Implanting the Fuel Cell

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Cover: The fuel cell power plant—small, clean, efficient, quiet, modular—seems the ideal option for downtown power. But can it be commercialized in time?

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The Fuel Cell: Where Is It Going?

To ask where the fuel cell is going may seem a surprising question today. After all, the fuel cell has come a long way. In the mid-1800s fuel cells were a scientific curiosity. Early in this century, the fundamental potential of the fuel cell as a power generator was recognized, but its technical implementation proved too difficult. By the 1960s, however, fuel cells were brilliantly successful as efficient and reliable power plants in the Gemini and Apollo space missions. And today the fuel cell is on the threshold of viability as an attractive new generating option for electric utilities.

Progress in the last 10 years has been particularly impressive. Fuel cells have advanced from devices that cost $100,000 a kilowatt and generated a few kilowatts from superpure hydrogen and oxygen to megawatt-size pilot plants that are not only capable of operating in a utility environment but have also demonstrated potential for using economic fuels and becoming cost-competitive power plants. This progress would not have happened without the vision of a number of utilities—gas and electric—that were able to discern the unique benefits of fuel cells and were willing to take the considerable risks associated with the development of a new and different type of power plant. Nor would it have happened without the engineering talent and the corporate resources committed by United Technologies Corp. to that development.

Given the fuel cell's basic potential and a definite pattern of R&D success, it was logical for EPRI and DOE to join in the development effort, especially when resource requirements began to tax the capabilities of participating utilities. This broadened partnership has clearly accelerated technical progress, and the successful demonstration of a 4.8-MW power plant module is expected in 1980–1981. Why, then, question the future of fuel cells?

This month's lead article traces recent developments and points to the benefits of fuel cells. It goes on to make clear that we do not yet have an answer to the crucial question of who will carry the burden of perfecting and commercializing this new technology during the next few years.

Will the manufacturer remain committed to a program that can reduce the techno-economic risk to a level acceptable to future users?

Will the utilities, through aggressive and early planning and by their active participation in introducing fuel cell technology, help to reduce the manufacturer's risk that stems from market uncertainty?

Will DOE demonstrate the flexibility for exploring the broad commercialization charter it appears to have been given under the law? Will it be able to focus sufficient resources on making fuel cells available in the near-term—a strategy that would maximize the benefits but also expose DOE and its partners to the risks inevitably associated with any new technology?

And, finally, will EPRI be able to play a positive role—beyond its demonstrated commitment to advance fuel cell technology—in catalyzing the national effort?

In short, will the partners assume their logical responsibilities or will the fuel cell go down as an early example of this country's inability to implement useful new energy technologies? The answers and future of the fuel cell may well depend on the decisions and actions of the coming months.

Fritz R. Kalhammer

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Authors and Articles

Successful R&D increasingly involves skills, tasks, considerations, and resources that go well beyond the researcher's report or the hardware in a developer's lab. This month's *Journal* touches on several problems that influence the commercial maturation of electric power R&D: front-end funding for a technological newcomer (the fuel cell), environmental implications of energy production (EPRI's Advisory Council seminar), proprietary incentives to apply R&D results (patents and licenses), user education (a new computer model for utility planning), and ethical perceptions (an EPRI adviser's opinion) of nuclear waste.

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Clean Power for the Cities" (page 6) reviews more than fuel cell materials, processes, and systems; more than their efficiency, operability, and cost in a utility grid. A new context is also reviewed in this article by *Journal* feature writer Nadine Lihach. That context is an awkward mix of energy policy and commercial financing problems that have everyone asking: Just how do we expedite this new power generation option?

The question has become an increasing preoccupation for Arnold Fickett, who started EPRI's fuel cell program in 1974. Fickett's own work for 15 earlier years provides the essential technical foundation. He was on the ground floor of General Electric Co.'s work in the field and in 1965 was honored by *Industrial Research* magazine as co-inventor of the Gemini fuel cell.

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Risk in the Pursuit of Benefit" (page 13) echoes both the harmony and the discord of more than a dozen energy technologists, government officials, medical authorities, research managers, regulators, and academicians as they developed the theme of the environmental implications of energy production. The occasion was the 1978 summer seminar of EPRI's Advisory Council, where members and their guests argued issues of risk assessment, air pollution, environmental policy, and radioactivity. *Journal* feature writer Stan Terra recorded the sessions and edited these excerpts.

