1966. In manufacturing, the results indicated about a 30% rate of return, based only on the effects of an industry's R&D on its own productivity. Those findings also showed that an industry's R&D had substantial effect on productivity growth in other industries, resulting in a social rate of return that greatly exceeded 30%.

How did the results of the studies of the 1970s compare with those of the studies of the 1960s? In general, they are quite consistent, although the marginal rate of return from R&D investment was not as high as in earlier years. But the marginal social rate of return is still relatively high, suggesting that there may be an underinvestment in R&D.

Returns from specific innovations

Microeconomic studies of the return from particular innovations have also been conducted. To estimate the social benefits from innovation, economists generally have used a model of the following sort. If innovation results in a shift downward in the supply curve for a product, the area under the demand curve between the pre- and postinnovation supply curves measures the social benefit. If all other prices remain constant, this area equals the social value of the additional quantity of the product plus the social value of the resources saved as a consequence of the innovation. Comparing the stream of R&D (and other) inputs with the stream of social benefits thus yields a social rate of return from the new technology investment.

Studies of this sort first involved only agricultural R&D, consistently showing a high rate of return. In 1977 my coworkers and I estimated the rate of return from R&D investments in 17 innovations that stemmed from firms of quite different sizes in a variety of industries. Most of these innovations were of average or routine importance, not major breakthroughs, and although the sample was not randomly chosen in the formal sense, neither was it biased in any obvious way toward profitable or unprofitable innovations.

"Nearly all studies indicate that the average social rate of return from investments in new technology tends to be very high."

To estimate social rates of return from these innovations, the model described above was extended to include the pricing behavior of the innovator, the effects on displaced products, the costs of the innovator's uncommercialized R&D, and the costs of relevant R&D done elsewhere. The median social rate of return from these innovations was 56%, a very high figure. On the other hand, the median private rate of return was 25%.

Data were also obtained from the 1960–1972 innovative activities of one of the largest U.S. firms. This firm has made an inventory of the technological innovations arising from its R&D and related activities, and it has made detailed annual estimates of their effect on its profit stream. The average rate of return for the 13 years was 19%, which is not too different from the median private rate of return given above. In addition, lower bounds were computed for the social rate of return from the firm's investment; they were about double the private rate of return, which also agrees with the results given above.

These findings pertain to the average rate of return. The previously summarized econometric investigations indicate a high marginal rate of return. In sum, nearly all studies indicate that the average social rate of return from investments in new technology tends to be very high. Moreover, the marginal social rate of return also seems high, generally at least 30%. Certainly, these studies—each with a variety of inherent problems and limitations—are frail reeds on which to base policy conclusions. Nonetheless it is remarkable that so many independent studies based on so many types of data result in so consistent a set of conclusions. Again, many economists view these conclusions as evidence of an underinvestment in R&D.

The role of basic research

None of the foregoing studies tells us anything about effect of an industry's or firm's R&D mix on its rate of productivity change. In particular, does basic research (original investigation to advance scientific knowledge, with no immediate commercial objective) make a significant contribution?

Most investigators have been unable to shed light on this question because they have not attempted to disaggregate R&D. But just this year I led an econometric study to assess the role of basic research when other relevant variables (notably the rate of expenditure on applied R&D) are held constant. Despite various limitations on this study, covering the period 1948–1966, our results indicate a direct and statistically significant relationship. This may reflect a tendency for basic research findings to be exploited more fully by the industries and firms responsible for them. Or it may reflect a tendency for applied R&D to be more effective when carried out in conjunction with some basic research. In fact, it is by no means clear whether the relevant distinction is truly between basic research and applied research. For example, there is evidence that basic research may act to some extent as a proxy for long-term R&D. If the amounts spent on basic research and applied R&D were both held constant, an industry's rate of productivity increase from 1948 through 1966 seemed to be directly and significantly related to the long-term R&D component. This is perhaps the first systematic evidence that the composition (as well as the size) of R&D expenditure affects the rate of productivity increase.

Changes in the R&D mix

If it is true that an industry's rate of productivity increase is favored by long-term R&D, one is led to investigate recent changes in the mix of various industries'

R&D. There is a widespread feeling (but few supporting data) that industry has been devoting a smaller share to basic research, long-term projects, and risky and ambitious projects. To help fill this gap, we obtained information from 119 firms concerning changes made between 1967 and 1977 and changes expected between 1977 and 1980. The firms surveyed, each of which spent over $10 million on R&D in 1976, accounted for about one-half of all such industrial expenditures in the United States in that year.

According to this study, the proportion of R&D devoted to basic research declined between 1967 and 1977 in practically every industry. In the aerospace, metals, electrical equipment, office equipment and computer, chemical, drug, and rubber industries, it dropped substantially. In the sample as a whole, it fell about one-fourth, from 5.6% in 1967 to 4.1% in 1977. According to the firms' forecasts for 1977–1980, there is no expectation that this drop will continue, or that the proportion will rise very much. For the sample as a whole, the proportion of basic research is expected to be about 4.3% in 1980.

In four-fifths of the industries, there was also a decline between 1967 and 1977 in the proportion of R&D devoted to what are perceived as relatively risky projects. In some industries (aircraft, chemicals, drugs, metals, and rubber), this reduction has been large. Risky projects are forecast to get more R&D attention between 1977 and 1980, with the result that the average for the entire sample is expected to get closer to its 1967 level.

Despite the decrease in the proportion of R&D devoted to basic research, the overall proportion devoted to relatively long-term projects did not decline appreciably between 1967 and 1977. In some industries (again, aircraft, chemicals, metals, and rubber), there was a substantial decline; but in others (including drugs) there was an increase.

But why have so many firms cut back on their proportion of R&D for basic research and relatively risky projects? Government regulation is a frequently given reason; it has reduced the profitability of such projects. Another reason is that breakthroughs are becoming difficult to achieve, because the field has been more thoroughly worked over. A third reason is that firms have come to view R&D as an activity that can and should be managed in more detail than was earlier thought to be optimal.

Overall productivity change

Finally, let's turn to recent changes in U.S. productivity. Output per manhour is still increasing, but at a decreasing rate. Between 1977 and 1978, it rose by only 0.4%. From 1973 to 1977, its annual rate of increase was 1.0%; from 1965 to 1973, 2.3%; and from 1955 to 1965, 3.1%.

Economists generally prefer to measure total factor productivity because it includes nonlabor inputs as well as labor. It thereby reflects changes in input quality, technology, and efficiency. But even the rate of increase of this productivity index has slackened in many recent years: 2.5% annually from 1948 to 1966, 1.1% annually from 1966 to 1969, then 2.1% annually (a little better) from 1969 to 1973.

Several factors are responsible for what's happening to productivity growth rates by any measure. One has been an increase in the proportion of youths and women in the labor force, whose output per manhour tends to be relatively low. According to the Bureau of Labor Statistics, this change in labor composition may account for 0.2–0.3 percentage point of the difference between the average annual rates of productivity increase for 1947–1966 and 1966–1973.

A second factor is the rate of growth of the capital-labor ratio (net nonresidential capital stock divided by aggregate hours worked in the private nonfarm sector). Between 1948 and 1973 relatively high rates of private investment resulted in an increase of almost 3% per year. Since 1973 the annual increase has been only about 1.75%. According to the Council of Economic Advisers, this change may account for an annual reduction of 0.5 percentage point in productivity growth.

A third factor is environmental and social regulation. Since reduced pollution, enhanced safety, and better health are generally not included in measured output, the allocation of more resources to regulatory compliance results in lower productivity growth, not to mention the resulting litigation and uncertainty that discourage production investment and efficiency. The Council of Economic Advisers believes that the direct costs of compliance may account for another 0.4 percentage point drop in annual productivity growth.

Despite general agreement that these factors are important, they tell only part of the story. Many observers point also to a slowdown in the rate of technological change. This is signaled, they believe, by the smaller percentage of gross national product devoted to R&D during the late 1960s and 1970s. National Science Foundation figures show that R&D expenditures (as a percentage of GNP) fell from 2.99% in 1964 to 2.25% in 1976. Unfortunately, it is difficult to estimate with any real accuracy the effect of this decline.

International productivity comparisons

Slackening rates of productivity growth and technological change stimulate comparisons of the United States with other nations. What about our technological lead? From 1960 to 1976, the percentage gain in labor productivity in the United States was 60%. France, West Germany, Japan, and the United Kingdom all registered higher gains; Japan's was about 290%. Comparisons of total factor productivity growth rates yield the same results, although, for perspective, it is important to recognize that other countries' productivity *levels* tend to be lower than in the United States.

R&D expenditures (again as a percentage of GNP) have risen in some other countries, such as Japan, West Germany, and the Soviet Union, while decreasing in the United States. The U.S. percentage is still higher than in most other countries, according to National Science Foundation figures in 1976, which show only the Soviet Union at a higher figure. Because a considerable portion of the industrial R&D in some foreign countries is carried out by U.S.-based multinational firms, international comparisons of this sort quickly become clouded. In the early 1970s, for example, U.S. multinationals are estimated to have carried out about one-half of the industrial R&D in Canada and about one-seventh of the industrial R&D in the United Kingdom and West Germany. Furthermore, a nation's rate of productivity growth depends heavily on how effectively it uses technology (both foreign and domestic), and this may not be measured at all well by its ratio of R&D expenditures to GNP.

National policy responses

Undeniably, U.S. productivity growth has slowed. Undeniably also, there is concern over the faltering U.S. lead over its foreign competitors in many areas of technology. These are issues for national policy response. As that response is formulated, evaluated, and eventually adopted in some form, it is important to bear in mind the relevant technoeconomic relationships that have been identified.

- R&D has had an apparently significant effect on the rate of productivity growth in those industries and for those time periods studied by economists.

- The marginal social rate of return from new-technology investment seems high, suggesting that more investment may be called for.

- From 1948 through 1966, the long-term component of R&D seems to have been directly and significantly related to an industry's rate of productivity change (assuming the overall amount spent on basic research and applied R&D was held constant).

- U.S. firms in the past 10 years have cut back the proportion of their relatively basic and risky R&D projects.

Federal response began in 1978 with a Domestic Policy Review on Industrial Innovation. For this review, the Industry Advisory Subcommittee alone prepared draft reports on (1) federal procurement, (2) direct support of R&D, (3) environmental, health, and safety regulation, (4) industry structure, (5) economic and trade policy, (6) patents, and (7) information policy. Further, the Labor Subcommittee presented a report, as did each of a large number of government agencies. The overall result was a large and far-flung effort to come up with useful and effective policy recommendations.

Two general areas that have received considerable review attention are regulation and tax credits. A theme running through the Industry Subcommittee's reports is that many aspects of the regulatory process deter innovation, even though we lack very dependable or precise estimates of the effects of particular rules on the rate of innovation. As might be expected, Industry Subcommittee recommendations with regard to regulatory changes were met with considerable opposition, if not hostility, by the Labor and Public Interest subcommittees. Whether these recommendations will prove to be politically viable is hard to say.

Some of the Industry Subcommittee reports also recommended enactment of tax credits for R&D expenditures. Perhaps the most important advantage of this mechanism is that it involves less direct governmental control than do some other possible mechanisms. But it has disadvantages too: rewarding firms for R&D they would have done anyway, failing to help firms that have no profits, encouraging the same kind of R&D that is already being done rather than the more radical and risky work where the shortfall, if it exists, is likely to be greatest. Tax credit proposals also involve the necessity of satisfactorily defining R&D, and the Treasury Department is understandably concerned about this problem.

At a minimum, the Domestic Policy Review indicates a laudable interest in promoting U.S. technology. Its effect depends on what measures are proposed and whether they are implemented. However, one thing is certain: The declining rate of productivity growth that began in the 1960s is continuing in the late 1970s. It is adversely affecting our rate of inflation and our rate of economic growth. Can the Domestic Policy Review produce effective and equitable ways to reverse this trend? Given the problems that this exercise faces, and given that earlier, similar efforts have not been notably successful, it would be unrealistic to set our hopes too high.

"The proportion of R&D devoted to basic research declined between 1967 and 1977 in practically every industry."

TECHNOLOGY TRANSFER: Making the Most of Federal R&D

Congress and the administration are seeking to revive U.S. innovation and productivity. Technology transfer is a key issue with no single answer, as many individuals testified at recent hearings.

Are Americans getting a fair return on their federal tax dollars invested in R&D? Many who scrutinize the federal R&D effort think not. And increasingly these observers are targeting technology transfer as a key step in the innovation process necessary to ensure that the benefits of federal R&D reach the private sector.

Capitol Hill interest in the potential of technology transfer for maximizing benefits from the federal R&D investment was strong enough this summer to spark several days of hearings in the Subcommittee on Science, Research, and Technology of the House Science and Technology Committee. Mechanisms for transferring technology developed in federal laboratories to private industry, state and local governments, and universities were examined. Subcommittee staff members agree that it is a complex subject. "It's a tangled web," stated Timothy Lynch, subcommittee staffer. "We're trying to understand the scope and the linkages."

Lynch emphasized that the technology transfer hearings were part of a broader examination of U.S. productivity and innovation that the subcommittee has been conducting for most of the year. And this examination, in turn, should be considered within the context of an even larger reevaluation that has involved the administration and other units of Congress for over a year.

On the administration side, the effort to reevaluate U.S. productivity and innovation is embodied in the Domestic Policy Review on Industrial Innovation requested by the White House last year and due for completion this fall. In the Senate the Committee on Commerce, Science, and Transportation has also been conducting a review of innovation and productivity. Two pieces of legislation have resulted thus far from the investigations in the House and Senate:

S. 1250, the National Technology Innovation Act of 1979, and a companion bill, H. R. 4672, the National Science and Technology Act of 1979.

Vast Federal Resources

Witnesses testifying at the technology transfer hearings this summer were quick to point to the vast financial, technological, and human resources associated with the federal research enterprise. National Science Foundation Director Richard Atkinson told the subcommittee that "the federal government employs some 48,000 scientists and engineers who are responsible for conducting $7.3 billion of R&D and for managing a total budget of about $28 billion."

Congressman Wesley Watkins of Oklahoma, who chaired the technology transfer hearings at the request of subcommittee chairman George Brown of California, described the dimension of federal R&D in another way.

"In constant dollars, the federal government is now spending more than the total pre–World War II R&D budget every two days," he noted. "My concern, and the subcommittee's concern, is that in most federal agencies there appears to be little additional return on this investment beyond the important but limited goals set by the mission agencies."

Witness Charles E. Miller of the Lawrence Livermore Laboratory agreed. Pointing to the vast reservoir of ideas, hardware, facilities, equipment, capabilities, processes, experience and individual expertise at the nearly 800 R&D laboratories and centers throughout the country, he noted a "widespread belief and much evidence that this reservoir of technologies lies largely untapped."

But witnesses generally conveyed a feeling of optimism that the situation could be reversed and that improving mechanisms of technology transfer is one way to do it.

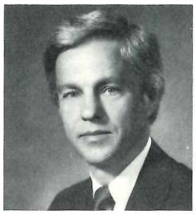
"We have the opportunity to plan, promote, and implement a successful approach to improve the utilization of the largest and most underutilized segment of U.S. R&D—federally funded R&D," insisted W. Novis Smith, director of R&D for Thiokol Corp., Chemical Division, and coeditor of a new book, *Federal R&D and Innovation.* "Significantly improved commercialization/utilization of this R&D [innovation] has the potential for making the greatest short- and long-term positive impact in U.S. innovation of any strategy that this committee could address."

Witnesses generally used the terms *technology transfer*, *technology utilization*, and *commercialization* interchangeably. Assistant Secretary of Commerce for Science and Technology Jordan Baruch suggested that the term *transfer* is a misnomer, erroneously implying that a technology can be "picked up from one place and sent to another—a pushing-on-a-string phenomenon." Baruch recommended that *utilization* of federal technology is a better term.

WESLEY WATKINS,
Congressman from Oklahoma

"The subcommittee's concern is that in most federal agencies there appears to be little additional return on this investment beyond the important but limited goals set by the mission agencies."

"We need well-defined and clearly stated patent and licensing policies before either the labs, industry, or universities can move with confidence into the commercialization stage of the innovation process."



RICHARD ATKINSON,
National Science Foundation

No specific definitions for the process were offered, although Samuel I. Doctors from the University of Pittsburgh explained what it is not.

"Technology transfer is not document dissemination," he stated. "It is, among other things, risk-taking, entrepreneuring, venturing, creative adaptation."

Miller identified its end result. "The transfer of a technology will be completed when the technology becomes generally accepted practice or when the technology is readily available in the marketplace."

Models for Success

In commenting on the current state of technology transfer efforts among federal agencies, Arlene B. Swerdloff, a technology transfer specialist with Cadcom, a division of Mantech of New Jersey Corp., seemed to echo the sentiments of the other witnesses. "With certain exceptions," she said, "government agencies have relied largely on serendipity to gently push technology into the marketplace."

Notable exceptions pointed to by witnesses as models were the following:

The Federal Laboratory Consortium, an informal network of 180 federal laboratories from 11 agencies that performs a broker function by seeking to facilitate the exchange of information and the transfer of technology from one government unit to another and from government to private industry and universities. Membership in the FLC is voluntary, however, and although praising its efforts, Swerdloff acknowledged its limitations.

"Even the FLC is operating under the handicap of not having a strong directive from Congress that would give [it] a mandate and an adequate budget to help convert federal technology into commercial products," she said. "At this time the FLC consists of a nucleus of dedicated people in various parts of the government who are working hard under difficult conditions to bring the technologies of their laboratories to the public. Nearly all of them have other jobs that their employers consider more important than technology transfer."

SAMUEL I. DOCTORS, University of Pittsburgh

"Technology transfer is not document dissemination. It is, among other things, risk-taking, entrepreneuring, venturing, creative adaption."

"A successful transfer program must seek out the rare individual with the capacity for looking across disciplines and conventional scientific categories."

JOHN S. TOLL, University of Maryland

The National Aeronautics and Space Administration, which cites "a seven-to-one return on its investments in technology transfer programs," noted Atkinson during the hearings. NASA's technology transfer effort is a mandate that is part of its mission and the agency has formally structured the program. It includes such efforts as technology transfer publications; application teams who identify public sector problems and provide technology-matching and problem-solving assistance; industrial application centers through which potential users of new technology can obtain scientific, technical, and management information; state technology application centers that focus on applying aerospace technology to the specific needs of public and private sectors in their state; and applications engineering projects through which NASA tries to adapt existing aerospace technology to meet specified needs of other government agencies and public sector institutions.

The Department of Agriculture, which perhaps epitomizes success in technology transfer through its extension programs in farming and cooperation among the land-grant universities, the agricultural research centers, and the farm community.

"First let us ask in what field has the United States clearly continued to lead the world in productivity and innovation? The answer is agriculture," stated John S. Toll, president of the University of Maryland, one of the original land-grant universities.

"Although we have been leaders in many areas of technology, it is especially in agriculture that our nation has excelled dramatically by increasing yields per acre, by the development of new species that are disease resistant, and by responding to the changing requirements of society. This unique success in agriculture has been due in great part to the consistent, comprehensive partnership between government and the great land-grant universities that has provided long-term, stable support for the total chain of technology transfer: from basic research in university science departments and elsewhere, through applied research in Agricultural Experiment Stations and federal installations, to the Cooperative Extension Service and its county agents who bring new techniques to the farmers and agribusiness and, in turn, feed back the problems of the farmer to expert researchers. Clearly, the federal support for agricultural development has been one of the best investments our nation has ever made."

The National Science Foundation, which has also supported a number of initiatives geared toward technology transfer. One such effort involves an experiment in university-industry cooperative research centers. Atkinson noted that the most successful of these is the MIT Polymer Processing Center. Although NSF provided the initial support for the center, the industrial partners soon picked up the full cost and the center is now self-sustaining. Other NSF-supported efforts include cooperative university-industry research projects and innovation centers for small businesses.

Recommendations

Pointing to the successful efforts of such agencies as NASA, DOA, and NSF, witnesses at the technology transfer hearings offered a number of suggestions for further steps to improve technology transfer in federal agencies and their supporting laboratories.

A key recommendation was that the technology transfer effort should not be left to chance but should be structured and formalized.

"One obvious characteristic common to most successful commercialization cases is that the transfer process is in itself a deliberative endeavor," stated Miller. "The activity is planned, staffed, scheduled, and directed, and most important, funding is made available."

Several witnesses suggested that at least one person in each laboratory or agency be assigned to carry out the activity, acting as a technology transfer agent. Miller added that such a person should have access to adequate technical resources and a high degree of freedom for independent action.

Toll cautioned that the job requires a special type of person. "The transfer of technology requires a special type of talent not always present even in the best of scientists," he noted. Explaining that the process may require applying technology developed for one purpose to an entirely new type of endeavor, he maintained that "a successful transfer program must seek out the rare individual with the capacity for looking across disciplines and conventional scientific categories."