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EPRI Inventions" (page 18) recognizes that patents may be a help or a hindrance when unique research solutions approach the transition between concept and commerce. Licensing arrangements can make the difference, and it takes well-thought-out practices to encourage this transfer of technology. Mary Wayne reviews some of the considerations as seen by Henry Darius, EPRI's corporate secretary since 1974. Darius has a background well suited to patent administration: an engineering degree from the U.S. Naval Academy, a law degree from the University of Connecticut, and 12 years at Northeast Utilities with successive responsibilities in operations, data systems, and corporate law.

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Field-Testing a New Planning Concept" (page 20) explores the workings of a special kind of classroom, the EPRI user workshop, where faculty and students constantly exchange roles. In this case, Systems Program staff members from EPRI's Energy Analysis Department and representatives from Decision Focus, Inc., explained the rationale and workings of a new modeling approach to reserve capacity planning. And there was interaction with utility planners, who contributed insights to refine the conceptual logic, extend the model's flexibility, and assure its practicality. Robert Taylor of EPRI's Communications Division built this case history with mathematician Jerry Karaganis, who led EPRI's eight-month model development and coordinated the first three test workshops.

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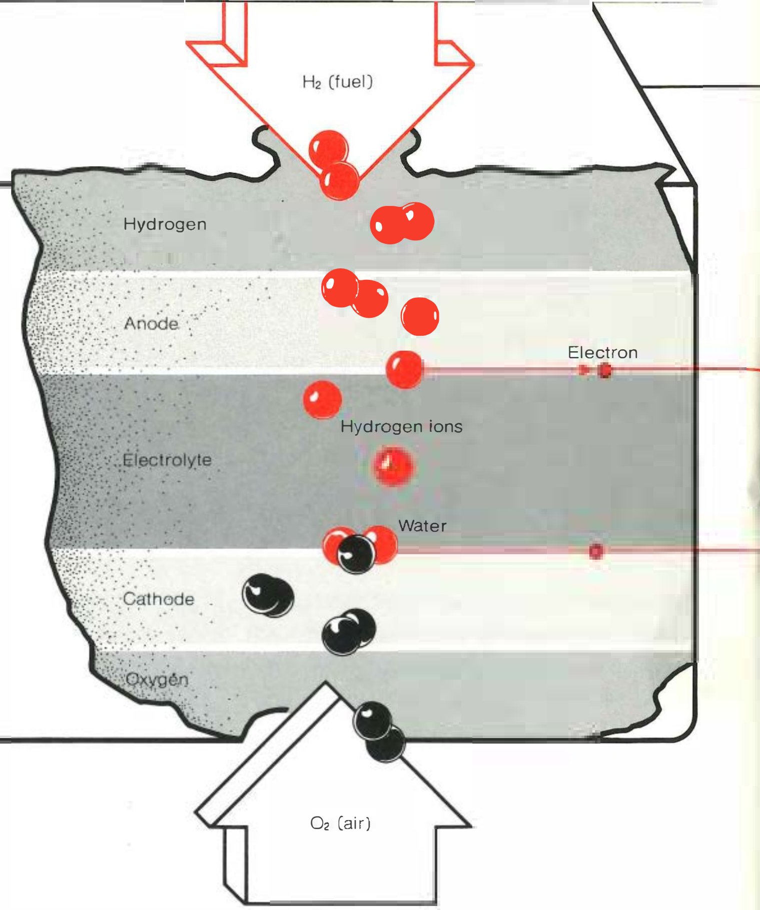
Margaret Maxey: The Ethical Eye" (page 22) continues the *Journal*'s series of interviews with members of the EPRI Advisory Council. Economists, communicators, physicists, biologists, educators, environmentalists, attorneys—all have registered their perceptions of energy politics and energy technologies. This month Maxey, professor of bioethics at the University of Detroit, explores the gray area between politics and technology, seeking to sharpen the contrast as an aid to clear and wise decision making. Feature writer Stan Terra captures Maxey's thinking, especially about nuclear power and its wastes.


Fickett

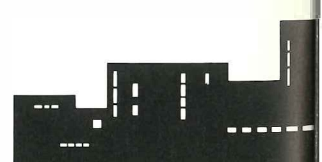
In the June 1978 *EPRI Journal,* EPRI reported that staff member Oliver Yu developed an approximation procedure for generation system reliability calculations. It has since been learned that similar procedures using different mathematical series expansions were independently developed by Mark Davidson, Edward Kahn, and Donald Levy of Lawrence Berkeley Laboratory (using the Edgeworth expansion). Their work is reported in a paper titled "An Assessment of the Potential for Full Co-ordination of the California Electric Utilities," LBL-5941, January 1977. A similar procedure was also developed by N. S. Rau of Canadian National Energy Board and K. F. Schenk of University of Ottawa (using the Gram-Charlier expansion).


Darius



FUEL CELL CHEMISTRY

The fuel cell electrochemically combines fuel and oxygen to produce electricity. Hydrogen-rich fuel gas is passed across the cell's fuel electrode (anode), where it dissociates into hydrogen ions and electrons. The ions migrate through the electrolyte to the oxygen electrode (cathode), while the electrons move through an external circuit to the cathode. At the cathode, oxygen, hydrogen ions, and electrons join to form water. The flow of electrons through the external circuit is electricity.



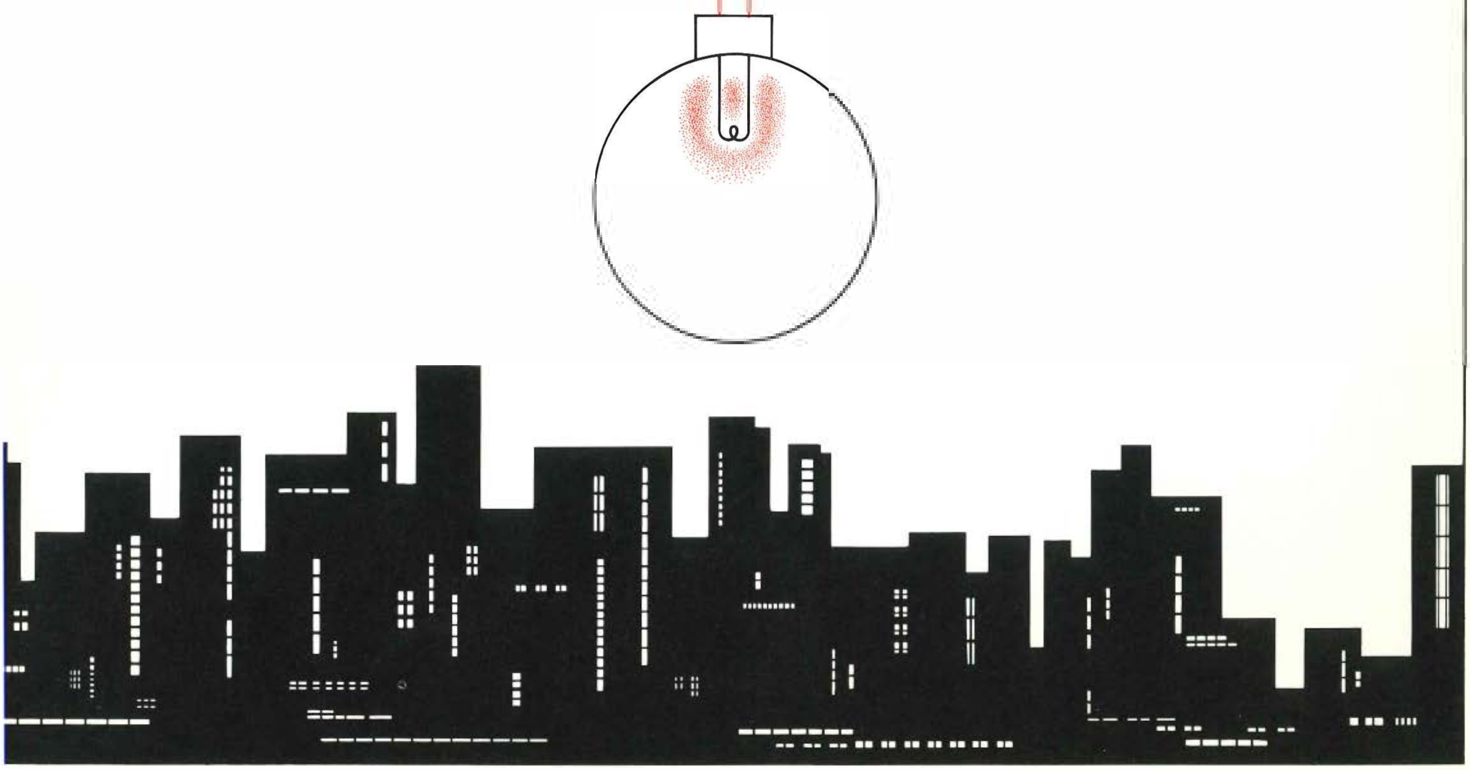
CLEAN POWER for the CITIES

Environmental constraints present no problem for the fuel cell power plant. Commercialization does—tomorrow's technology will require special funding considerations today.

Scenario: A major U.S. city, 1983. The power supply planner at the local electric utility groans softly over the report on his desk. A mammoth commercial complex is being planned in the heart of the city, and he has but two years to scrape together the power to supply it.