Another suggestion was that Congress and the administration should "legitimize" the technology transfer function, either by issuing a policy statement expressing support for it or by enacting legislation to make the function a mandate of the mission agencies. As explained in a Congressional Research Service paper outlining the major points developed by witnesses during the hearings, the absence of such a mandate in agencies other than NASA has relegated the function to the back seat of other operations that support the agencies' primary responsibilities.

NSF's Atkinson also emphasized the importance of strengthening ties between federal, university, and industry laboratories. He pointed to sharing of facilities and personnel exchange as key mechanisms to accomplish this. And he suggested that the federal laboratories should be offered incentives to establish better links with industry and universities.

"Incentives affect the way laboratories allocate scarce R&D resources, chiefly in the form of money and personnel," he commented. "And the central fact about the resources available to federal lab directors is that they must be justified each year in terms of the mission of the sponsoring agency. If these resources are subsequently used to further relations with industry and universities, or to solve a problem for a state or local government, or, in fact, for any purpose that is not central to the sponsoring agency's mission, then the lab is vulnerable to the argument that the mission itself could be accomplished with a smaller budget or fewer personnel."

Atkinson called for a policy statement from both Congress and the administration saying that the laboratories should devote some portion of their resources to university or industry cooperation. He said that this statement should be backed up with the understanding that each laboratory's budget and personnel allocation should be justified partly in terms of nonmission work. He also suggested that consideration be given to allowing the laboratories to share some of the royalties earned on innovations developed in the laboratory and successfully transferred to industry.

Patent and licensing policy was another area that witnesses identified as needing reform. Atkinson called for "well-defined and clearly stated policies before either the labs, industry, or universities can move with confidence into the commercialization stage of the innovation process."

Baruch agreed. Pointing to some 4 million patents on file in the United States, he called them "useless to anyone who wants to do design and engineering because they are organized for examiners and not for engineers."

Smith criticized government policy requiring nonexclusive licensing, calling such a license arrangement a nonlicense, and saying that it "offers no incentive for the licensee to develop a technology into a commercial product. The initial technology in the licensed patent may represent about 5% of the total cost of carrying a new product into the marketplace," he said. "The holder of a nonexclusive license will not develop and market a resulting product that can be immediately duplicated by a competitor who has avoided 95% of the total research and development costs." Smith recommended that the government adopt a uniform patent policy permitting and encouraging the assignment of exclusive patent rights.

A final recommendation was implicit in the testimonies of most witnesses but was best expressed by Baruch. He argued that the needs of industry in integrating new technology into the marketplace must be taken into account during the formation of the research agenda at the federal laboratories. "The labs must have the market needs of industry considered at the outset," he insisted. "It will affect the direction of R&D." ■

Reconstructing the Accident Sequence

NSAC completes initial analysis, publishing a minute-by-minute account of the first 16 hours of the TMI-2 accident.

The new Nuclear Safety Analysis Center (NSAC), established by EPRI at the request of the nation's electric power industry, has been moving into high gear. NSAC professional staff now numbers more than 25, including those from EPRI and loaned employees from utilities, reactor suppliers, and engineering firms. There are also short-term contracts with some 30 professional specialists to complement the staff in key technical areas.

NSAC has published its first two formal technical reports: an initial analysis of the sequence of events that took place in the Three Mile Island Unit-2 plant in the early morning of March 28 and an indexed bibliography of 360 documents in NSAC's files about the accident. Both reports are now available from Research Reports Center.

In the accident analysis report, the sequence-of-events narrative is reconstructed second by second and minute by minute over the first 16 hours—the point when forced circulation of the core was reestablished. This narrative is followed by 17 detailed appendixes on different aspects of the accident, such as system thermal-hydraulic behavior, integrated control system, and description of radiation monitors and their locations.

The report required more than 60 man-months of professional effort by NSAC, including participation of individuals from more than 30 organizations. The report focuses exclusively on the observable aspects of the accident that are supported by firm recorded data and the main inferences on the physical course of events that can reasonably be calculated or deduced from the known data. The sequence of events was reconstructed on the basis of the plant's instruments, recorders, and logs, including about 75,000 frames of microfilm and data made available to NSAC by General Public Utilities Corp. and Metropolitan Edison Co., and supporting data from Babcock & Wilcox Co., Burns and Roe, Inc., and NRC.

Technical supplements and additional appendixes to the report are in preparation or planned.

The second report, a bibliography of 360 documents accumulated by NSAC through June 29, will be periodically updated and reissued. It divides the subject matter into 24 categories and provides an author index and a permuted title index (permitting ready search for the key word in the title). The data include reports and supporting references published by both industry and government that are useful in the analysis of such accidents.

These reports are already being used to aid utilities in their required reviews of the TMI-2 accident and as teaching aids in training programs. Moreover, they will provide a baseline for NSAC's further detailed studies of the causes and effects of the accident and for evaluation of remedies to make certain such a chain of events does not recur.

The sequence-of-events report, together with future supplements and a separate report on core damage assessment, embodies the principal results of the initial phase of NSAC's work. Current work is concentrating on causes, lessons learned, and analysis of generic remedial or preventive measures that may be appropriate. ■

Coal Leaders Visit EPRI

EPRI President Floyd Culler (left) reviews the Institute's major coal development programs with National Coal Association President Carl Bagge during a recent visit to EPRI. It was the first visit by Bagge and members of the NCA Board to EPRI.

Briefing on Recovery at TMI

Late in July 85 utility officials and engineers working with NSAC met in Hershey, Pennsylvania, to review results to date and the plans for NSAC's efforts. The group, joined by 12 members of NSAC's Utility Scientific Advisory Council, also heard an extensive briefing by General Public Utilities Corp. and Metropolitan Edison Co. (the owner-operator of the twin-unit station) on the status and recovery of TMI-2 and on restart of TMI-1. They then toured the accessible portions of TMI-2.

The group observed the construction work being pushed by Met Ed and its contractors to install water cleanup and waste concentration equipment for handling some of the large volumes of radioactive water still inside the plant. A small chemical cleanup building had been built adjacent to the turbine building, and this is being used to house the new equipment for treating the low-activity water in the plant auxiliary building.

Special equipment has been designed to draw a water sample from inside the reactor containment building and it is expected NRC will permit its installation. Analysis of such a sample will aid in determining the level of activity in the containment building water (whether it is higher than that in the auxiliary building) and in selecting the type of equipment to treat it. ■

EPRI to Expand Noise Research

EPRI has recently agreed to expand its noise research plan because of growing concern about noise from utility operations. To implement this plan, 40 experts from industry, government, and universities were recently invited to a planning conference in St. Louis, Missouri. Attendees were divided into four working groups: power plant acoustics, transmission and substation noise, community effects, and occupational impact. Each of these groups submitted ranked recommendations for future research. These recommendations ranged from research on improving the design of noise sources (such items as draft fans and transmissions) to noise prediction models, as well as recommendations on acquiring a better understanding of the annoyance quality of certain sounds. Summaries of these recommendations are now available from Leonard A. Sagan, manager of EPRI's Biomedical Studies Program. ■

CALENDAR

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

OCTOBER

22–23
Nuclear Nondestructive Evaluation Program Workshop
Palo Alto, California
Contact: Gary Dau (415) 855-2051

25–26
Topical Conference: Particulates
St. Louis, Missouri
Contact: Guy Farthing (415) 855-2392

NOVEMBER

8
Regional Review: Fossil Fuel Programs
Westboro, Massachusetts
Contact: B. G. McKinney (615) 899-0072

JANUARY 1980

15
Regional Review: Fossil Fuel Power Plants Department
Jacksonville, Florida
Contact: B. G. McKinney (615) 899-0072

16
Regional Review: Fossil Fuel Power Plants Department
New Orleans, Louisiana
Contact: B. G. McKinney (615) 899-0072

MARCH

9–13
Second International Symposium on Gaseous Dielectrics
Knoxville, Tennessee
Contact: Don Bouldin (615) 574-6200

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

FABRIC FILTER PILOT PLANT

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/10⁶ 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. One such research effort focuses on defining the optimal design and operating parameters of fabric filters (baghouses).

The electric utility industry has installed or committed over 5000 MW of baghouses on pulverized-coal-fired utility boilers. Based on the range of design and operating criteria of the baghouses purchased to date (e.g., air-to-cloth [a/c] ratios of 1.7–3.4 ft/min [0.5–1.0 m/min]) it appears utilities are making choices with less than complete information at their disposal. In many cases this situation is likely to lead to higher capital and operating costs than necessary without any assurance of satisfying regulatory requirements. Accordingly, EPRI has initiated a baghouse pilot plant project to remove the intuitive aspects from baghouse design and quantify the design and operational factors necessary for optimal performance. It is expected that this characterization will enable the utility industry to prepare optimized baghouse specifications for both retrofit and new coal-fired boilers.

To ensure that the results obtained will be of direct application to the utility industry, the pilot plant project is governed by the following constraints: sufficient size to properly simulate a full-scale baghouse; the use of fly ash and flue gas from a pulverized-coal-fired utility boiler; hardware that permits a complete and systematic evaluation of all major design and operating parameters without restriction to a particular manufacturer's design; and well-controlled and -characterized operating conditions. EPRI contracted with Lodge-Cottrell Operations, Dresser Industries, Inc., to design, fabricate, and assist in testing a 10-MW pilot plant consisting of a 35,000-aft³/min (14 m³/s) four-compartment baghouse. This unit is currently being installed at the EPRI Emissions Control and Test Facility, located at the Arapahoe station of Public Service Co. of Colorado.

The pilot plant will be used for an extensive series of tests designed to achieve the following goals.

- Establish criteria for proper gas-flow distribution in inlet-outlet manifolds, hoppers, and cell plates
- Quantify the effects of inlet velocity distribution on pressure drop, particulate penetration, and cleaning effectiveness
- Evaluate shaker, reverse-air, and shaker–reverse-air combination cleaning and define the most effective method of fabric cleaning
- Establish the dependence of pressure drop and particulate penetration on a/c ratio, time between cleaning, and inlet concentration
- Determine the importance of bag aspect (length-to-diameter) ratio
- Evaluate different levels of baghouse compartmentalization
- Examine the effect of filter cake particle-size distribution on pressure drop and particulate penetration
- Determine optimal startup and shutdown techniques
- Identify improved fabrics or methods of cleaning that require less off-line cleaning time

Pilot plant design

The design philosophy of the fabric filter pilot plant (FFPP) was to construct a research facility that would be both flexible and representative of commercial utility baghouses. After several configurations were evaluated, an arrangement was selected that consists of a four-compartment, hopper inlet, inside bag collector similar to existing utility baghouses. However, the FFPP differs from commercial baghouses in that each of the four compartments can be operated and controlled independently.

Bypass ducts are an important feature of the design. They maintain constant-volume flow conditions through the on-line compartments when a fourth compartment is removed from service. Accordingly, the FFPP can be operated as one 4-compartment baghouse or four 1-compartment baghouses.

Sufficient latitude is provided in the FFPP design to evaluate the wide ranges of hardware design and operating procedures currently used in commercial baghouses. For example:

- The a/c ratio is variable, from 1 to 4 ft/min (0.3–1.2 m/min).
- The inlet particulate concentration is variable, from 0.2 to 7 grains/ft³ (0.5–16 g/m³).
- An adjustable bag support mechanism permits evaluation of bags that are 22, 26, 30, and 34 ft (6.7, 7.9, 9.1, and 10.4 m) long.
- Tubesheets are removable to permit evaluation of bags that are 6, 8, and 12 in (152, 203, and 305 mm) in diameter.

▫ A 0.5–6.0 ft/min (0.18–1.8 m/min) variable reverse-gas-flow cleaning system is provided.

▫ The shaker mechanism is adjustable for evaluation of vertical or horizontal movements or numerous intermediate combinations.

▫ The shaker frequency is variable, from 2 to 40 cycles per minute for natural spring-loaded damped frequency oscillation, and the shaker can be easily modified for reinforced oscillation with a frequency range of 10 to 200 cycles per minute.

▫ A microprocessor permits the control and operation of four independent baghouse compartments. It controls all gas-flow rates (inlet, bypass, reverse air, clean gas, and preheat) and cleaning duty cycles.

Test program

The FFPP will be operated and characterization tests performed during an initial 15-month test period. The major test variables include types of bags and fabrics, cleaning mechanism and duty cycle, gas volumetric flow rate (a/c ratio), inlet-outlet concentration, and pressure drop. The test program will be performed under the hypothesis that for a given fabric-cleaning technique, an optimal combination of a/c ratio and cleaning cycle exists that yields a minimum pressure drop for the required level of outlet concentration. A second premise is that with proper characterization of the FFPP, the results will be of direct application to full-scale utility units constructed by different manufacturers and handling various types of fly ash.

The FFPP test plan is divided into four basic sequences: air-load testing, startup and bag-conditioning tests, first-year characterization tests, and long-term testing of more advanced concepts.

The current schedule calls for air-load testing to start in November 1979, with startup and bag-conditioning tests beginning in late 1979 or early 1980. It is anticipated that characterization tests will be conducted in 1980; however, the ultimate timing will be highly dependent on the results obtained. Schedules for the long-term testing program will be developed at a later date. To expedite the transfer of information to the electric utilities, intermediate reports will be issued as meaningful information becomes available, probably on a quarterly basis. *Project Manager: Robert Carr*

ADVANCED CYCLES

EPRI's advanced-cycles research is divided between two project groups: the magnetohydrodynamics (MHD) group, which is concerned with the development of open-cycle MHD power generation, and the heat engine group, which is currently assessing power generation methods appropriate for small utilities.

MHD systems

The MHD group has two primary objectives: the development of power-conditioning equipment for MHD systems and the design and analysis of first-generation MHD power plants.

EPRI's development effort in MHD power-conditioning equipment is a two-part project. In the first part a 250-kW inverter was

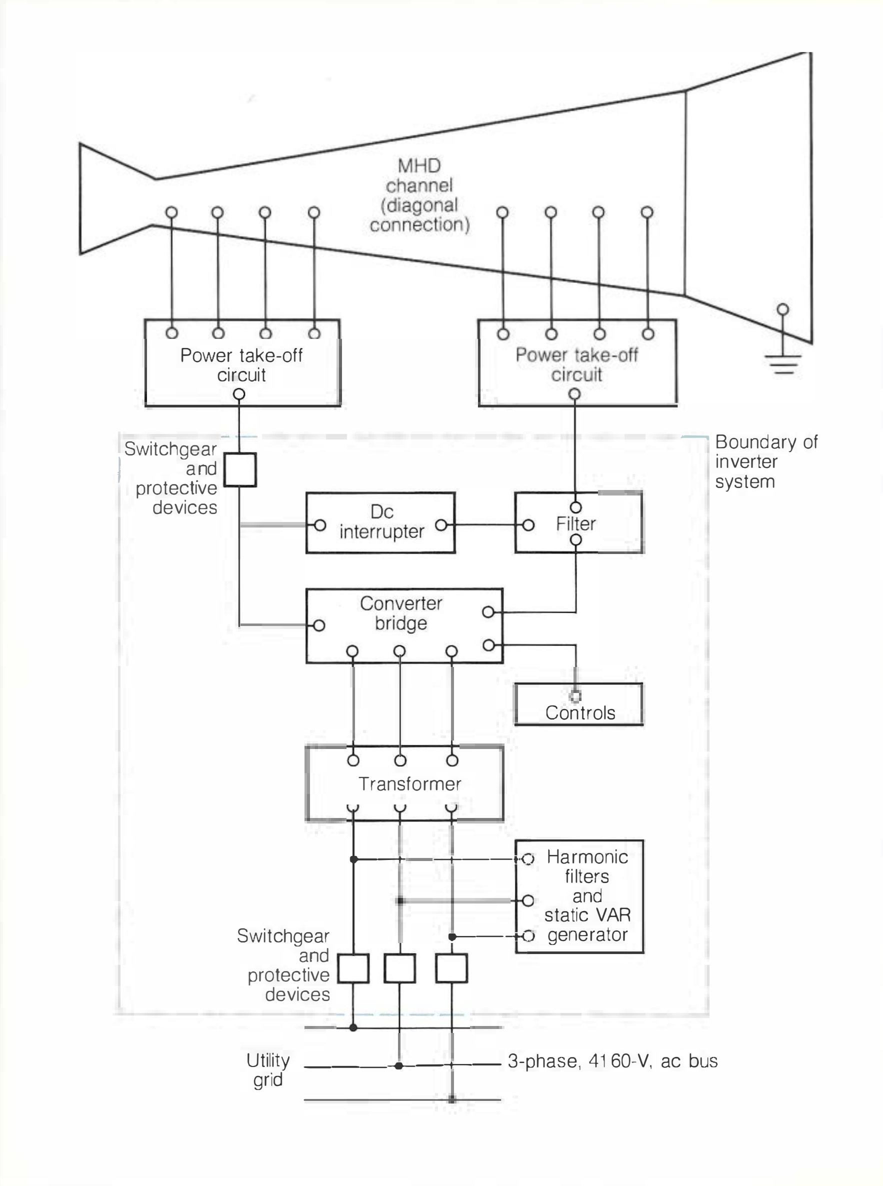


Figure 1 The primary function of the inverter system is to convert the dc output of the MHD generator to 60 Hz. The system must also control the flow of real and reactive power between the MHD generator and the grid. This control is accomplished by adjusting the operation of both the converter bridge and the static VAR generator. A dc interrupter is required to protect the inverter system from the short-circuit current of the generator during possible faults.

developed by Avco Everett Research Laboratory, Inc. (RP642-1). This recently completed work was successful in identifying several interface requirements and operational procedures necessary for the reliable operation of a forced-commutated inverter. Avco achieved the significant milestone of inverting the full output of an MHD generator for 12 hours. During this test, the inverter started, adjusted load, and shut down without significant operational problems.

The second part of the power-conditioning project will provide a 3.5-MW inverter for DOE's MHD test facility in Butte, Montana (RP642-2). The contract for this work has been awarded to Westinghouse Electric Corp., and work is scheduled to begin in the last quarter of this year. As shown in Figure 1, the complete system will consist of a converter bridge, a static VAR generator, and a dc interrupter.

The second objective of the MHD project group, the design and analysis of first-generation power plants, has been the focus of three projects—two studies by Westinghouse (RP639-1 and RP640-1) and one by STD Research Corp. (RP640-2). These projects compared the operational characteristics of several configurations of MHD power plants in an attempt to identify candidates for first-generation application (Figure 2).

The most significant variation in the plant designs studied was the method employed to achieve the high combustion temperatures (2800 K; 4580°F) required by the MHD cycle. The two methods considered were (1) preheating the combustion air to 1640–1920 K (2500–3000°F) and (2) enrichment of the combustion air to approximately 33 wt% oxygen.

Cycles that use preheated combustion air can be differentiated by the source of energy used by the preheaters. The most efficient cycle configuration (referred to as directly fired) regenerates heat from the combustion gas exiting from the MHD channel. Advanced plants using directly fired preheaters have been projected to attain cycle efficiencies approaching 50%. This configuration, however, was not considered to be a first-generation option because of the difficulties in developing reliable heat exchangers, ducts, and valves capable of handling a high-temperature (1800 K; 2780°F) potassium- and slag-laden gas.

The second preheat option employs a separate combustor for firing the preheater. Because it no longer regenerates a significant amount of energy from the MHD channel exhaust, this separately fired configuration results in a cycle efficiency that is approximately 3 points lower than that of the directly fired configuration. The separately fired preheater, however, represents a simpler engineering development task because the cleanness of the preheater combustion gases can be controlled.

Separately fired preheaters similar to those that would be required for MHD applications are commercially available in the steel industry. A typical preheater consists of a ceramic bed through which hot combustion gases and air are alternately flowed in opposite directions. Preheater units fired by clean fuels have demonstrated high availability.

No similar engineering data base exists for preheaters fired by a dirty fuel, such as coal. Thus, first-generation MHD units incorporating separately fired preheaters would require clean fuels for approximately one-third of the thermal input to the plant. This requirement represents a serious economic and performance penalty.

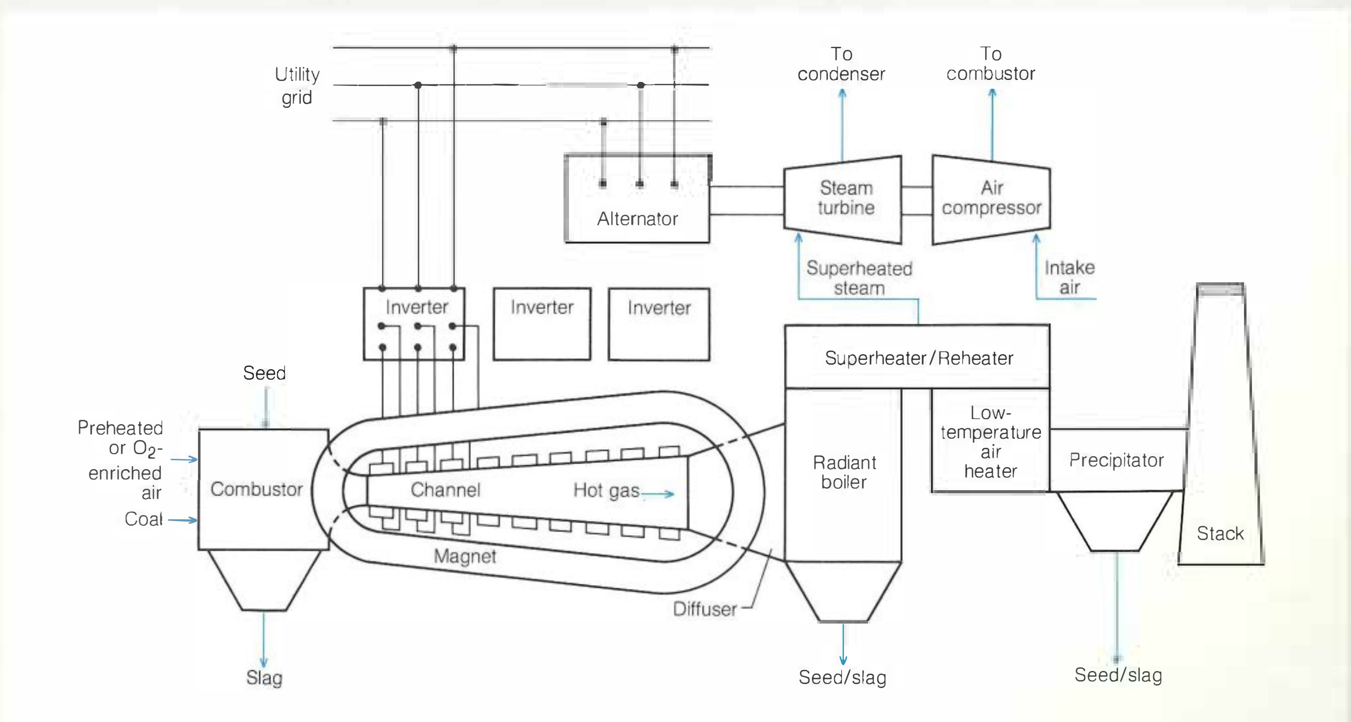


Figure 2 Open-cycle MHD power plant. The plant can be fired with either preheated or oxygen-enriched air, although the preheaters are not shown. The interface between the MHD topping cycle and the steam bottoming cycle occurs at the end of the diffuser.

The use of oxygen enrichment for attaining high flame temperature also results in a degradation of the cycle efficiency because (1) the cycle does not regenerate significant amounts of energy from the MHD channel exhaust and (2) the energy cost for producing the oxygen is high. For oxygen production power of 200 kWh/tO_2 (typical of the most efficient plants now in operation) and an enrichment of the combustion air to 33% oxygen, 7% of the power plant output must be used to run the oxygen plant. This is equivalent to a 3-point loss in cycle efficiency.

The cycle efficiencies for open-cycle MHD plants with either oxygen enrichment or clean-fueled, separately fired preheaters are therefore essentially equal. Capital cost requirements for the two designs are also expected to be comparable. In light of this close comparison in performance and cost for the two options, oxygen enrichment was preferred for first-generation power plants because this more conventional technology could be expected to yield a more reliable plant that would not rely on producing or buying a clean fuel.

A 500-MW (e) first-generation MHD power plant using oxygen enrichment is projected to achieve a station heat rate of 8710 Btu/kWh (39% thermal efficiency). The net output power is split roughly 1:2 between the MHD and steam cycles. Several characteristics of this power plant that significantly affect its heat rate:

- Oxygen is produced at an energy cost of 200 kWh/tO_2.
- The steam plant efficiency is 39.2% (efficiency defined approximately as percentage of steam flow enthalpy converted to shaft power).
- Sulfur emissions are controlled to 1.2 lb/10^6 Btu by using limestone scrubbers.

The potential of oxygen-enrichment MHD plants to attain higher efficiencies has been evaluated in a conceptual study sponsored by NASA. In general, the plants studied by NASA's two contractors, General Electric Co. and Avco, are less conservative than the plant just described. Although the NASA study has not been completed, preliminary results are projecting plant heat rates to be in the neighborhood of 7940 Btu/kWh—equivalent to a 43% plant efficiency. The principal reasons for the improvement in performance over the EPRI design are a larger plant size (900 MW versus 500 MW), a more sophisticated steam plant (42% steam plant efficiency versus 39%), and use of an energy-efficient seed-regenerating process for sulfur control instead of scrubbers.

The operational analysis phase of the project identified the following operations and maintenance requirements of the first-generation MHD power plant as significantly different from those of conventional steam plants.

- Need for planned maintenance of the MHD channel at intervals of 12–24 weeks
- Operation of an on-site oxygen plant
- Maintenance of a potassium seed recovery and injection system
- Maintenance of the cryogenic system for the superconducting magnet
- Possible changes in maintenance procedures for the boilers because of high concentration of potassium seed

Although not present in electric utility systems, the oxygen plant, seed injection system, and magnet cryogenic system either exist or have counterparts in other industries, and so their operating and maintenance procedures are known. The MHD channel, however, presents a unique situation. Current experience indicates that MHD channels undergo slow physical degradation, which limits their useful service lifetime. A reasonable projection for a first-generation plant, based on current technology, is for a channel to have a 2000-hour lifetime. This would necessitate maintenance of the channel every 12–16 weeks, a schedule that is not typical of utility practice.

Following its service period, most of the MHD channel would still be operational, although the gas-side surface and insulators would probably require refurbishment. Because the channel is an inexpensive component of the plant (approximately 1% of the total plant capital cost), it should be practical to install a spare channel while the first channel is being overhauled. Plant downtime would thus be limited to the time required to shut down, replace the channel, and restart the plant. A preliminary DOE study of plant outage attributed to MHD channel replacement indicates that the maintenance procedure can be completed over a weekend. This study is still in progress, however, and these preliminary results may have large uncertainties associated with them.

Table 1
ADVANCED THERMOMECHANICAL POWER SYSTEMS

Cycle	Overall Thermal Efficiency (%)	Capital Cost of System ($/kW [e])
Combined cycle, directly oil fired, 11.6 MW	40	600
Combined cycle, indirectly coal fired, 3.8 MW	25	1500
Simple closed cycle, atmospheric fluidized bed, coal fired, 2.5 MW	35	870
Simple closed cycle, directly oil fired, 2.5 MW	36	800

Advanced thermomechanical cycles

The heat engine group has performed two studies on characterizing small advanced thermomechanical power cycles. These cycles are based on fuel-flexible combustion turbines in simple and combined-cycle configurations, with and without heat recuperation, and with both open and closed cycles. Power plants in the 1–10 MW (e) range were studied. The purpose of these studies was to present to the small utilities a number of candidate combustion turbine power cycles that have efficiencies in the range of 25% to 40% and that could be demonstrated by 1985, burning either coal or oil (Table 1). Costs for these systems are projected to be in the range of $800/kW (e) to $1500 kW (e) (1978 dollars).

The studies supporting the Table 1 data will be used to perform a market survey to determine the degree to which small utilities will be interested in acquiring some form of such generating systems, assuming the technology will be available in 1985.

A study is also being undertaken to characterize the factors associated with the use of diesel generators by small utilities. This study will consist of a survey of utilities with installed diesel generating capacity and will develop information related to the real operating factors and problems encountered by such utilities in maintaining and operating diesel generators. The survey will also elicit information on the utilities' planning for future new generating capacity to replace retired equipment or for growth. *Project Managers: Andrew Lowenstein and Henry Schreiber*

FOSSIL PLANT PERFORMANCE AND RELIABILITY

Large fossil-fueled steam power plants, which constitute a major portion of the baseload capacity in this country, have, on the average, the poorest availability records, and it can be shown statistically that the availability of these large machines is decreasing. With increasing environmental restrictions that result in the need for additional auxiliary control equipment, as well as reduced fuel quality and off-design operating requirements, this deterioration of availability is expected to continue. Through the Fossil Plant Performance and Reliability Program, EPRI has dedicated resources to the overall improvement of reliability and performance of both new and existing fossil-fueled power plants.

This three-year-old program (*EPRI Journal*, November 1976, pp. 25–26) has paid significant dividends to the utility industry through its work on short-term projects. Causes of major losses in plant availability are being addressed, and a close working relationship with utility industry representatives has been established. Also, in those areas where failure cause cannot be clearly defined by statistics, in-plant root cause analysis projects are under way.

At the end of 1979 fossil-fueled plants accounted for 69.1% of the electric power industry's installed generating capability. Planned capacity additions for fossil units are nearly equal to those for nuclear. Nearly 92% (134 GW) of the planned new fossil capability will be fueled by either coal or lignite. For this reason, greater emphasis has been placed on the problems encountered with these fuels.

Increased environmental restrictions, as well as reduced fuel quality and off-design operating requirements, will tend to continue to reduce current availability and efficiency. Therefore, this program of reliability and performance improvement becomes essential to the financial health of the utility industry. On the basis of current operating experience, the required environmental control devices are expected to reduce equivalent availability by at least 3% and overall efficiency by as much as 4%. At a fuel cost differential of 12 mills/kWh and assuming coal costs to be $25/t, this degradation is valued at more than $460 million per year for the 134 GW of planned coal additions mentioned earlier. One goal of this program is to provide the technology for at least a 5% improvement in equivalent availability for these large, baseload fossil units in the near term.

In attaining this goal, the program has identified the failure areas of highest priority and is addressing these problems through five major study areas: turbine-generators, steam generators, plant auxiliaries, plant chemistry, and plant integration.

Turbine-generators

Turbine blade failures continue to be the leading cause of lost availability in the turbine area. Stress corrosion/corrosion fatigue, solid-particle erosion, and water induction have been identified as the major causes of these blade failures.

Stress corrosion/corrosion fatigue has been responsible for many extended outages. More seriously, however, this cause has been responsible for catastrophic failures because of loss of blades and discs during operation. It is presently believed that small amounts of steam-borne impurities deposit on low-pressure turbine components, causing corrosion, pitting, and crack initiation. It has been estimated that at least 10% of the nation's fossil units are affected by this phenomenon. Currently, 13 EPRI projects are being directed at finding solutions to this problem. It is expected that these intensive R&D efforts will provide technological solutions by early 1981. These will include corrosion-resistant titanium blades (RP912, RP1264) and possible redesign of susceptible components, such as the blade root (RP1185). Solid-particle erosion is believed to result from boiler and piping exfoliation. The steam generator and plant chemistry projects are addressing the possibilities of inhibiting this steam-side corrosion process.

Water induction is a major cause of damage to turbine blades. EPRI, Westinghouse, and Boston Edison Co. are testing a system for detecting water induction in an operating unit (RP637). This project will delineate the conditions that lead to water induction incidents and provide an alert system to warn operators of impending water induction. The final report is expected late in 1979.

Reduction of bearing-system failure is a major objective of the turbine-generator subprogram. Over a 10-year period, close to 23% of forced-outage time on units over 600 MW was caused by bearing systems, making this area the leading cause of forced outages in turbine-generators. Many bearing failures result from inadequacies in the design and dynamic performance of lubrication systems. In addition, rotor vibration problems are directly influenced by bearing dynamic characteristics and turbine operating conditions.

The program is addressing bearing problems by analyzing past failures to determine root causes (RP1265-3) and by addressing known, current deficiencies (RP1648). In the latter, improved techniques are being developed for design and analysis in the following areas.

- Rotor-bearing dynamic performance of multibearing systems
- Improved bearing designs and bearing power losses
- Transient performance of lubricating systems during emergency shutdown
- Design and erection practices for lubricating-oil systems
- Fuel-flow filters for lubricating-oil systems

Because of the generic bearing-failure problems that pervade the utility industry, practical solutions must be developed. The principal emphasis in each of these contracts is on problem prevention and reduction through improved methods of analysis, proper specification guidelines, and improved hardware designs for new and existing bearing and lubrication systems.

Steam generators

Tube failure in the water-wall sections, economizers, and superheat portions of the boiler is estimated to account for approximately half of all boiler availability losses. Failure modes include tube failure at the transition welds of dissimilar metals, embrittlement, erosion, and corrosion. Current efforts include analysis of the root causes of failures in several plants known to have severe boiler curtailments because of tube failure. This analysis will determine the R&D priorities for the most severe causes of boiler pressure part failures. Battelle, Columbus Laboratories is the contractor, and final analysis should be completed in mid-1980 (RP1077).

Boiler tube fouling and excessive slag formation from the burning of pulverized coal are major causes of boiler capacity losses. In a long-range study, Brigham Young University is using a small laboratory combustor to investigate what effect the mixing of fuel and air has on the kinetic processes in pulverized-coal combustors. Two initial reports are now in circulation, with follow-on work to be completed in late 1980 (RP364). In conjunction with this work, fuel and combustion additives are under scrutiny (RP1035) and those elements present in coal that are most likely to cause these problems are being identified (RP736). Boiler cleaning equipment that uses water has been demonstrated to be very effective in removing tenacious ash deposits, but the direct impingement of subcooled water on the surface of boiler furnace-wall and superheat tubes operating at temperatures up to 1200°F (650°C) is viewed very cautiously by utilities and boiler manufacturers. Before boilers can be cleaned with this aggressive and effective cleaning medium, an accepted method for predicting the long-term effect of repeated thermal shocks on boiler tubes must be developed and verified. Babcock & Wilcox Co., as both contractor and cosponsor, is developing appropriate analytic models, verified and validated by laboratory tests, to predict the life of boiler tubes subjected to various frequencies of water cleaning over a long period of time (RP1650).

In an attempt to eliminate the cause of solid-particle erosion of high-pressure and intermediate-stage turbine blades and in conjunction with the Empire State Electric Energy Research Council, EPRI plans a full-scale boiler retrofit of a pressurized chromate conversion treatment developed by EPRI with Foster Wheeler Energy Corp. (RP644). When field-proved, this process should provide the utility industry with an effective means of preventing solid-particle erosion in both new and existing models.

Plant auxiliaries

Failure of plant auxiliary components accounts for an average plant availability loss of 8%. The plant auxiliaries' focus is divided into three elements: water-steam, air-gas, and fuel-ash subsystems.

Water-Steam Subsystem Condenser problems have been identified as the most frequent cause of availability loss in plant auxiliaries (FP-422-SR). Consequently, EPRI has initiated a research project to investigate condenser problems and provide the technology to improve condenser reliability (RP1698). Current work includes (1) identification of the problems associated with steam surface condensers and the development of improved design guidelines and (2) identification of problems associated with the condenser and its auxiliary systems and recommendation of further R&D needs. Other condenser work presently planned for 1980 will investigate the root causes of tube failures and tube inlet end erosion.

A boiler feed pump (BFP) reliability study has exposed generic weaknesses in BFP design that have been corrected in several cases (RP641). Current follow-on work includes the development of guidelines for utility purchase of feedwater pumps. This is a joint effort with Edison Electric Institute's Prime Movers Boiler Subcommittee. The preliminary guidelines have been used successfully by one utility for the purchase of several pumps.

Air-Gas Subsystem A research effort has been initiated to improve fan reliability (RP1649). Current projects include development of field-proved guidelines for the improved design of fan foundations, investigation of erosion problems in fan wheels and blades, and validation of field test procedures. Other fan-related research to be initiated in 1980 includes a root cause analysis of fan failures, a study of the aerodynamic disturbances caused by fan blades, and a study to control induced fluid instability at reduced loads.

Large-amplitude, low-frequency pressure pulsations in air-gas systems are also currently being investigated (RP1651). This area has been identified as a significant cause of steam generator–auxiliary equipment failure. The objectives of these research projects are to achieve a mathematical understanding of the air-gas system dynamics, to optimize a fluidic control system for damping the pressure pulsations, and to identify the possible fluid excitation sources in resonant frequency ranges.

Fuel-Ash Subsystem A coal-pulverizer reliability study has determined generic weaknesses in certain designs. Before the end of 1979 a final report summarizing more than 450 pulverizer failures will be published. This effort has determined the priorities for addressing generic problems in coal pulverizers and has delineated further R&D efforts for reducing failures (RP1265-1). Specific pulverizer components responsible for these failures have been identified, which will lead to improved products through utility specifications based on EPRI design guides.

Plant chemistry

At present, five projects are under way in plant chemistry and two more are planned. Major emphasis is placed on addressing the problem of turbine blade and rotor failures. The work involves metallurgical or materials design, as well as chemical processes that affect the plant operation. In one project EPRI is working with Southern California Edison Co. to test a number of turbine blade coatings that were selected for their ability to withstand the corrosive-erosive effects of low-pressure steam. Development and application of these coatings are expected to take one year (RP1408).

Consolidated Controls Corp. has assembled and begun testing equipment to detect chemical corrodents deposited on steam turbine components. When fully developed, this system will be able to continuously monitor and identify the chemical species present on certain turbine stages (RP1409).

Corrosion fatigue in turbine blades is being investigated by Westinghouse. Fatigue tests are being performed to define the effects of environment, material composition, and applied stress on metal behavior. Concurrently, a nationwide steam-sampling program is under way to provide information on what steam purity levels are needed to ensure reliable turbine blade performance (RP912).

Advanced manufacturing methods for producing high-temperature steam turbine rotor forgings that have improved center quality and improved mechanical properties are being investigated. Three ingots have been forged to rough dimension, two in Japan and one in Europe. Rough machining is progressing, and delivery to Westinghouse Corp. is expected shortly (RP1343).

Other projects relating to fossil fuel power plant chemistry are now being developed. They include a study to produce a definitive test for boiler chemical cleaning methods and a project to address specific aspects of steam quality and their effects on steam turbine performance and reliability.

Integrated plant

The integrated plant subprogram will produce recommendations and guidelines on component design, plant operation, and maintenance practices; overall plant performance data; and statistical data on reliability.

Currently, activities include the development of diagnostic tools for plant operation.

The goal is to provide a coordinated approach to producing information on impending failures of specific components through changes in acoustic emissions and vibration signatures. Equipment necessary to accomplish this has been installed by Rockwell International Corp. at New England Power Co.'s Brayton Point plant. This project should lead to optimization of maintenance schedules and will ultimately predict the possibility of catastrophic failures. A first generation of this diagnostic equipment should be available in 1980 (RP734).

In the same predictive mode, dynamic simulations of generic fossil units are being developed with Bechtel and Babcock & Wilcox. These models will provide the utility industry with information on dynamic stability of equipment combinations for the initial design and retrofit correction of control systems. The project sets the stage for future development of steady-state models that could be offered in the same format as the dynamic simulations for easy utility use. These steady-state models would be used by the industry in optimization of new designs and in troubleshooting problem areas of existing plants (RP1184).

Both sets of models will be especially useful in predicting deficiencies and retrofit applications in cases where units that were originally designed for baseload duty are required to cycle. Work in root cause failure analysis (RP1265), mentioned earlier, and investigations of fossil plant improvement concepts (RP1266) are also coordinated within this study area. The improvement concept investigations provide the ability to conduct analyses of concepts and potential projects and to more closely delineate necessary follow-on R&D work.

Reversing the availability trend

EPRI's Fossil Plant Performance and Reliability Program, working closely with the utility industry, will continue to provide technology to reverse the downward trend of the equivalent availability of this country's large, baseload fossil units and to compensate for the decrease in availability caused by increases in environmental regulation.

As mentioned earlier, lost availability is very costly to the individual utility. In addition, however, this program is important in keeping with the national goals of efficient energy use and reduced dependence on oil and gas because it promotes higher availability of more efficient, mostly coal-fired, baseload equipment. *Program Manager: David Poole*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

ZIRCALOY WATERSIDE CORROSION

During reactor operation, corrosion products form on the outside surface of the Zircaloy cladding. An oxide layer forms as a result of a chemical reaction between the Zircaloy and the coolant, and circulating corrosion products (crud) released from steam generators and piping can deposit on the oxide film. These corrosion products can degrade fuel rod performance, especially at high burnups, because the heat transfer properties of these films are poorer than those of the cladding substrate.

The uniform corrosion rate of the outside surface of Zircaloy cladding is such that it does not limit operating strategies or the life of LWR fuel rods. However, the goals of minimizing uranium feedstock requirements and spent fuel rod storage have led to introduction of fuel rod designs and duty cycles that will result in higher Zircaloy temperatures (as a consequence of higher coolant temperatures) and longer in-reactor residence times (as a consequence of longer or additional exposure cycles). Singly or in combination, these changes increase the uniform corrosion of Zircaloy. To confirm that the increased Zircaloy corrosion caused by these more demanding conditions would not result in undue degradation of the cladding, EPRI has initiated projects that address the subject of Zircaloy corrosion.

Of primary concern is that the observed in-reactor corrosion is generally greater than that observed in out-of-reactor studies under comparable test conditions. Currently, the details of the processes responsible for this increased in-reactor corrosion cannot be defined quantitatively, although local fuel rod surface temperatures, coolant chemistry conditions (particularly the oxygen content), and neutron irradiation effects are believed to be important. A project was initiated with Combustion Engineering, Inc. (C–E) and Kraftwerk Union (KWU) to obtain data on uniform Zircaloy corrosion under conditions where accelerated corrosion would be anticipated (RP1250-1). The broad objectives of this project are to generate statistically significant corrosion thickness measurements, characterize the physical and chemical properties of these corrosion films, and develop an analytic correlation that predicts the in-reactor corrosion of Zircaloy in PWR environments.

The first milestone of the project called for a review of published data relevant to Zircaloy corrosion in PWRs and for release of hitherto proprietary KWU measurements of oxide film thicknesses from German PWRs. Full results of this work, summarized below, are documented in an EPRI report, *Review of PWR Fuel Rod Waterside Corrosion Behavior,* which is available from the project manager.

Oxide film thickness data have traditionally been obtained during hot cell examinations from measurements on metallographic cross sections after sectioning irradiated fuel rods. Only limited data have been reported because such examinations are very costly. The bulk of the corrosion data in this project are being obtained by using a new poolside eddy-current technique that provides a nondestructive procedure for measuring oxide film thickness. The state-of-the-art capabilities have been significantly improved by KWU's development of this nondestructive measuring technique.

An axial trace from a typical PWR rod dramatically illustrates the variation in oxide film thickness along the length of the fuel rod—a likely consequence of local variations in both coolant temperature and neutron fluence (Figure 1). The decreased oxide film thickness at the grid support positions is probably caused by changes in local coolant chemistry and flow conditions. The eddy-current-probe data were selectively checked against metallographic measurements, and agreement was found to be good, particularly for oxide film thicknesses greater than 5 μm, which is the regime of most interest.

Traces similar to that of Figure 1, which were obtained from five KWU PWRs over 16

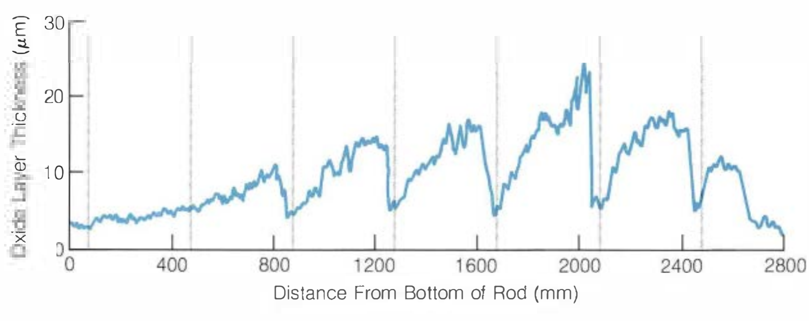


Figure 1 Trace of oxide film thickness as a function of axial position, obtained by using the KWU eddy-current nondestructive evaluation technique. The increase in oxide thickness toward the top of the rod is clear, as is the reduction of oxide thickness at the grid positions (gray lines).

operating cycles, and published data from five commercial U.S. PWRs were analyzed. The key point that emerges is that the enhancement factor (i.e., the ratio of in-reactor to out-of-reactor corrosion rates obtained under similar conditions) varies from reactor to reactor and can even vary from cycle to cycle within a given reactor. The enhancement factors cluster into two groups, one around a value of about 1.8 and the other at about 2.2. The higher value suggests that Zircaloy waterside corrosion may impose a design limit at burnups approaching 50,000 MWd/t. The focus of the remaining experimental work in this project is to determine the factors responsible for the observed variations in enhancement factor. It appears that additions of lithium hydroxide to the coolant and subsequent incorporation of lithium into the oxide film result in accelerated corrosion rates. Also, values of the thermal conductivity of the oxide film lower than hitherto measured, as well as neutron flux per se, may be responsible for the in-reactor corrosion enhancement and variations thereof.

The data discussed above were obtained from reactors in which coolant chemistry conditions were carefully maintained so that crud formation was minimal, thereby avoiding complications in interpretation of the oxide film thickness measurements. Since U.S. PWRs currently operate under coolant chemistry conditions where crud formation is typical, C–E undertook oxide–crud film thickness measurements, using the eddy-current system at the Calvert Cliffs reactor during the May 1979 outage. An evaluation of these measurements to establish whether the eddy-current device can be used when crud has deposited on the fuel rods awaits confirmation from metallographic measurements following destructive evaluation of these rods in late 1979.

Additional information on corrosion and crud formation will be provided by Atomic Energy of Canada, Ltd., which will review data obtained from commercial pressurized heavy water reactors and experimental loops at Chalk River (RP1250-2). The data will address the effects of coolant conditions and Zircaloy microstructure on corrosion behavior under in-reactor conditions. The response of corrosion coupon specimens will be discussed and compared with that of the fuel cladding. Crud measurements obtained from the same irradiation studies that will provide the corrosion film data and from the NRX reactor will also be presented. The effects of coolant conditions on crud thickness and crud properties will be discussed. Mathematical models of crud buildup will be described, and a comparison of the models' predictions with data obtained from the Pickering and Bruce reactors will be provided. This project began in January 1979, and a report discussing the Canadian experience with Zircaloy corrosion is being prepared.

EPRI has recently solicited proposals for an experimental study that will address the impact of crud formation on LWR fuel performance. This project will begin early in 1980. *Project Manager: Howard Ocken*

STEAM GENERATOR OWNERS GROUP NDE PROGRAM

The presence of denting and its effects in steam generators have resulted in the need for nondestructive examination (NDE) methods with capabilities beyond those currently available. In particular, there is a need for techniques to determine support plate integrity, tube integrity in regions where denting causes severe distortion of conventional eddy-current inspection signals, and the condition of the gap between tube and support plate. A variety of techniques are now being explored in order to develop the improved inspection capabilities that are needed.

The Steam Generator Owners Group, made up of utilities owning PWR nuclear power plants, was established in early 1977 for the specific task of finding the best solutions to steam generator problems. To facilitate this effort, the Steam Generator Project Office was formed within EPRI to direct and manage the necessary research programs (*EPRI Journal,* April 1978, pp. 53–56). Chemically and mechanically induced damage to steam generator tubing and support plates has been the main area of concern. To better characterize and assess this damage, the development of new or improved NDE methods was given high priority in the Owners Group program.

The research is organized into three major areas.

- Determination of extent of damage and characterization of defects, with emphasis on tube integrity and support plate integrity
- Diagnosis of damage precursors, particularly by determining the extent of blockage of the tube–support plate crevice and by measuring sludge depth
- Processing and evaluation of detector output, with emphasis on data storage and analysis techniques and methods of NDE system qualification and evaluation

For each of these areas there are several applicable NDE technologies, many of which are being evaluated in Owners Group and EPRI projects. NDE projects in progress range from laboratory feasibility studies to demonstrations of field-serviceable systems. Highlights of selected Owners Group projects are discussed below. The full scope of the NDE program is outlined in an EPRI special report (NP-900-SR).

Tube and support plate integrity

Eddy-Current Testing Under project S115 a commercially available multifrequency eddy-current (MFEC) unit and appropriate recording instruments were combined to provide an MFEC system that would have significant advantages over conventional eddy-current systems for near-term use in testing tube integrity. This system has been used in the field for steam generator inspections with great success. The primary benefits of MFEC testing include (1) reduced inspection time, since data can be obtained at several frequencies during one probe, and (2) the ability to reduce extraneous signals from support plates and tube dimension variations by properly mixing appropriate frequency channels.

Optical Solid-State Scanner Project S103 demonstrated the feasibility of using a circular diode array for imaging a circumferential section of a tube's interior surface. Good defect detection and excellent dent-profiling capabilities were demonstrated. Further work is in progress to develop an improved, higher-resolution probe with automatic data acquisition and analysis capabilities.

Strain Gage Project S108 involves the field-hardening of a laboratory device that determines the profile of a tube by using eight strain gages attached to arms that ride on the tube's interior surface. By measuring the eight tube radii, an accurate tube profile can be obtained. This technique will be particularly useful in providing data for dent growth-rate studies and for tube and support plate stress analyses. The device has been successfully used during a steam generator field inspection.

Gamma Radiography Under Project S105 a system has been developed that uses gamma rays to inspect for support plate ligament fractures. A gamma ray source is inserted into one tube, and radiographic film cassettes are placed in several appropriate surrounding tubes. A delivery system is included that is capable of simultaneously positioning the source and up to six film cassettes in the surrounding tubes.

Damage precursors

Magnetic Flux Leakage Project S125 has shown the feasibility of detecting changes in the crevice gap clearance by measuring changes in the magnetic flux pattern of a coil passing through the area. The technique is sensitive to small changes in tube-hole diameters caused by magnetite buildup. Follow-on work is under way to optimize the probe design and to develop the necessary signal-processing techniques.

Tube Vibration Analysis Project S102 has demonstrated that the clearance between a tube and a support plate can be measured by vibrating the tube with a rotating eccentric mass and analyzing the tube's acceleration as measured in two orthogonal directions. Work is in progress to refine the probe and the data analysis techniques for field use.

Low-Frequency Eddy-Current Testing The conventional low-frequency eddy current can be used to determine sludge depth. One of the advantages of a multifrequency eddy-current system is that by using one low frequency, information on sludge depth can be gathered at the same time as information on tube integrity.

System qualification and evaluation

Standard Sample Test Rig Under Project S126 a fixed-site mock-up based on three PWR vendors' designs has been constructed. The mock-up, which contains tubing with simulated defects representative of those found in the field, was discussed in detail in an earlier report (*EPRI Journal,* July-August 1979, p. 42).

Future efforts

The Steam Generator Project Office will continue its efforts to improve steam generator NDE technology. As new or improved approaches are proposed, it will evaluate them and pursue those that will contribute most to satisfying the needs of the utility industry. These improvements in NDE capability will increase the efficiency and reliability of in-service inspections and thus help ensure that steam generator integrity is being properly monitored and maintained. *Project Manager: Gary DeYoung*

HALDEN REACTOR PROJECT

EPRI has sponsored power ramp tests on nuclear fuel rods in the Halden test reactor to investigate mechanical deformation of the fuel rod cladding. In these tests instrumented assemblies provide measurements of rod diameter, length, and local power during reactor operation. The results serve as a check on the predictions of fuel rod performance codes used by utilities to estimate fuel rod performance in power reactors.

The capacity factor of a nuclear plant is sensitive to the fuel rod failure rate. Several percent of capacity can be lost by restricting overall plant performance to avoid fuel rod failures and from early shutdowns to replace actual failures. Because the cost of losing 1% of capacity factor is greater than $1 million a year in replacement power for each nuclear power plant, the economic incentive for reducing fuel rod failure is large.

Most recent fuel rod failures have been associated with increases in power and are attributed to pellet-cladding interaction (PCI)—an adverse interaction between the UO_2 fuel pellets and the Zircaloy cladding—which results in penetration of the cladding wall by small longitudinal cracks. Many nuclear plants place restraints on the rate of power increase during periods of increasing electrical demand to prevent this type of failure. These restraints, which are a major source of lost capacity, can be reduced or eliminated if the design parameters and operating conditions that lead to cladding crack formation can be better determined. Understanding the effects of design parameters on fuel rod failure aids in selecting fuel types that offer improved performance, and such work is the subject of several EPRI projects. Other studies are concerned with understanding the effects of operating conditions on PCI failures. These projects often involve test reactor irradiation of highly characterized fuel rods that are subjected to severe operating conditions.

EPRI has supported three such test reactor projects designed to improve the ability to predict fuel rod failures.

- The Halden Reactor Project (RP216 and RP335; *EPRI Journal,* June-July 1977, pp. 14–19)
- The Studsvik Inter-Ramp (BWR) Project (RP507; *EPRI Journal,* April 1979, pp. 37–38)
- The Studsvik Over-Ramp (PWR) Project (RP1026)

The last two projects involved ramp-to-failure tests that provided data on the PCI failure thresholds as a function of power ramp magnitude and rate of change. The Halden tests have provided information on one aspect of the failure mechanism: the mechanical deformation of the cladding during ramping. (The chemical aspect of the PCI failure mechanism will be addressed in later Halden tests.)

The IFA-512 experimental fuel assembly used in the initial Halden tests is an instrumented power-ramping rig that is nearly identical to an earlier EPRI rig, IFA-435, developed by Norway's Institutt for Atomenergi. The instruments in this rig are specially designed to provide accurate measurements of the local mechanical deformation of BWR-type fuel rods (specifically the cladding diameter and length) as a function of local power.

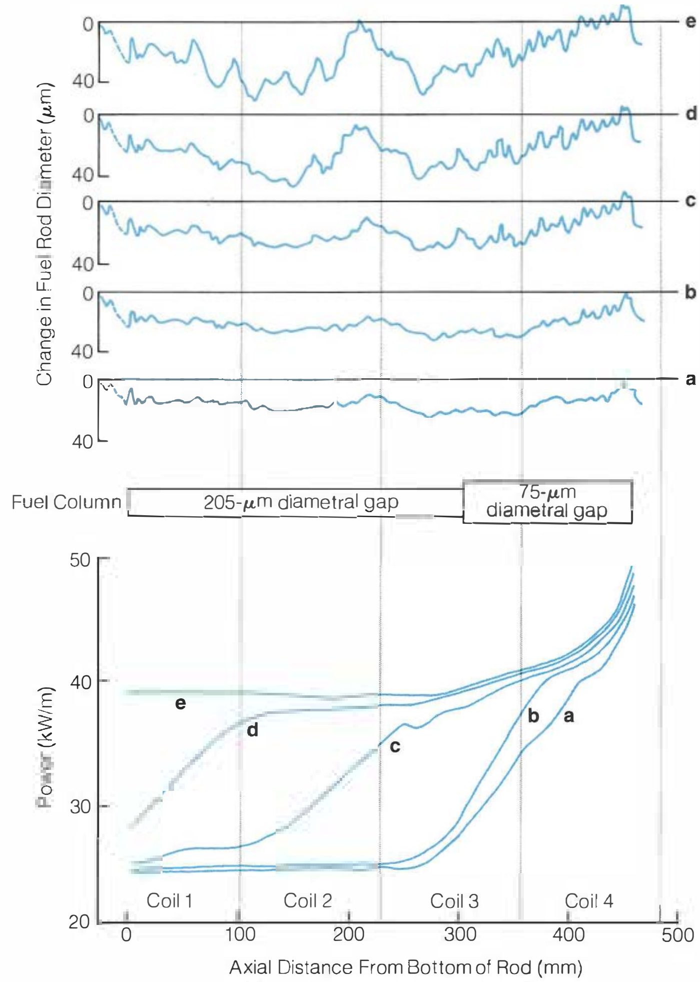
Each loading of the IFA-512 rig contains three 500-mm-long (20-in) fuel rods. These rods are surrounded by four coils that can be pressurized with the neutron flux poison ^3He to depress the local rod power. The coils can be manipulated independently as axial segments to enable localized axial power control. Self-powered neutron flux detectors provide axial and radial flux profiles. Elongation detectors at the bottom of each rod provide measurements of rod length. Axially movable diameter gages perform linear profilometry (measurement of each fuel rod's outer diameter along its length) when desired. All these data are collected during reactor operation to accurately determine cladding deformation as a function of local fuel rod power.

The first loading of the IFA-512 rig in late 1977 consisted of three carefully characterized BWR-type fuel rods that had been previously irradiated in the Halden reactor to ~7 GWd/tU burnup at ~25 kW/m average linear heat rating (ALHR). Two of the rods contained standard-size fuel pellets with a 205-μm fuel-to-cladding diametral gap—that is, a 205-μm difference between the inside diameter of the cladding and the diameter of the fuel pellet. The third rod contained standard pellets in the lower two-thirds of the fuel column, but the upper third contained oversized pellets with a 75-μm diametral gap. The small-gap region was intended to simulate a longer rod by creating an early hard contact between the fuel and the cladding as power increased, thus preventing the fuel from moving up the rod during ramping. The small gap also produced cladding ridges at the interfaces between fuel pellets at a lower burnup.

During the next ~4 GWd/tU burnup, the rods were ramped eight times from ~25 kW/m ALHR to ~40 kW/m ALHR. Two types of ramps were used: sequential removal of the ^3He from the coil segments and simultaneous removal of the ^3He from all four coils.

In the first ramp type, which has some of the characteristics of the withdrawal of a control blade from a BWR core, the ^3He poison was removed from the four axial coils sequentially from top to bottom. Such a sequence can cause the fuel column to become mechanically locked to the cladding as the power increases in the upper portion of the rods; thus axial fuel movement is restricted during subsequent power increases in the fuel column.

Figure 2 Increase in power (lower section) and consequent deformation of fuel rods (upper section) resulting from depressurization of ^3He gas coils. Curve **(a)** is the preramp profile, with all four coils pressurized. In **(b)**, the pressure is maintained in coils 1, 2, and 3 while coil 4 is depressurized. Depressurization of coils 3 and 2 is shown in **(c)** and **(d)**, respectively, and in **(e)**, the ^3He has been released from all four gas coils. Note the ridging effect evident in the right third of the tube-diameter measurements for **(c)**, **(d)**, and **(e)**.



Diameter traces performed between depressurization of each ^3He coil segment revealed ridges in the cladding. The increase in thermal flux during each coil depressurization caused an increase in local fuel rod power and in fuel temperature. The higher fuel pellet temperatures caused the pellet diameters to increase, and the increased radial temperature gradients in the pellets distorted them into an hourglass shape. As power continued to increase, the pellets pressed against the cladding, with the hourglass shape deforming the cladding most at the pellet interfaces, causing ridges to form. These localized strains at the pellet interfaces are thought to contribute to the formation of small cracks in the cladding wall by stress corrosion cracking.

Figure 2 shows the changing axial power profile (for the rod containing oversized fuel in its top third) and the resulting progressive change-in-diameter profiles following the sequential depressurization of the coils. As local axial power was increased, short-wavelength variations that had peak-to-peak spacings equivalent to the fuel pellet lengths appeared in the small-gap region (toward the right of Figure 2). These localized cladding strains represent the ridging mentioned above. In this first IFA-512 test, these ridges were primarily elastic and disappeared when the power was decreased. The strains also decreased with time at full power because of fuel creep. These measured strains provide a detailed data base for indexing and checking the mechanical deformation models of fuel performance codes.

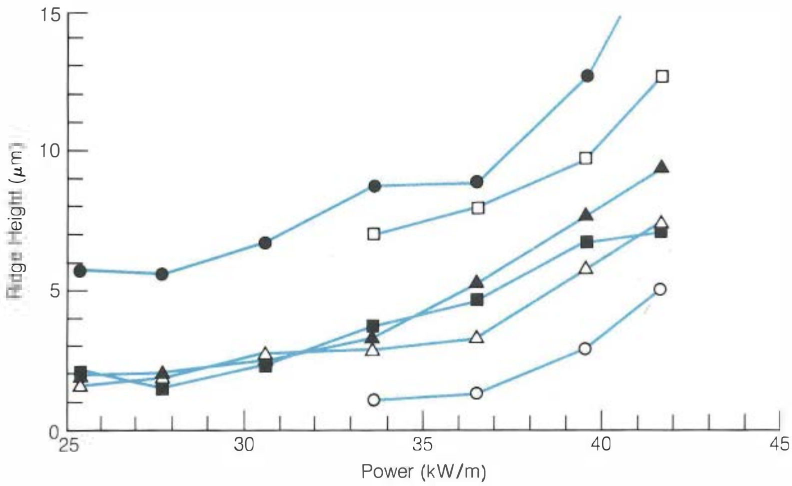
The longer-wavelength variations shown in Figure 2 were unexpected and are poorly understood. This phenomenon may be associated with the cladding fabrication. At higher burnups the mechanical PCI in the large-gap region was greater, and the long-wavelength variations decreased in amplitude.

In some later IFA-512 tests, all the ^3He coils were simultaneously depressurized, causing a simultaneous increase in fuel rod power over the full rod length. The diameters of several specific ridges were measured periodically during the depressurization. Figure 3 shows the resulting typical ridge height as a function of power and central fuel temperature. These data provide a direct measure of cladding elastic strain (stress) with little time for strain relaxation by fuel creep, and thus constitute a good index for verifying fuel strength models in fuel performance codes.

Following the power ramp, the power was maintained and the diameters were periodically monitored to determine the relaxation of the cladding ridge strains, which occurs primarily because of fuel creep. The resulting strain decay curves provide an index for verifying the fuel creep models used in fuel performance codes.

Future experiments will address the chemical as well as the mechanical aspects of the PCI problem. Rods containing fuel with a large grain size are being irradiated to determine if the release of gaseous fission products can be reduced by increasing the distance through which fission-product atoms must diffuse to reach a grain boundary (believed to be the path out of the fuel). In addition, rods with pellets that have a higher enrichment of ^{235}U in their outer volume than in their center are being tested

Figure 3 Height of six individual ridges as a function of power during a continuous power increase. The period of increase was less than 13 min.



to determine if the resulting decrease in central fuel temperature and in the amount of fission products produced in the high-temperature region of the fuel will effectively decrease the amount of fission products released. These rods contain internal pressure transducers for measuring fuel rod pressure throughout the irradiation. The critical power-ramping experiments for these rods will be performed in late 1979 and 1980. *Project Manager: David Franklin*

FLUID-STRUCTURE INTERACTION

Reactor structures in a fluid environment have traditionally been designed on the basis of a hydrodynamics analysis that assumes the surrounding structures to be rigid. In certain situations the fluid and structural responses are strongly coupled, and therefore a realistic description of structural loads requires a simultaneous solution of fluid and structural dynamics. EPRI is supporting research concerned with the development of computational methods for analyzing fluid-structure interaction. The principal effort in this program is the coupling of a nonlinear finite element structures code to finite difference fluid codes of both Eulerian and Lagrangian description. Simple fluid-structure interaction experiments are being performed to investigate coupled fluid-structure dynamics and to provide data for use in verifying the coupled codes. Specific applications are currently focused on BWR containment dynamics and the analysis of PWR structures for asymmetric hydrodynamic loads that may result during a postulated loss-of-coolant accident (LOCA).

Analyses of reactor structures in a fluid environment for design operation or postulated accident conditions have to date been performed by an uncoupled, two-step procedure. The fluid response is first determined by hydrodynamic models that omit the structural behavior, usually by treating the structural walls as rigid. The pressure predicted on the rigid walls by the hydrodynamic model is then applied to a model of the structure to determine its response. The rationale underlying this two-step approach is that it is usually conservative. It is generally believed that the pressures exerted on rigid walls are greater than those on a flexible wall; therefore a conservative structural design can be established by assuming rigid-wall loadings. While this type of uncoupled analysis is acceptable in most situations, it does carry the penalty of excessive conservatism and can lead to substantial over-design in many components. The quantification of excessive conservatism is especially important for older plants, where backfitting or structural modifications may be difficult. More important, if it is possible for a resonance to develop between the fluid-structure system and the energy release mechanism in the fluid, the uncoupled analysis procedure may in fact lead to the development of an unsound structural design.

General analytic methods are required that can treat the thermal-hydraulic behavior of a fluid and the deformation response of the structure in a completely coupled fashion. Such methods will allow the effects of structural deformation to influence the predicted behavior of the fluid and thus the pressures imparted to the structure. In cases where energy release mechanisms are enhanced by the response of the structure, a fully coupled analysis can provide insight into potential design flaws and aid in the development of improved designs.

There are presently several areas of reactor safety analysis where such coupled fluid-structure methods are desirable:

- Evaluation of BWR pressure suppression pool–structure dynamics during normal and postulated accident conditions
- PWR pressure vessel support loads and asymmetric internal loads resulting from a postulated rapid depressurization in the cooling system
- Flow-induced vibrations of reactor components
- Propagation of hydraulic transients in reactor piping systems
- Fast reactor containment dynamics for hypothetical core-disruptive accidents

Fluid-structure code development

Methodologies for compressible and incompressible hydrodynamics analysis have been extensively developed over the past 15 years by the defense community. The STEALTH code, recently developed under EPRI sponsorship, represents a hydrodynamics analysis program for compressible media that embodies the most effective developments of the defense community in a form that is readily accessible to engineers in the reactor industry (RP307). Similarly, computation methods for unsteady incompressible and compressible fluid dynamics have been developed at Los Alamos Scientific Laboratory (LASL) and are readily available for multidimensional fluid dynamics. In the past five years, substantial progress has also been made in developing computer programs for predicting the transient, nonlinear response of structures. Thus the tools for both thermal-hydraulic analysis and structural analysis are available, but they have not been effectively coupled. EPRI-supported efforts are aimed at developing mathematically and physically sound techniques for coupling existing structural and fluid dynamics codes.

The model structural code employed in these studies is the sophisticated nonlinear structural dynamics code WHAMS, developed at Northwestern University. The WHAMS code (which contains a variety of structural and continuum finite elements, options for both implicit and explicit time integration, and capabilities for geometric and material nonlinearities) is generally representative of the current state of the art for finite element structural dynamics.

Two codes are being applied for the fluid dynamics analysis. The first code is the STEALTH program, which is a general-purpose finite difference code for continuum dynamics that uses explicit time integration and a Lagrangian material description. A special version of STEALTH that deals with hydrodynamics only has been developed for coupling with WHAMS. The second code is the SOLA series of fluid dynamics programs developed at LASL. The SOLA codes are an expanding set of multidimensional finite difference codes for single- and multiphase fluid dynamics based on an Eulerian frame. These codes represent the state of the art for computational fluid dynamics.

Both sets of fluid dynamics codes are being pursued to provide options for the accurate and efficient solution of coupled fluid-structure problems over the wide range of thermal-physical conditions encountered in reactor safety analysis. The coupling logic between WHAMS and STEALTH and between WHAMS and SOLA is being developed at Northwestern University under RP1065-3 and RP965-2, respectively. At present, two-dimensional experimental versions of the coupled codes STEALTH–WHAMS and SOLA–WHAMS have been developed and are being tested against experimental fluid-structure interaction data and analytic solutions of simple coupled fluid-structure systems.

Fluid-structure interaction experiments

Experimental data on simple fluid-structure systems are required to verify the integrity of the coupling techniques. In addition to providing data for code verification, these experiments provide insight into the phenomena associated with strongly coupled fluid-structure systems. Under RP817, a series of two- and three-dimensional hydrodynamic impact experiments have been performed at Developmental Sciences, Inc. (NP-798). In these experiments, designed to provide data on the effects of fluid-structure interaction for hydrodynamically impacted structures, rigid and flexible circular cylindrical shells were driven down into a pool of water. Using the STEALTH code and the SOLA–SURF code, the rigid-cylinder impact experiments have been successfully analyzed (NP-824). The coupled SOLA–WHAMS code is presently being used to simulate the two-dimensional flexible-cylinder impact experiments.

A series of fluid-structure interaction experiments are being performed by Aeronautical Research Associates of Princeton, Inc. (RP965-6). In these experiments, fluid-filled flexible tanks of varying stiffness are subjected to mechanically induced oscillatory loading and to transient loads that result from rapid steam condensation. Using the coupled SOLA–WHAMS code, efforts are under way to analyze these experiments.

Additional fluid-structure interaction experiments are being planned to provide a wide range of data for code validation and to investigate specific aspects of fluid-structure dynamics applicable to postulated accident sequences for BWRs and PWRs.

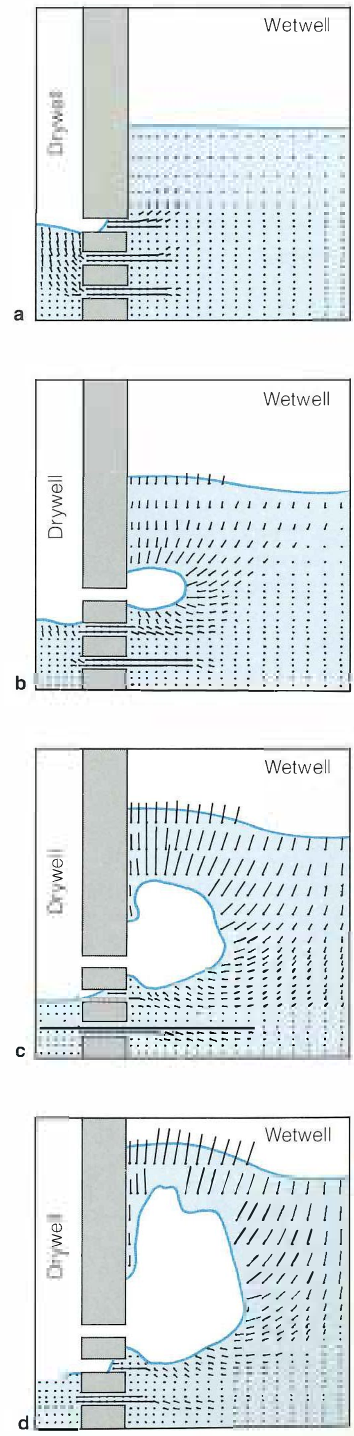
Code applications

The coupled STEALTH–WHAMS fluid-structure code is being developed with principal application to the analysis of asymmetric hydrodynamic loads associated with a postulated rapid depressurization in the cooling system of a PWR. Preliminary results obtained by LASL on the response of a simplified PWR core barrel during blowdown have shown that the effects of fluid-structure interaction are significant. The coupled results show a lower frequency and a lower amplitude of motion, with the consequence of generally lower induced stresses.

The SOLA series of codes and the coupled SOLA–WHAMS fluid-structure interaction code are being applied principally to an investigation of BWR pressure suppression pool–structure dynamics during a postulated loss-of-coolant accident. So far this investigation has focused primarily on hydrodynamic phenomena in pressure suppression pools and is being performed at LASL (RP965-3).

A new computation technique developed in this effort for complicated, multiple-free-surface hydrodynamics analysis has been embodied in the SOLA–VOF code. The code, which is particularly well suited to pressure suppression pool dynamics analysis, has been used to successfully simulate small-scale pool-swell experiments. Figure 4 shows an application of SOLA–VOF to horizontal venting in a suppression pool typical of a BWR MARK III containment design; this series of "snapshots" gives fluid configurations and velocity distributions at selected times during the pool-swell transient and demonstrates the versatility of SOLA–VOF for BWR containment dynamics. Current effort is concerned with the documentation of the two-dimensional SOLA–VOF code and its extension to three-dimensional fluid dynamics analysis. *Project Manager: John J. Carey*

Figure 4 Fluid configurations and velocity distributions at selected times after initiation of drywell pressurization: **(a)** 0.84 s, **(b)** 0.98 s, **(c)** 1.08 s, **(d)** 1.15 s.



R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

SUBSTATIONS

Gases superior to SF_6

Sulfur hexafluoride (SF_6) is the preferred gas for electrical insulation applications. It has superior dielectric strength and heat transfer properties, is relatively stable, and has low toxicity. These favorable factors have enabled SF_6 applications to develop and grow. However, despite these apparent advantages, this gas has a number of liabilities: It has a relatively high boiling point and is sensitive to imperfections, such as electrode surface irregularities and free particles. Furthermore, it is relatively expensive compared with certain Freons or nitrogen. In practical applications SF_6 gas suffers dielectric breakdown at a lower level than its theoretical breakdown strength.

Accordingly, there is an interest in seeking gases that are potentially superior to SF_6 in one or more of the above areas. A project was initiated in early 1977 with a team from Westinghouse Electric Corp. (primary contractor) and E. I. du Pont de Nemours & Co., Inc. (subcontractor) to identify or develop gases or gas mixtures superior to SF_6 (RP847). An earlier report reviewed the screening process employed by du Pont and the fact that this procedure focused on approximately 30 gases of potential interest (*EPRI Journal*, September 1978, p. 49). Gases known to be dangerously toxic, such as the perfluoralkylnitrile family, were intentionally eliminated from this study.

Work by the Westinghouse–du Pont team focused on numerous aspects of the overall problem: dielectric breakdown strength in both quasi-uniform and nonuniform fields, arc interruption behavior, carbonization aspects, compatibility with polymeric materials, stability, and cost. The screening and testing process ultimately located eight gases that were superior in terms of ac breakdown strength in a quasi-uniform field. One of these gases exhibited a breakdown strength more than twice that of SF_6: hexafluoro-2-butyne (C_4F_6). This gas has recently been reported as being relatively toxic, and therefore was not studied in great depth. One of the gases listed, trifluoronitromethane (CF_3NO_2), was considered to be of high interest, as its molecular structure implies an electronegative character like that of the perfluoralkylnitriles; this gas was synthesized for testing.

The results of this work have helped to focus on the question of how to define superiority and on the problems involved in developing alternatives for SF_6. It is clear from this project that although no single gas will be superior to SF_6 in every property, gas mixtures can be tailored for specific applications. *Project Manager: Bruce Bernstein*

Ice-release coating for air-break switches

Ice buildup on outdoor disconnect switches has been a severe deterrent to satisfactory remote or automatic switch operation. Clear ice buildup in particular, which can develop under certain subfreezing temperature conditions, can lead to incomplete switch operation. A project with Siemens-Allis Corp. (RP931) is exploring the use of thin-film coatings to promote release of the ice during closing and opening operations and possibly reduce the buildup of ice at the outset.

Under Phase 1 of this project, eight coating materials were selected for a comprehensive test and evaluation program. Of these eight materials, one was selected for trial on high-voltage copper and aluminum switches for a full ice-release test in a laboratory.

This recently concluded test showed a substantial reduction in the force required to open the switches under ice conditions—less than half the force required on uncoated switches with ice accumulated under similar conditions. It is premature to assess the material's effectiveness during the closing operation, but future field experience will provide more meaningful information.

The original goal of this project was to find a coating material that would reduce the ice buildup. This has not materialized, primarily because once a very thin layer has formed around the coated metal surface, this layer isolates subsequent ice buildup from the surface coating. It has been concluded that the most effective ice-release design involves application of the coating to the reverse-loop stationary contacts of a disconnect switch. This is especially encouraging because replacement of currently used switch contacts with the new coated contacts can be accomplished with minimal outage time. While this research addressed the performance of only one design (Siemens-Allis), this coating should work equally well on other designs.

During the severe winter of 1978/79, EPRI received many requests from utilities in the nation's ice belt expressing interest in this project and offering substations on their systems for possible field trials of coated disconnect switches. Now that the research work is completed and the performance is determined, it is suggested that utilities concerned with iced disconnect switches either contact Siemens-Allis or encourage other switch manufacturers to take advantage of this development. *Project Manager: Vasu Tahiliani*

Bushings for gas-insulated equipment

Gas-insulated compact substations, as well as SF_6-insulated circuit breakers, have generally used bushing designs that employ a porcelain shell filled with high-pressure SF_6 gas. This design, with its simple construction, has been well accepted in the industry for voltages rated through 362 kV. The only apparent limitation of such a design is that in the event of failure, the porcelain pressure vessel, being inherently brittle, is susceptible to catastrophic failure, thereby posing a danger to people within approximately 100 yards. Utility field experience thus far has been uneventful, but there have been isolated bushing failures under laboratory test conditions, especially when the bushings have been subjected to extreme test conditions (often beyond their ratings). It would be desirable to improve the state-of-the-art design in anticipation of such a rare occurrence and thereby reduce the severity of any failures that might occur.

Further, these bushings are limited in their effectiveness for voltage grading (top to bottom). This appears to pose no severe penalty for voltages up to, say, 362 kV. However, the size of the bushing and consequently the cost penalties are substantial when this design approach is extended to 550 kV and beyond.

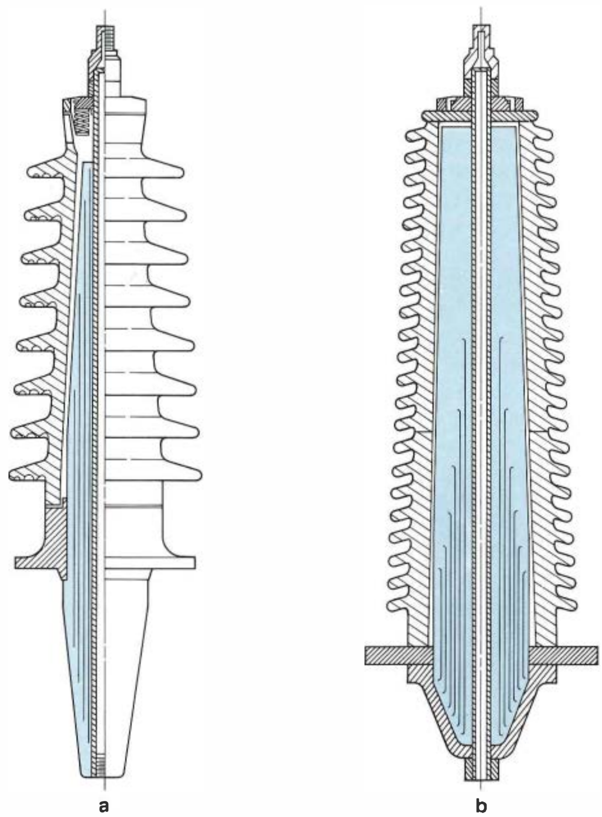
With increased application of gas-insulated equipment expected for the future, EPRI is pursuing development of new insulating concepts for bushing designs that do not require high-pressure gas volumes within porcelain housings. These designs should easily incorporate capacitive grading structures that will result in a cost-effective, safe bushing for gas-insulated equipment.

Two independent projects have been initiated to develop such bushings. One project (Lapp Insulator Div., Interpace Corp.) is an attempt to extend manufacturing technology (which can presently produce bushings for up to 242 kV) to a 550-kV design (RP1423-1). This design (Figure 1a) employs a condenser core of epoxy resin–impregnated paper, which is assembled in a porcelain weathershed. For equipment applications that use insulating oil as a primary insulation system, the bushing designs also employ an oil cushion between the core and the porcelain weathershed, as in oil-paper condenser bushings used on transformers. For obvious reasons, it is necessary to replace the oil with a suitable, alternative insulating material for gas-insulated equipment applications.

In the second project, with Gould–Brown Boveri Corp., a new design concept employing SF_6 foam material is being investigated (RP1423-2). This material was originally developed by Gould under a previous EPRI contract (RP749). The work thus far has centered on producing insulation material with a superior high-voltage capability and a low dielectric constant that can be used to construct capacitively graded insulation cores; this will then serve as the primary bushing insulation.

Cycloaliphatic epoxy resin, blown with SF_6 gas under pressure in the cells, demonstrates an improved dielectric strength far superior to that of the base resin. Its dielectric strength is enhanced by the gas held in the closed cell structure of this foam material. The high-pressure SF_6 gas contained in these cells offers other advantages for the insulation system. Because the dielectric strength depends on the pressure of the gas trapped in the cells, an increase in the gas pressure results in improved electrical strength without increasing the low dielectric constant. This foam insulation system, being such a flexible matrix, easily accepts metallic embedments. This allows the formation of a large SF_6 foam casting (Figure 1b) and therefore makes this insulation system suitable for the manufacture of explosion-resistant bushings. A considerable cost reduction is anticipated because a smaller, low-pressure porcelain weathershed will be employed in this type of a bushing design. It is hoped that at the conclusion of this project, research on foam-filled bushings will be extended to the demonstration phase in a 362-kV prototype test program. *Project Manager: Vasu Tahiliani*

Figure 1 Two types of capacitively graded bushing designs for gas-insulated equipment: **(a)** a condenser of epoxy resin–impregnated paper is set in a porcelain weathershed, resulting in an oilless design; **(b)** a newly developed SF_6 foam material made from cycloaliphatic epoxy resin blown with pressurized SF_6 is used to give the bushing high electrical strength, a low dielectric constant, and ready acceptance of metallic embedments.



DC STATIONS AND EQUIPMENT

HVDC system control

The ability to control power flows on HVDC transmission lines has been used to lend a degree of support to ac systems by improving their dynamic characteristics. In fact, some skilled control system designers have applied HVDC system power modulation controls quite successfully to increase the power transfer capacity of important, parallel ac tie lines. However, experience from the early operation of two recently completed dc projects has shown that if not properly designed, the HVDC converter control systems can excite nearby generators in the subsynchronous resonance frequency region. This must be avoided, which places yet another constraint on the designers of converter control systems. EPRI has therefore initiated two projects with General Electric Co. in an attempt to answer some questions of importance to utilities.

The first contract concerns HVDC system control of subsynchronous oscillations (RP1425). The purpose of this project is to find out how HVDC converters can be prevented from exciting subsynchronous resonances in turbine-generators. If converter control systems can be designed to avoid this, it might also be possible to design them to provide positive damping in the subsynchronous resonance region.

Phase 1 of this project involves a theoretical analysis of the generator–converter system interactions. The analytic work will be validated by using simulators, which provide either analog scale model simulations or digital computer simulations of the important ac and dc system elements. The frequency range of interest for this study is from 5 to 40 Hz. The study will consider all the important control modes of the HVDC system. It would be desirable, of course, to design a converter control system with characteristics that will damp the generator resonances in the frequency range of interest. Therefore, in the second phase of the project, conceptual subsynchronous damping control system designs will be evaluated for their effectiveness in damping subsynchronous oscillations while being assessed as a potential source of negative or undesirable side effects. At the end of the project, guidelines will be published that can be used by utilities to determine the benefits of a subsynchronous damping controller on HVDC converters, including a design specification for such a controller.

The second contract is concerned with unified active and reactive power modulation control of HVDC systems (RP1426). The ability to control the power flow of a dc link has long been recognized as an important benefit in enhancing the transmission capability of a combined ac and dc transmission system. However, how to best take advantage of this ability is not fully understood. For instance, it is known that a change in the active (dc) power flow to the converters also affects the ac reactive power flows, causing voltage changes at the converters that reduce the effectiveness of the active power change. However, it is not clear how to control active and reactive power modulation simultaneously. The purpose of this project is to investigate control techniques that will alleviate this problem.

The contractor will study typical ac systems where dc power modulation controls might be used. Theoretical analysis will be supplemented with simulator studies. Both digital and analog simulators will be used for these studies, with the analog simulator studies used primarily for validation of digital models. Various dc modulation controller concepts will be studied, and the improvements or potential side effects of the dc modulation controller will be evaluated as a part of the simulation studies. Finally, the contractor will develop a method for evaluating the costs and benefits of HVDC power modulation techniques. *Project Manager: Stig Nilsson*

POWER SYSTEM PLANNING AND OPERATIONS

Engineer's handbook—touch-and-step potentials

A recently completed EPRI project produced data on touch-and-step potentials for jacketed underground residential distribution (URD) cables subjected to short-circuit conditions at normal operating voltages (RP671). However, these data are applicable only to the set of environmental conditions that prevailed at the Franksville, Wisconsin, test site. To broaden the usefulness of these data, EPRI initiated a project to develop a general computer program that calculates touch-and-step potentials at any location (RP797-1). The Franksville test data were used as a basis for verifying the program. An additional objective was to compute earth surface potentials resulting from operation with an open neutral.

The resultant computer program, named BCAB, permits the simulation of URD cable faults for a wide variety of cables, soils, and excitation parameters. The program has been validated against actual field measurements and, with the proper selection of input data, can be used for simulations of general distribution systems. Although the BCAB program is a very valuable analytic tool, it requires approximately 30 input parameters for each case studied.

The objective of a follow-on project, RP797-2, is to extend the usefulness of the BCAB program by using the computer to develop appropriate curves and graphs from which distribution engineers can easily find touch-and-step potentials for all types of faulted URD cables. The results of this study will be presented as an engineer's handbook, complete with general user's notes and examples. The curves and graphs will cover a wide variety of practical conditions but will require only a minimum of input data. *Project Manager: Tom Kendrew*

Detection of high-impedance faults

In the year and a half since RP1285 was started, substantial progress has been made in developing a means for detecting high-impedance faults on distribution circuits. Considerable insight into the electrical properties of these faults has been gained, and two potential detectors have been brought to an advanced state of development.

The designation *high-impedance fault* implies that the fault current flow is too small to be recognized by conventional overcurrent relays. If a 60-Hz current magnitude cannot be used to identify this kind of fault, what indication can be used? An answer to this question is being sought by Power Technologies, Inc. (PTI), one of three contractors addressing the problem. The key to PTI's approach is its simulation of the high-impedance fault; only by this means can changes in all the electrical parameters be investigated in a systematic way. Using data taken from recordings of voltage and current before and during staged faults, analytic models of faults have been developed. The wide frequency range of the recordings permits examination of low-order harmonic behavior, as well as radio frequency behavior up to about 10 kHz. This wide range is important, as it fits in well with the work being performed by the other two contractors, who are each developing detection instruments.

The third-harmonic component of current has always been considered potentially useful for high-impedance fault detection. Hughes Research Laboratories has used this third-harmonic approach to design and build a potentially successful prototype detector. This detector has demonstrated its ability to identify high-impedance faults and to discriminate between faults and other disturbances, such as those caused by capacitor or load switching. Because many normal system disturbances mimic the high-impedance fault to some degree, this discriminatory capability is important in preventing false tripping.

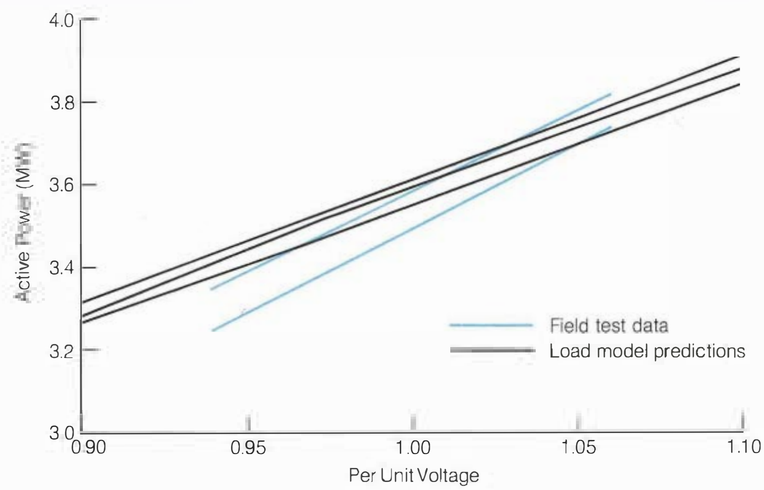
The principal limitation of this instrument is its inability to accurately detect faults of very low current in which no arcing occurs or in which no current at all flows, as when a wire dangles but does not touch the ground.

The detector designed and built under this contract by researchers at Texas A. & M. University also shows considerable promise. This work identified the high-frequency signature produced by arcing during a high-impedance fault. Although development of the identification technique was started prior to this study, it was continued through the prototype stage under this project. The prototype has demonstrated the security and selectivity required of protective relaying devices; for example, fault currents of less than 10 A can be detected if arcing occurs, and normal system events are ignored.

Because proper operation depends on the conducted reception of signals in the 2–10-kHz range, the major limitation of the instrument may be set by the propagation characteristics of distribution circuits.

Although the Hughes and the Texas A. & M. instruments both have limitations, it is probable that either is a more capable high-impedance fault detector than any now available. Development of these detectors is continuing, and testing is proceeding with a wide range of staged faults and normal system operations. The results of these tests, with analytic input from the PTI work, are expected to be the basis for substantial improvement in both instruments. *Project Manager: Herb Songster*

Figure 2 A typical comparison of the load model predictions and field test data for real power as a function of small step changes in voltage shows close agreement.



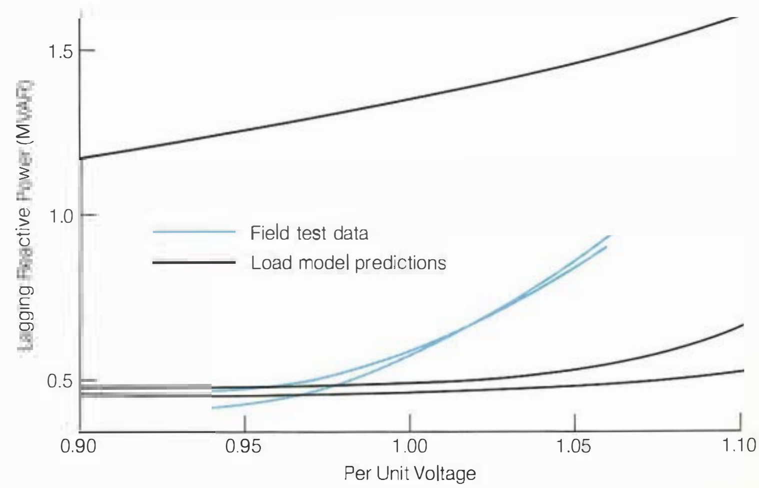


Figure 3 A typical comparison of load model predictions and field data for reactive power as a function of voltage illustrates the lack of agreement between the model and field data and, in particular, shows that the load is more nonlinear than predicted by the model.

Load model evaluation

Engineering a robust power system—one that can withstand a major disturbance—requires an understanding of how power system loads can influence power system performance. Power system planners use digital computer programs that simulate the behavior of the power system to help establish transmission line loading limits and evaluate alternative system expansion configurations. The computer programs that simulate power system response must contain accurate mathematical models for the response of customer loads. The response of customer loads to the variations of voltage and/or frequency that accompany disturbances is an important factor in designing a robust power system. The model of load response to slow changes of voltage and/or frequency must be incorporated in both the power flow and the stability analysis computer programs. But the model for load response to rapid changes of voltage need only be incorporated in the stability analysis computer program.

Data from field tests conducted in 1978 have been analyzed by researchers at General Electric Co. (RP849-1) to evaluate the load-model-building procedure produced by researchers at the University of Texas at Arlington (RP849-3). The preliminary findings of this early analysis are the subject of this report. Data from later tests are now being analyzed.

The load-model-building procedure being evaluated uses measured responses of common load components (e.g., electric ranges, air conditioners) as a data base. When the user of this prototype model-building procedure specifies the expected load composition (percent of load represented by each load component) supplied from a substation, the model-building procedure produces a composite model for the high side of the substation transformer. Documentation of this procedure and samples of component responses to voltage (0.7–1.2 per unit) and frequency (57–63 Hz) variations are included in the final report for RP849-3, EL-849 (5 vols).

The field data collected under RP849-1 came from three sites in New York and represent 1978 summer (near-peak) residential and commercial load compositions. Additional tests have been run and are now being analyzed to update the preliminary findings. For the purpose of discussion and analysis, the responses of loads are described as either steady state or dynamic. Slow rates of change in voltage and/or frequency cause what the researchers call a steady-state response from the load. Slow voltage changes were produced in the field by moving the voltage tap on the respective substation transformer. To perform the change-in-frequency tests, a distribution substation was isolated from the interconnected system and powered from a local gas turbine generator. Frequency was manually ramped over a range of 6 Hz in 50 seconds.

Graphs of typical steady-state response data led to a variety of conclusions.

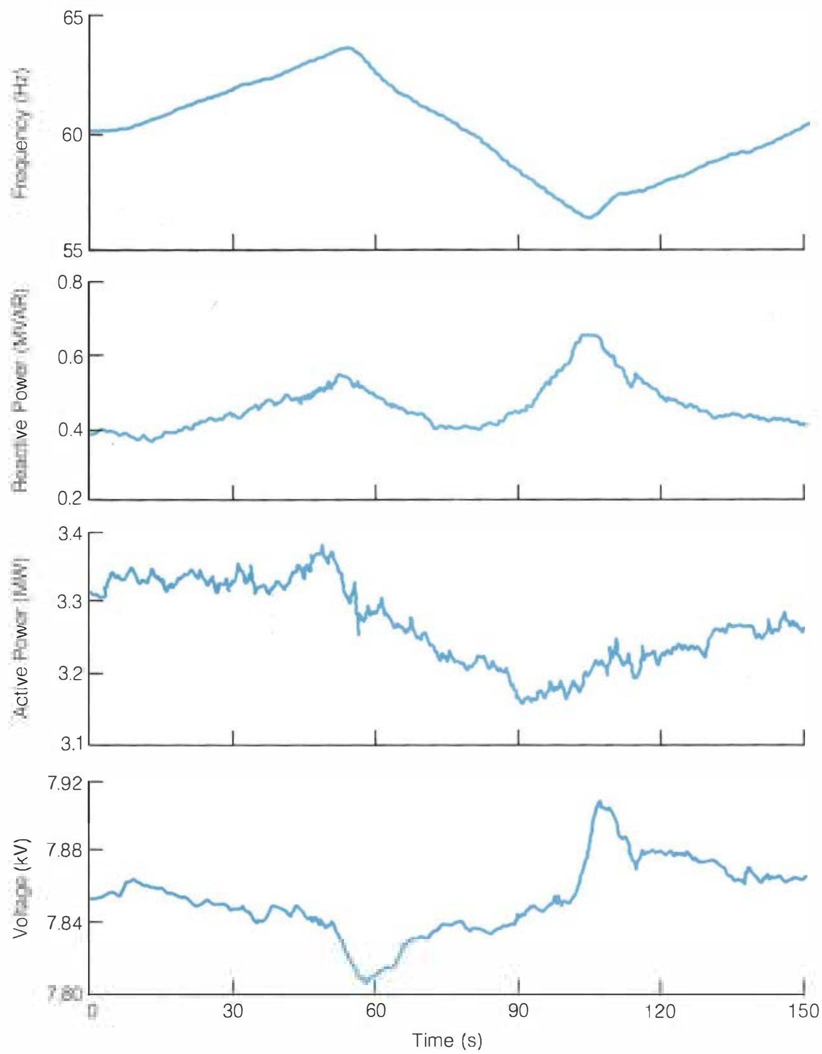
The model for the steady-state response of the composite load at the New York sites predicted that:

- Active power should vary linearly with voltage.
- Reactive power should be nonlinear for voltage changes.
- Active and reactive power should both vary linearly with frequency.

Figure 2 compares the model predictions with the test data for the steady-state response of the substation load as a function of small step voltage changes. All small step change tests produced similar results, leading researchers to the conclusion that the field data match the model prediction for active power as a function of voltage, but not for reactive power (Figure 3). The researchers at General Electric are investigating several possible reasons for the greater sensitivity of load reactive power to step voltage increases than predicted by the model.

Figure 4 is a plot of the field data from a test where frequency was ramped and voltage was not intentionally varied. As one can see, the voltage did in fact vary slightly during this test. By comparing the active power plot with the frequency plot, one can see that as frequency is lowered and raised, the active power tends to change linearly and in the same direction as the frequency is changing. This comparison tends to confirm the predictions of the load model. However, the behavior of reactive power as a function of frequency is quite different from the model's prediction: the reactive power does not follow the changes in frequency and is not linear.

Figure 4 Response of the load as the frequency is varied between 57 and 63 Hz demonstrates that the active power component matches the model predictions while the reactive power component does not.



The dynamic response of loads generally results when rapid changes in supply voltage occur and the load consists of induction motors and those network components (such as transformers and capacitors) that retard the rapid rate of change for voltage or current. A voltage change from 1.2 to 0.8 per unit was achieved in the field tests in an attempt to excite the dynamics of the load. This range of rapid voltage change, however, is not as broad as is needed for validating load models that are to be used in stability analysis computer programs. Data from real (or staged) faults on power systems are required if bus voltages in the range of 0.4–0.8 per unit are to be included in the evaluation of the load-model-building procedure. The present collection of field test data includes only one staged fault test; therefore, additional data sets from faults are needed for a proper evaluation of the model-building procedure.

At this time, tentative conclusions for the dynamic response of loads cannot be made. Sufficient field data that contain load dynamics excited by a rapid change in voltage have not yet been analyzed. Additional sources of field data, including staged fault tests containing dynamic response, are being sought. *Project Manager: Donald Koenig*

Distribution class, vacuum-arc fault current limiter

Distribution equipment is being subjected to fault currents that have increased in magnitude as the demand for electric power has grown. As fault currents approach the limits of the interrupting capability of normal cir-

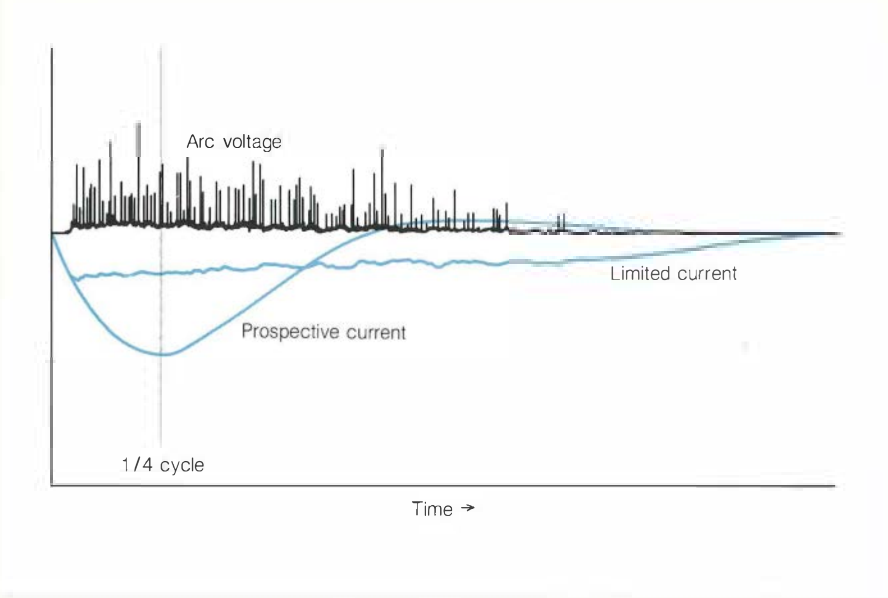


Figure 5 Arc voltage, prospective current, and limited current. The current is limited to 40% of the available current by the vacuum-arc current limiter.

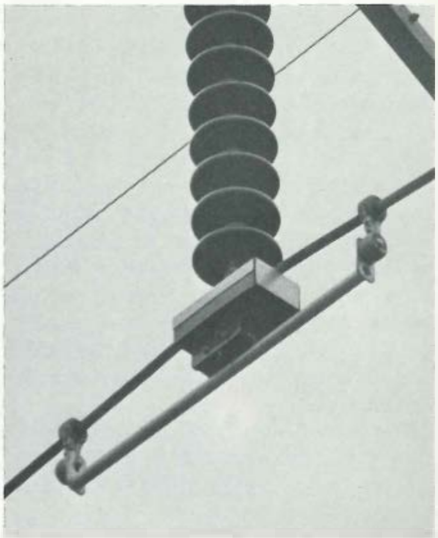


Figure 6 The bar-shaped experimental amplitude detector, EGADD, is designed to sense and count conductor motions that are difficult to detect by observation. If results obtained from this device prove reliable, it could be applied extensively throughout the country to develop statistical data on galloping that would be comparable to that now available on lightning.

cuit-interrupting devices, techniques presently used to adjust to this condition include the use of high-impedance transformers and/or operation with a split bus to reduce the available fault currents. One increases losses; the other limits system flexibility. An alternative measure, a distribution class, vacuum-arc fault current limiter, is being developed by McGraw-Edison Co. for use on 15-kV systems (RP1140-1).

In this project the current-limiting capabilities of vacuum arcs will be pursued for improvement, which may lead to two design concepts. The better concept will then be selected for prototype model construction and test.

At present, work is being carried on to upgrade a commutating-switch concept in parallel with a bypass switch. The bypass switch normally carries load current and the commutating switch (an open gap in vacuum) is activated when a fault is sensed, opening the bypass switch. This action generates an arc voltage, allowing the vacuum arc to be ignited in the commutating switch. The vacuum arc alone, or in combination with a resistive element, dissipates the energy flowing in the faulted circuit.

Improvement of the device's capability to limit higher fault currents and successful introduction of an anode of high energy-dissipating capability may lead to development of a second concept—the fault-current-limiting circuit breaker.

To date, current limitation has been achieved within 0.3 μs (0.02 cycle) of fault initiation, continuing to the first natural current zero. The limited current peak is approximately 40% of the available current peak. Voltage spikes are of sufficient magnitude to commutate the fault current to a parallel resistive element to dissipate the energy, but well below system impulse withstand levels. The oscillogram of the test for this demonstration is shown in Figure 5. *Project Manager: Robert Tackaberry*

OVERHEAD TRANSMISSION

Galloping control

Ice that collects on transmission lines can form airfoils that oscillate in the wind. This oscillation can lead to a violent up-and-down motion known as galloping, which may cause line or tower damage. Data-gathering for an EPRI project to control this phenomenon by detuning the natural oscillation frequency of a line has been completed for a second icing season (RP1095). Despite the fact that there were about 50% more EPRI-outfitted test sites operational than in the first season and despite the fact that there were more icing storms than normal, fewer hard results were obtained. While disappointing, this situation is understandable.

Galloping is a random event. Utilities participating in the project went to great lengths to select line sections with a known propensity for galloping for use as test sites. Nevertheless, many reports this year stated that extensive galloping did occur on the system, but not at the test sites. In a few cases, galloping actually occurred on the very line where the control devices were located but were as few as 10 spans away.

Not only are results to date few in number, they are often difficult to interpret and correlate. Results are reported by specially trained observers sent to the sites during storm conditions that usually precipitate galloping. At the site the observers follow a recommended regimen for making subjective judgments. They first identify the mode of cable motion. Then they attempt to quantify the amplitude and frequency of the motion, wind direction and velocity, ice buildup on the conductors, and movement of insulators and structural components. The observers do this for each phase having control devices and compare the action with that of the control phases that have no detuning treatment.

Such observations are not easy to make. The weather is, at best, unpleasant. The motion taking place on any conductor in any span is likely to change often.

Valuable data are often lost because the event occurs at night and cannot be seen or is of such short duration that the observers cannot get to the scene soon enough. To correct this situation, an experimental amplitude detector called EGADD (EPRI galloping amplitude detection device) has been developed as an adjunct to RP1095 (Figure 6).

Three of the devices have been produced and are undergoing field trials at test sites involved in the detuning experiments. EGADD is designed to sense and count conductor motions that are too high in frequency to be caused by wind blowout and too low to result from aeolian vibration. Thus, it provides a positive indication of galloping occurrence but does not provide the definitive information of the type gathered from personal observation. If EGADD proves out, it could be applied extensively to systems all over the country to detect the occurrence of galloping. Such widespread data-gathering capability could lead to development of a statistical data base similar to that for lightning occurrence. EGADD could also be applied in pairs, one on a treated phase and one on an untreated phase, to give a go/no-go operation indication for any control scheme applied on the treated phase.

The observations to date show that the detuning devices under test in RP1095 afford positive control some of the time, partial control (reduced amplitude) some of the time, and little or no control some of the time. The problem is that the differences in the degree of control cannot be explained, nor can the probabilities of control be predicted from the amount of information currently available. It is not clear how much additional field testing will be required before the performance of detuning pendulums can be adequately determined. Several statistical analytic methods are now being applied to the available data.

It is hoped that one of the methods will indicate how much additional data will be required. Once this is known, estimates can be made (keeping in mind the randomness of the event) on how long it will take to accumulate the necessary experience from the present test sites. The project is currently funded to carry through the 1979/80 season.

It is now apparent that the detuning pendulum is not a universal control for galloping of transmission lines, but much has been learned through its field testing that will aid in the development of other control systems. Such new systems will be required to fill the gaps and offer a total solution to this continuing problem. *Project Manager: Phillip Landers*

Polysil material systems for electrical applications

Polysil* is a low-cost, high-strength material developed by EPRI with many potential applications for the electric power industry. Lindsey Industries Inc. recently completed a 15-month research project to improve the electrical and mechanical properties of Polysil and to reduce its manufacturing costs (RP1203). Polysil is a relatively new insulating material with a silica filler (which can make up more than 85% of the material) bound by a resin, such as methyl methacrylate or polyester-styrene. It has the potential of replacing porcelain for insulators. The purpose of this project was to develop new formulations and fiber reinforcing to increase tensile, shear, and compressive strengths, while maintaining and possibly even improving electrical characteristics. These objectives were met.

With methyl methacrylate, compressive strengths of 181.2 MPa (26,290 psi) and splitting tensile strengths of 28.5 MPa (4,128 psi) were achieved. With polyester-styrene, compressive strengths of 168.7 MPa (24,470 psi) and splitting tensile strengths of 24.4 MPa (3,537 psi) were obtained.

Porcelain has a compressive strength of only 69–110 MPa (10,000–16,000 psi) and is much more brittle than either resin system; in addition, metal end caps may easily be inserted into Polysil, whereas metal must be cemented to porcelain in a difficult and expensive process.

This project has demonstrated that Polysil can be formulated with either methyl methacrylate or polyester-styrene to obtain superior mechanical and electrical properties. It now remains to be shown by field tests that insulators made of this material are superior in practical use. *Project Manager: Mario Rabinowitz*

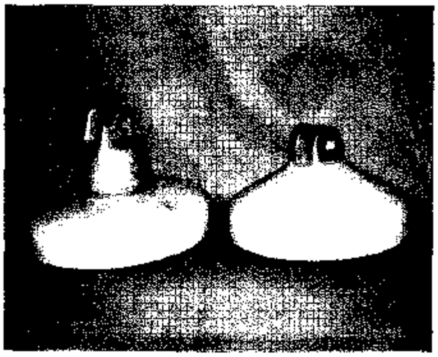
*Polysil is an EPRI trademark.

Dc line insulators

Recent research projects have offered a better understanding of how to design insulators for HVDC lines to combat the serious problem of contamination. This, combined with the development of new insulating materials, has provided the tools to make significant improvements in dc insulator design. Therefore, EPRI is sponsoring the development of new types of insulators for use on HVDC lines (RP1206).

There are two important reasons for developing an insulator especially for HVDC. First, insulators behave differently on HVDC lines than on HVAC lines. Since dc produces a steady electric field, nearby particles are attracted and held to the insulator surface. For side-by-side ac and dc lines, insulators on the dc line will suffer much more contamination. Another difference is the absence of a voltage zero for dc. Scintillations across high-resistance areas do not readily extinguish, and may grow to flashover.

Figure 7 Prototype Polysil insulator (right) alongside a conventional porcelain suspension insulator.

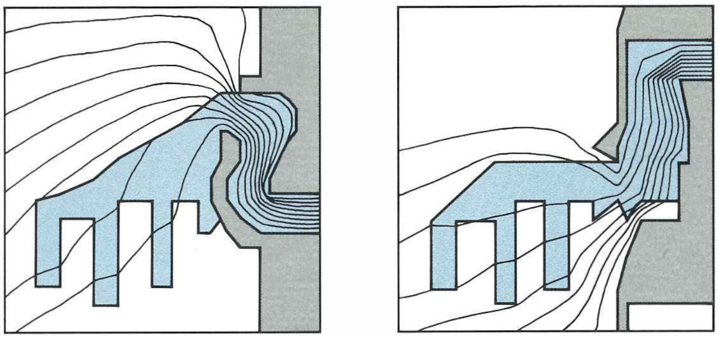


The second reason to pursue this work is to make use of new insulating materials. In a project with Lindsey Industries, insulators made of Polysil are being investigated for use on HVDC lines. The process for making a Polysil insulator is less complicated than that for making conventional insulating materials. In fact, the Polysil insulator is constructed in much the same way as a concrete block. Silica sand, liquid monomers, a catalyst, and a promoter are mixed together and poured into a mold. The catalyst and promoter cause the monomers to be converted by cross-linking to copolymers, thus enhancing their properties. The insulator's metal fittings are cast into the insulating material, rather than cemented on later after the insulating material is formed and fired. Polysil has approximately 50% greater dielectric strength than porcelain and equivalent mechanical properties.

At Lindsey Industries, HVDC insulators are being developed that look very much like conventional suspension insulators. However, it is likely that they will be lighter, shorter, less expensive, and electrically superior to what is now used on HVDC lines. Figure 7 shows a prototype Polysil insulator and a conventional suspension insulator.

In this project the problem of insulator contamination was approached by designing the insulator so that most of the contamination is forced to accumulate on the upper surface of the insulator where wind and rain perform the best cleaning action. Figure 8 shows computer-generated field plots of the Polysil insulator and a conventional porcelain insulator. Since contamination will accumulate more rapidly in the areas of highest field strength, the Polysil insulator has been designed to force this to occur on the top surface, as shown by the close spacing of equipotential lines. Conventional cap-and-pin suspension insulators have a similar

Figure 8 Computer-generated exponential field plots of a Polysil insulator (left) and a porcelain insulator (right). In the Polysil plot, the lines of force converge as the field is forced into the area of highest field strength, near the top of the insulator. In the porcelain plot, the field tends to be attracted to the area of weakest field strength, near the bottom of the insulator.



high-field area on the bottom skirts, near the pin.

The ability to cast the metal fitting in the Polysil material eliminates the need for a metal cap and the cementing process required for fired insulating materials. The elimination of the cap allows the insulator string to be shortened without reducing the leakage distance.

As this project continues, Lindsey Industries will produce several designs, using various shapes for the sheds and embedded metal fittings. Insulators will be tested by using internally cast resistive grading. Although Polysil can be cast with a smooth, track-resistant surface, various coating materials will be tested to improve the ability of the surface to repel moisture.

In the final stage of this project several hundred insulators will be manufactured for laboratory and field testing. *Project Manager: John Dunlap*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

SITING OF COAL-BURNING POWER PLANTS

Recent trends in air quality regulation discourage the construction of large coal-burning power plants. Utilities have generally found that large plants have economic advantages, but no one has carefully compared the environmental consequences of large and small power plants. Consequently, EPRI has initiated a project to examine the economic, social, and environmental costs of the large and small power plant options.

The siting of coal-fired electric power plants has become increasingly difficult because of environmental and societal concerns, which have led to technical constraints and procedural delays. These concerns have been motivated by public perception of environmental degradation from coal-fired power plants. Some of these considerations, particularly those about the effects of air pollution on human health, have been addressed by constructing larger power plants farther from load centers. Although this strategy has not eliminated the problem, it has shifted the focus from the effects on humans to those on the natural environment. Concerns will probably increase in the near future as greater use is made of coal and fewer environmentally ideal sites for plants are available.

Because new coal-burning power plants will most likely be located on rural sites far from load centers, economic advantages can generally be gained by clustering units at a single location rather than dispersing them at several different locations. It is unclear, however, whether the economic benefits of concentrated siting are accompanied by social and environmental benefits. It is particularly important to ascertain these latter benefits because recent air quality regulations may make the concentrated-siting option difficult or impossible.

A study by General Electric Co.—Tempo and Mathtech, Inc., evaluates the economic, environmental, and social impacts of a capacity addition of 2200 MW (e) in coal-burning units (RP1114). The addition is made by constructing four 550-MW (e) units that come on-line at yearly intervals. Two cases are considered: Under the first (concentrated) option, four units are sited at a single location; under the second (dispersed) option, four units are sited at four different locations. The distance between the units under the dispersed option was determined according to the following air quality criterion: The minimum distance between two units is such that the ground level air quality concentration where the two plumes intersect is only 10% greater than the ground level air quality concentration from a single-unit plume when the concentrations are averaged over 24-hour periods. The rationale for this criterion was that air pollution considerations would most likely provide a limiting factor for siting.

The air quality criterion was obtained by applying an EPA computer program to model the diffusion of stack emissions and calculated ground level concentrations. Using historical meteorological data for a site in the Southwest, the minimum spacing turned out to be 10 km. Different meteorological conditions can lead to other spacing distances, and additional analyses are now under way to determine the minimum spacing for different meteorological conditions.

The optimal spacing configuration for the dispersed option in the Southwest example places the four units at the corners of a square 10 km on a side; for the concentrated option the units are assumed to be clustered at the square's center. This arrangement of the dispersed units requires the least total length of interconnections and also requires a lower number of vehicle-miles than other configurations. Specific geographic features could make another configuration less costly in a given area; however, the chosen design appears to minimize costs for a generic area.

The capital, operating, and maintenance costs for the standard plants were estimated for the two options at the geographic site studied. The plants were designed to satisfy federal and state air quality standards. Flue gas desulfurization scrubbers were assumed to be present, and the cooling system was assumed to consist of mechanical draft wet towers. The plant costs estimated by Tempo were assumed to have an accuracy of ±20%, although possible errors in the differential costs between the dispersed and concentrated siting options were believed to be much less than this.

The preliminary results indicate that in constant 1977 dollars the capital costs of the dispersed option are about $179 million greater than those of the concentrated-siting option. Annual operating and maintenance costs are about $11 million greater for the dispersed option. Estimated total costs (1977 constant dollars) over the lifetime of the plants show an advantage of over $500 million for the concentrated siting.

Surprisingly, preliminary estimates of the differential environmental costs between the two options show the concentrated-siting option to be environmentally superior for practically all the effects studied. This can be largely attributed to the additional land required by the dispersed option. Structures, settling pond, and coal piles would require about 274 additional acres under the dispersed option. The Tempo group estimates that transmission line rights-of-way would require 192 additional acres under the dispersed option, and if additional fenced (albeit unoccupied) land with restricted access is included in the estimate, the dispersed option would require a total of about 646 additional acres. The perturbation of so many additional acres of land leads to potentially greater ecological impacts.

Preliminary estimates indicate that the differences in water resources required under the two siting approaches are small. The effect on water would then be virtually the same for both siting options, provided that the locations of the plants do not involve different hydrologic systems. Some differences could result from additional pollution of rainwater runoff in the dispersed option because of the need for 16 additional acres of coal storage; erosion problems could be greater with the dispersed option because of the increased acreage disturbed during construction.

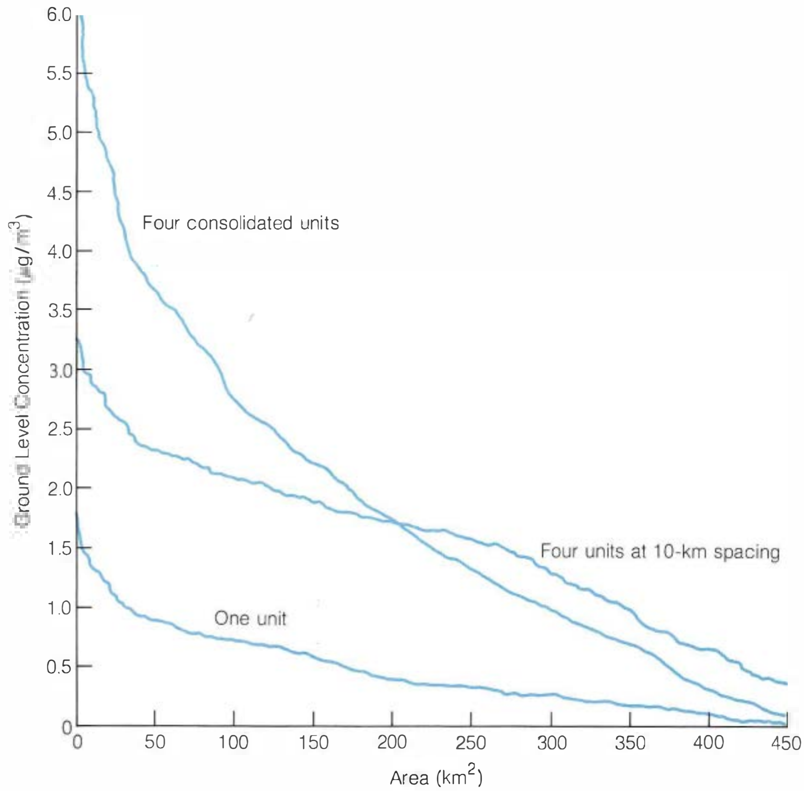
The differences in socioeconomic effects between the two options depend on the employment predictions and population characteristics of each option, with the former assumed to be the principal variant. If population characteristics (population density, demographic distribution) are assumed to be relatively homogeneous at all sites, employment levels will generally govern other socioeconomic factors, which are generally directly related to the size of the population influx—the greater the influx, the greater the impact. The construction of four dispersed units would require 425 more employees than if the four units were built at one site. Operation of the power plants would require 117 more employees at the dispersed sites. These estimates suggest that socioeconomic effects would be greater under the dispersed siting option. Nonhomogeneous population characteristics could, however, invalidate this result.

The operation of the power plants would result in emissions to the air from the stacks, cooling towers, vehicles, and other fuel-burning equipment. Fugitive dust from coal-handling areas and other plant operations would also be a problem. Of greatest concern are the stack emissions of gaseous pollutants and fine particles. The general distributions of the annual average ground level concentrations of stack emissions by area are shown in Figure 1. As expected, the highest concentrations occur with the concentrated option, while the dispersed option results in relatively lower concentrations spread over a larger area. It is important to note that the areas under these curves (the integral of concentration and area) is the same for both siting options; that is, over a large enough area and a long enough time, the same amount of stack emissions will diffuse to ground level for both options because the same quantities of gases and particles are emitted from the stacks.

The difference in distributions makes it difficult to compare the effects of air pollution from the two options. By the above argument, any effects of acid deposition or secondary pollutants (e.g., sulfates, nitrates) are likely to be the same under the two options. For the gases and particles emitted directly from the stacks, the impacts of alternative siting options are sensitive to the shape of the dose-response curves relating pollutant concentrations to effects. If the dose-response curve has a threshold and if population densities are similar around all sites, greater effects would be expected for the concentrated-siting option because of the greater probability of exceeding the threshold concentrations. The same would be true for an exponential dose-response curve. If the dose-response curve is linear with a zero threshold, one would expect little difference between the two siting options because the total quantity of pollutants emitted would be the same for both options.

Tempo is currently verifying the above results and examining the two options at additional geographic sites. Sensitivity analyses will also be performed to indicate the robustness of the results. *Project Manager: Ronald E. Wyzga*

Figure 1 Annual average ground level concentrations of stack emissions for a hypothetical emission rate of 1 lb/10^6 Btu.



SOLUTION MINING OF URANIUM

Conventional uranium production requires the mining, hauling, crushing, and milling of 500–1000 tons of ore for every ton of uranium. For economic reasons, many known deposits will never be tapped by conventional techniques. Such deposits may require moving 3000–4000 tons of ore for every ton of uranium produced. Other deposits, although of higher grade, are too small in total resource tonnage to justify a large, fixed investment in mine shaft and surface processing (milling) facilities. Still other small, isolated deposits are uneconomic because their development would require hauling many tons of ore long distances to mills. The relatively new application of solution mining to uranium production is one possibility for making recovery of uranium from these problem deposits feasible.

Uranium solution mining (also called in situ leaching) is disarmingly simple in concept. The technique involves drilling into the deposit, injecting and circulating a solution that dissolves the uranium in place, pumping the solution to the surface, and extracting the uranium from this solution in a surface plant. Thus this technique avoids direct physical movement of the ore body and the resultant costs and environmental effects. Other advantages of this method are lower initial capital requirements, reduced lead times, lower labor requirements, safer operation, and improved possibility of extracting deep, low-grade deposits and/or small or isolated ore deposits.

In practice, many geologic, hydraulic, and chemical factors can combine to make solution mining more difficult than it appears from this description. Nevertheless, the technique is being used more frequently, mostly in pilot plant operations but to an increasing degree in full-scale production as well.

Solution mining of uranium was first proposed in 1957, but only R&D projects existed until 1975, the first year of commercial production. Table 1 shows its rapid expansion since that time, with in situ production increasing from 75 tons (0.6% of U.S. uranium production) in 1975 to a 1979 projection of 1500 tons (7.7%).

Eight commercial-scale plants with a total rated capacity of 1488 t/yr are now operating in Texas, and three more are under construction.

In Wyoming 14 pilot-scale plants are currently in operation; two of these will be expanded to commercial scale in 1980 and a third in 1981. Pilot-scale operations are being conducted in Utah, New Mexico, and Colorado. One of the Colorado sites is targeted for expansion to commercial scale in 1981. Other states, including Montana, Arizona, South Dakota, and California, also have attracted some interest as potential locations for in situ mining operations.

Using public sources of information, the U.S. Bureau of Mines was able to identify 22 operators working on 33 projects at pilot or commercial scale. However, there are additional projects in various stages of planning. In early 1979 Hunkin Engineers, Inc., a consulting firm specializing in this field, stated to EPRI that 40 U.S. and 5 Canadian projects were known to them.

EPRI's Supply Program is concerned with forecasting uranium availability and price. As one portion of this program, NUS Corp. developed an economic model of uranium solution mining. The results of this research were recently released in an EPRI report (EA-731). The cost model developed by NUS is not designed to compute detailed site-specific economics. Rather, it is intended for use in studying the relative cost impacts caused by changes in various resource, financial, and operational conditions.

Table 1
U.S. SOLUTION-MINED URANIUM PRODUCTION
(U_3O_8)

Year	Rated Capacity (t/yr)	Estimated Production (t/yr)	% of Total Uranium Production
1975	250	75	0.6
1976	500	250	2.0
1977	1350	650	4.4
1978	1488	1100	7.0
1979	1850*	1500*	7.7*

Source: William Larson. "Uranium In Situ Leach Mining—A Third Alternative." Presented at the April 1979 meeting of the American Association of Petroleum Geologists.

*Projected.

The cost model is a process-oriented analysis technique that computes the capital investment, operating costs, and selling prices required to provide a desired return on investment. The costing methodology involves four submodels corresponding to four major cost categories: exploration and initial development drilling costs, well-field costs, plant and equipment costs, and operating costs. A fifth submodel, which deals with financial analysis, computes the required selling price, using discounted-cash-flow methodology. Costs are computed in constant 1977 dollars.

Costs for the first submodel (exploration and initial development) are related to average figures from actual industry experience. In this submodel, acquisition costs can be included or excluded. The well-field submodel computes the solution flow rates required and the cost of the corresponding number of required wells. The well-field pattern assumed is the commonly used five-spot pattern (four injection wells surrounding a single production, or recovery, well at the center of the pattern). The plant and equipment submodel computes the surface plant costs, which are based on a standard 0.09 m^3/s (1500 gal/min) plant with scale correction factors appropriate to the size of plant required. Costs of wells and equipment for environmental monitoring are included in the preceding two submodels. The operating submodel computes costs for chemicals, labor, pumping energy, annual well-field development, and aquifer restoration. Information for this submodel is based on data from service suppliers and historical data from ongoing solution operations. The financial submodel computes total project and unit costs as opposed to the forward-cost form (in which uranium resource figures are presented and such items as exploration cost and the cost of money are excluded).

The costs computed by the NUS model therefore include the cost of capital for the project—that is, return on investment is included in the production cost (in conformance with the economic concept of production costs). The model will compute required selling price for a variety of solution mining situations dictated by the user. The analyst must specify values for the following 11 input variables: annual production level, concentration of production solution, solution injection rate, uranium extraction efficiency, depth of deposit, ore thickness, well-pattern spacing, ore grade, reserve tonnage, required return on investment, and type of solution (acid or alkaline).

A primary application of the model would be in resource planning studies, but it could also be used as a common basis for evaluating the relative merits of various mining situations. Results of the NUS work appear in the final report in both a detailed hand-computation version and a simple, faster graphic analysis (EA-731). *Project Manager: Richard Urbanek*

ACID RAIN REPORT

The U.K. Central Electricity Research Laboratories (CERL) recently published the proceedings of an acid rain workshop, which was sponsored by EPRI and organized by CERL in September 1978.

The report, *Ecological Effects of Acid Precipitation,* details workshop discussion of the role played by atmospheric acids in terrestrial and aquatic ecosystems and is available from Robert Goldstein, manager of EPRI's project on acid rain, (415) 855-2593.

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP922-6	Definition of a Conceptual Design of a Small Fusion Reactor	11 months	120.0	Cornell University *D. Paul*
RP1129-3	Installation of Test Baghouse	10 months	888.9	Bumstead-Woolford Co. *R. Carr*
RP1201-8	Evaluation of New Technical Options for Improved End-Use Efficiency: Ultraviolet Radiation Curing	10 months	21.0	Fusion Systems Corp. *Q. Looney*
RP1260-8	Evaluation of Asbestos Cement Fill Leaching From Cooling Towers	5 months	22.4	Brown & Caldwell *R. Jorden*
RP1260-11	Evaluation of Alternative Drift Measurement Methods	6 months	38.6	Massachusetts Institute of Technology *J. Maulbetsch*
RP1260-12	Research Needs for Priority Pollutant Control	4 months	29.8	Water Purification Associates *W. Chow*
RP1260-15	Investigation of Methodologies for Water Flow Rate Measurement	3 months	49.6	Environmental Systems Corp. *J. Bartz*
RP1406-1	Model of Subsurface Transport of Leachate From FGD Sludge Disposal	2 years	96.7	Battelle, Pacific Northwest Laboratories *D. Golden*
RP1403-02	Engineering Assessment of a Low-Heat-Rate Pulverized-Coal Power Plant	15 months	528.5	General Electric Co. *D. Giovanni*
RP1648-1	Reduction of Bearing Losses in Electric Utilities	15 months	153.0	Mechanical Technology Inc. *J. Parkes*
RP1650-1	Water Blowing of Fireside Deposits in Coal-Fired Utility Boilers	19 months	678.2	Babcock & Wilcox Co. *J. Dimmer*
RP1651-2	Air-Gas System Dynamics of Fossil Fuel Power Plants: Field Tests of 125-MW Balanced Draft Unit	4 months	33.7	NUS Corp. *I. Diaz-Tous*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Nuclear Power Division				
RP886-4	Influence of Dynamic Effects of Crack Arrest	14 months	114.0	Fraunhofer-Gesellschaft *T. Marston*
RP892-12	Integration Report: Dual Ultrasonic Testing	3 months	5.1	COE Associates *M. Lapides*
RP966-2	Formation and Properties of Colloidal Corrosion Contaminants in Nuclear Power Plants	22 months	695.7	Clarkson College of Technology *R. Shaw*
RP1253-4	Proliferation Risk Comparison of Options for Spent-Fuel Disposal	4 months	30.3	Science Applications, Inc. *R. Williams*
RP1324-3	Evaluation of Pipe Whip Analysis Capability	4 months	43.0	Hibbitt & Karlsson, Inc. *H. Tang*
RP1442-1	BWR Core Power Distribution Analysis and Control	9 months	242.0	Systems Control, Inc. *A. Long*
RP1445-2	High Temperature Filtration	61 months	378.0	Westinghouse Electric Corp. *M. Naughton*
RP1449-1	On-Line Monitoring and Diagnostics for Turbines and Primary System Machinery	6 months	87.5	Westinghouse Electric Corp. *G. Shugars*
RP1452-1	Benchmarking to Verify Modifications to COMETHE–IIIJ	10 months	191.8	The S. M. Stoller Corp. *F. Gelhaus*
RP1563-2	Evaluation of BWR Resin Intrusions on Stress Corrosion Cracking of Reactor Structural Materials	35 months	483.0	Battelle, Pacific Northwest Laboratories *J. Danko*
RP1566-1	Evaluation of the Use of Inconel 690 in BWR Components	23 months	247.0	Southwest Research Institute *J. Danko*
RP1578-1	Development and Test Methods for the Nondestructive Assay of Spent-Fuel Bundles	7 months	12.0	National Nuclear Corp. *R. Williams*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1579-1	High-Level Waste Form Properties and Technology: Chemical and Physical Stability of Amorphous and Crystalline Waste Forms	5 months	32.6	NPD Energy Systems, Inc. *R. Williams*
RP1702-1	Coordination of Fission-Product Migration and Release Program	18 months	80.0	SRI International *H. Ocken*
Electrical Systems Division				
RP1469-1	Long-Term System Dynamics Simulation Models	1 year	315.9	Boeing Computer Services, Inc. *J. Lamont*
RP1499-1	Power Transformer With Two-Phase Cooling	6 months	1003.2	General Electric Co. *E. Norton*
RP1518-1	Development of Improved Plow for Installing Underground Distribution Cable	9 months	447.2	ORETEK Laboratory, Inc. *T. Kendrew*
Energy Analysis and Environment Division				
RP883-2	Foreign Uranium Supply, 1979	6 months	40.0	NUS Corp. *J. Platt*
RP1301-1	Assessment of FGD Issues	13 months	140.0	Radian Corp. *R. Urbanek*
RP1317-2	Integrated Environmental and Safety Assessment of Selected Mechanical Energy Storage Systems	1 year	124.9	NUS Corp. *R. Wyzga*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1365-1	Uranium Resource and Cost Assessments	7 months	96.1	NUS Corp. *A. Halter*
RP1430-2	Integration and Application of EPRI Coal and Electric Utility Supply Models	19 months	105.0	Charles River Associates Inc. *T. Browne*
RP1430-3	Integration and Application of EPRI Coal and Electric Utility Supply Models	18 months	105.0	Gordian Associates Inc. *T. Browne*
RP1483-2	Electricity Supply Model Evaluation	15 months	54.0	Economic Resource Associates *M. Searle*
RP1491-1	Economic Controls of Utility Emissions	1 year	145.0	ICF Incorporated *R. Wyzga*
RP1589-1	Remote Power Sensor	6 months	132.7	Robinton Products, Inc. *E. Beardsworth*
RP1622-1	Development and Validation of the Remote Acoustic Atmospheric Motion Monitor System	13 months	241.0	Aerovironment, Inc. *G. Hilst*
RP1642-1	Analysis of Recent EPA Community Health and Environmental Surveillance System Data	1 year	169.1	H. Daniel Roth Associates, Inc. *A. Colucci*
RP1643-1	Evaluation of Carcinogens Associated With Coal Combustion and Conversion	1 year	735.4	Systems Applications, Inc. *A. Colucci*

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 a small charge. Research Reports Center will send a catalog and price list on request.

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Microfiche copies are available from National Technical Information Service, P.O. Box 1553, Springfield, Virginia 22151.

ELECTRICAL SYSTEMS

Midterm Simulation of Electric Power Systems

El-596 Final Report (RP745)

A new intermediate (midterm) simulation tool was devised to analyze disturbances to power systems during postfault transients in the 10-s–5-min range. It models power plants and automatic generation control and computes individual shaft speeds and intermachine oscillations. A network reduction process, similar to the Ward-Hale reduction, was developed. The contractor is Arizona State University. *EPRI Project Manager: John Lamont*

Further Development of Polysil Material Systems for Electrical Applications

EL-1093 Final Report (RP1203-1)

New formulations and fiber reinforcing to increase Polysil* strength were developed. Both methyl methacrylate and polyester-styrene resins were used. Mold materials and mold release agents were evaluated and mold release problems solved. Aggregate particle-size distribution, processing methods, and the organic phase were optimized. Gel, Teflon, and silica surface coatings on Polysil were evaluated. The contractor is Lindsey Industries, Inc. *EPRI Project Manager: Mario Rabinowitz*

*Polysil is an EPRI trademark.

Effect of Operating Considerations on Reliability Indexes Used for Generation Planning

EL-1102 Final Report (TPS77-719)

A detailed Monte Carlo simulation computer program was developed to consider the impact of a great variety of operating details, constraints, and policies on generation reliability performance and to investigate the effect of these factors on computed reliability indexes. A system of 513 generating units was used to study the relationship of actual historical reliability performance to that predicted by both a conventional analytic method and the Monte Carlo method. The contractor is Texas A. & M. University. *EPRI Project Manager: M. P. Bhavaraju*

ENERGY ANALYSIS AND ENVIRONMENT

Implementation and Coordination of the Sulfate Regional Experiment (SURE) and Related Research Programs

EA-1066 Interim Report (RP862)

This report describes in detail the operating procedures for SURE (Sulfate Regional Experiment), a comprehensive program for monitoring air quality over much of the Northeast. It also discusses the coordination of SURE with other regional programs. SURE is aimed at defining the relation between emitted primary pollutants and ambient concentrations of secondary products. The main elements of SURE are a ground monitoring network, air quality measurements by airplane, a detailed emissions inventory, and a modeling program. The contractor is Environmental Research & Technology, Inc. *EPRI Project Manager: Ralph Perhac*

Identification and Quantification of Polynuclear Organic Matter (POM) on Particulates From a Coal-Fired Power Plant

EA-1092 Interim Report (RP1057-1)

An analysis of stack ash and electrostatic precipitator hopper ash showed that hopper ash could be used only qualitatively to predict the constituents, particularly polycyclic aromatic hydrocarbons (PAHs), adsorbed on fly ash. Solvent extraction methods for recovering PAHs from ash were evaluated. Implications of the results on ash ponding were examined. Multialkylated PAHs, separated from coal liquefaction product and characterized, showed bacterial mutagenic activity. The types of PAHs adsorbed on hopper ash were determined. The contractor is Oak Ridge National Laboratory. *EPRI Project Manager: P. W. Jones*

Analysis of Household Appliance Choices

EA-1100 Final Report (RP1005)

Factors that affect household appliance choices were examined, especially those related to space-conditioning systems. The literature on discrete choice models was surveyed; the applicability of the models to appliance choice problems was assessed; and methods of sampling and aggregating households were addressed. The sequential logit model and two versions of the probit model were empirically tested. The contractor is Charles River Associates Inc. *EPRI Project Manager: James Boyd*

FOSSIL FUEL AND ADVANCED SYSTEMS

Reheat Study and the Corrosion-Erosion Tests at TVA's Colbert Pilot Plant

FP-940 Final Report (RP537-1)

Adjunct testing in conjunction with the operation of a 1-MW lime/limestone scrubber flue gas desulfurization pilot plant determined operating and heat transfer characteristics of a flue gas recirculation reheat system and an in-line indirect steam reheater. The cyclic reheat system was not tested; however, operating costs and capital investment of all three systems were estimated. The resistance of construction materials to erosion-corrosion by process lime/limestone slurry was measured. The contractor is Tennessee Valley Authority. *EPRI Project Manager: T. M. Morasky*

Requirements Assessment of Wind Power Plants in Electric Utility Systems

ER-978 Final Report, Vols. 2 and 3 (RP740-1)

Volume 2 of this report describes the method developed for assessing the prospects for wind power application to electric utility systems. This method was used to assess requirements and analyze the impact and penetration of wind generation on three utility systems (in New York, Kansas, and Oregon). Available wind plant designs were surveyed, five candidates selected, and models developed for a 20-MW plant and a 10-kW residential system. The study determined that it is possible to calculate the long-term value of wind power plants in utility systems. Volume 3 (appendixes) deals with loss-of-load probability methodology; utility system production costing (in terms of energy disposition, fuel consumption patterns, and fuel operating costs); and analysis of wind data for each of the regions studied. The contractor is General Electric Co. *EPRI Project Manager: E. A. DeMeo*

Characterization and Combustion of SRC-II Fuel Oil

FP-1028 Final Report (RP1235-3, RP1235-4, and RP1412-1)

An SRC-II fuel was analyzed, characterized, and compared with petroleum distillate products. Combustion tests were performed with SRC, No. 2 fuel oil, and No. 5 fuel oil. Combustion performance and NO_x emission and control were evaluated. It was concluded that SRC fuel oil behaves and burns similarly to No. 2 fuel oil except for producing substantially higher NO_x emissions. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: William Rovesti*

The Lime FGD Systems Data Book

FP-1030 Final Report (RP982-1)

This manual provides (1) detailed guidelines for design features, equipment specifications, and selection criteria of lime scrubbers and (2) specific procedures to determine which system design parameters are critical in selecting a lime slurry system. Lime-scrubbing process chemistry and its interrelationship with the proper selection of system components are described. The contractor is Pedco Environmental Specialists, Inc. *EPRI Project Manager: T. M. Morasky*

Solar Water-Heating and Data-Monitoring System at South County Hospital, Wakefield, Rhode Island

ER-1078 Final Report (RP554-1)

A solar domestic water-heating system was installed in the South County Hospital, Wakefield, Rhode Island, and its performance was monitored from December 1976 through March 1978. This report describes final stages of the development of the computerized monitoring system and gives performance results for the 16-month period. The contractor is Daystar Corp. *EPRI Project Manager: Gary Purcell*

Design Study of a Fusion-Driven Tokamak Hybrid Reactor for Fissile Fuel Production

ER-1083 Final Report, Vols. 1 and 2 (RP473-1-3)

The feasibility of fusion-fission applications based on projections of late 1980s tokamak plasma physics and technology was evaluated by means of a conceptual design study of a tokamak hybrid facility. Plutonium production assessment showed that by using natural or depleted uranium as feed material, near-term, beam-driven, tokamak fusion-fission devices could produce abundant amounts of plutonium, enough to supply the makeup fuel for about five LWRs of equivalent thermal power. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: N. A. Amherd*

Catalyst Development for Coal Liquefaction

AF-1084 Final Report (RP408-1)

This third annual report covers work from February 1977 to February 1978 on catalyst screening (Task II) and short-term aging (Task III). Under Task II, information is presented on new catalysts, hydrogen donor solvents, modifications in product workup procedure, and effects of impregnating aids on initial performance. Under Task III, the effects of surface properties and different catalytic metals on catalyst aging were studied, and the aged catalysts characterized to establish reasons for deactivation. The contractor is Amoco Oil Co. *EPRI Project Manager: William Rovesti*

Optimization-Simulation Methodology for Wet-Dry Cooling

FP-1096 Final Report (RP1182-1)

A method was developed and demonstrated and a computer program was formulated to include electrical supply and production economics in the design procedures and operating strategies for wet-dry cooling systems. The code provides a methodology for quantitatively determining optimal economic trade-off between loss of performance and the sizing of the wet-dry cooling capacity; it is applied in the case study evaluation of a typical large fossil-fired baseload plant (at two sites). The contractor is Dynatech R/D Co. *EPRI Project Manager: J. A. Bartz*

Heber Geothermal Demonstration Power Plant

ER-1099 Final Report (RP580-2)

This report describes the optimized baseline design for the 45 MW (e) binary-cycle Heber Geothermal Demonstration Power Plant and documents the work that formed the basis for this design. The work accomplished during Phase II, Preliminary Design, is recorded, providing a base for detailed plant design. Licensing, environmental, cost, and scheduling activities are described. Analysis showed that a binary-cycle plant can be designed for the Heber geothermal reservoir to yield a 10–15% higher efficiency than a direct-cycle plant. The contractor is Fluor Engineers and Constructors, Inc. *EPRI Project Manager: Vasel Roberts*

Proceedings: Second NO_x Control Technology Seminar

FP-1109-SR Special Report

The Second EPRI NO_x Control Technology Seminar, held in Denver, November 8–9, 1978, focused on controlling NO_x emissions from pulverized-coal-fired utility steam generators. These proceedings include the prologue to the technical sessions, the papers presented, and transcripts of the discussions. The prologue considers general aspects of NO_x emissions. The papers discuss control techniques, including burner design, combustion modification, and postcombustion gas treatment. *EPRI Project Manager: Edward Cichanowicz*

Proceedings: Workshop on Economic and Operational Requirements and Status of Large-Scale Wind Systems

ER-1110-SR Special Report

This workshop, held in March 1979 in Monterey, California, was one of a series of six on wind energy topics. The proceedings describe most of the North American analytic and experimental investigations of wind generation's integration into utility networks. Overviews of activities in wind turbine generator hardware, wind energy resource assessment, and environmental issues are also included. The papers presented and transcriptions of panel sessions and discussions are included in this report. The contractor is Altas Corp. *EPRI Project Manager: E. A. DeMeo*

Integral Cell Scale-Up and Performance Verification

EM-1134 Final Report (RP842-4)

The integral cell, an advanced phosphoric acid fuel cell concept, is described. The integral cell configuration was scaled up to the 4.8-MW demonstrator cell size (3.7 ft^2) and tested in a 20-cell stack. Technology improvements gave performance improvements that translate to a 7% reduction in cell area. A conceptual design effort for a 7.4-ft^2 ribbed substrate stack was initiated, using a preliminary FCG-1 system concept that included operation at a higher pressure than the 4.8-MW demonstrator. The contractor is United Technologies Corp. *EPRI Project Manager: Edward Gillis*

NUCLEAR POWER

Workshop Proceedings: Outage Planning and Maintenance Management

WS-78-94 Workshop Proceedings, Vols. 1 and 2

A workshop was held in Denver, Colorado, in August 1978 to present the state of the art of nuclear power plant outage planning and maintenance management and to provide a forum for information exchange by members of the power industry. Some new methods were also presented. Volume 1 includes the presentations and summaries of workshops. Volume 2 includes the information packages for the work sessions, which were sent to each of the registrants. The workshop was hosted by Public Service Co. of Colorado. *EPRI Project Manager: Randall Pack*

Pool-Type LMFBR Plant 1000-MW (e) Phase-A Extension-2 Design

NP-1014-SY Final Report, Vol. 1: Executive Summary (RP620-20 and RP620-21)

A conceptual design of a 900-MW (e) (net) pool-type LMFBR plant has been developed to approximately the same level as current loop-type LMFBR designs. This summary briefly describes the plant, significant findings (deck structure, thermal barriers, auxiliary cooling system, maintainability, operability, inspectability, fabricability, constructibility, seismic response), areas needing development, and conclusions reached during the study. The contractors are General Electric Co. and Bechtel National, Inc. *EPRI Project Manager: J. G. Duffy*

Generalization of the ARMP Depletion Capability: Interfacing of the Stand-Alone EPRI–CINDER With EPRI–CELL

NP-1073 Final Report (RP452-2)

An automated interface between EPRI–CELL, a reactor analysis code, and EPRI–CINDER, a point depletion and fission-product code, has been generated for use in the Advanced Recycle Methodology Program (ARMP) system. It enables an efficient sequential operation of the two codes without direct handling of intermediate CELL output that is used to modify the CINDER input at each depletion time step. EPRI–CINDER was provided with new capabilities and the input requirements were greatly simplified. The contractor is Science Applications, Inc. *EPRI Project Manager: Odelli Ozer*

Symposium Summary: Nuclear Data Problems for Thermal Reactor Applications

NP-1098-SY Summary Report (RP975-1)

Proceedings of a symposium on the status of nuclear data for thermal reactor applications are summarized. Main topics addressed were microscopic cross sections of importance to reactor design, clean critical benchmarks and analysis of clean critical experiments, dependence of power reactor benchmarks on nuclear data, and interaction of methods and data in industrial experience. Included are lists of problem areas and recommendations for future development. Brookhaven National Laboratory hosted the symposium. *EPRI Project Manager: Odelli Ozer*

Symposium Proceedings: Nuclear Data Problems for Thermal Reactor Applications

NP-1098 Symposium Proceedings (RP975-1)

This report includes the papers presented at a symposium on the status of nuclear data for thermal reactor applications. Main topics discussed were microscopic cross sections of importance to reactor design, clean critical benchmarks and analysis of clean critical experiments, dependence of power reactor benchmarks on nuclear data, and interaction of methods and data in industrial experience. The report also includes discussion summaries that cover the present status of these topics, directions for future development, and specific recommendations. Brookhaven National Laboratory hosted the symposium. *EPRI Project Manager: Odelli Ozer*

Pressure Boundary Technology Program: Progress 1974 Through 1978

NP-1103-SR Special Report

This report discusses all completed, ongoing, and proposed projects in the Pressure Boundary Technology Program, which covers characterization of materials, evaluation and analysis of flaws, and fabrication and repair. Summary descriptions of the projects are included. Major efforts include new curves for predicting mechanical properties of irradiated steel, simplified methods for predicting behavior of ductile materials in the presence of flaws, new corrosion fatigue design curves, and alternative repair weld procedures. *EPRI Project Manager: K. E. Stahlkopf*

Semiautomatic Weld Crown Contouring Equipment

NP-1107 Final Report (TPS78-793)

Information from a review of pertinent welding practices was translated into specifications for contour and surface requirements suitable for nondestructive testing of welds, which serve as performance goals for a weld-contouring machine. A conceptual design of an external lathe that uses a microprocessor-controlled cutting head was developed, and a simplified test machine fabricated. Cutting tests with this machine verified performance characteristics of the main machining control parameters. The contractor is Sigma Research, Inc. *EPRI Project Manager: Gary Dau*

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