Circumstances have cornered the harried planner. His present generating system is already strained to its limits by a burgeoning population and an expanding economy. The only solution is a new power plant. But coal and nuclear units take 10 years to build, and he scrambles for options with shorter lead times. His most obvious choice is a gas-fired turbine, which can be installed in only two years. But after further consultation he finds he must scrap the idea. A conventional plant couldn't be built in the downtown area where power is needed. Conventional plants present emissions problems and siting obstacles. They have to be located far away from the city, necessitating new transmission lines, as well as causing many frustrations in gaining rights-of-way.

One simple option remains, and he grabs it. Eighteen months later, trucks



bearing peculiar modules begin rolling up to a bustling downtown site. The modules are unloaded and assembled. Almost overnight, a new power plant—certainly not a conventional one—assumes shape.

1985. The commercial complex opens its doors for business. Lights, typewriters, telexes, fans switch on, boosting power demand. From its downtown niche, the strange new power plant responds—quickly, cleanly, efficiently, noiselessly. Fuel cells are in the right place, at the right time.

Or will they be?

The fuel cell power plant, answer to the increasing power demands and decreasing siting options that will characterize the 1980s, may not be available when it is most needed.

It won't be for lack of trying. First-generation fuel cell technology and demonstration programs are now well under way. By 1982, it is likely that the fuel cell's operational, siting, and environmental characteristics will have been verified by the test of a 4.5-MW ac (4.8-MW dc) demonstrator in New York City. And an improved version of cell technology should have been validated by about the same time. From the technological point of view, the fuel cell power plant could be in commercial electric utility service by 1985.

Successful demonstration, however, is not the same as commercialization, emphasizes Arnold Fickett, manager of EPRI's fuel cell program. Commercialization means a sure market, affordable prices, factories, spare parts, customer service, a sales force. Despite its demonstration successes, the first-generation fuel cell power plant lacks these. Hundreds of millions of dollars are necessary to pave the fuel cell's way into the electric utility market. And that kind of funding is nowhere in sight.

A simple concept

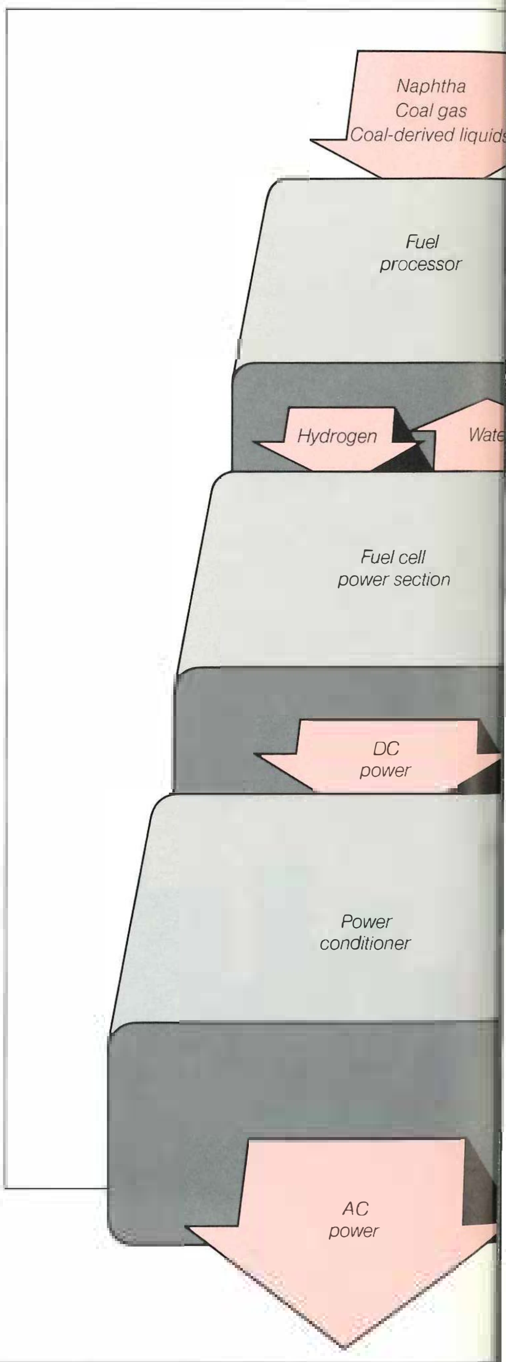
Commercial complexities aside, the fuel cell is simple in concept. It converts the chemical energy of a fuel directly to dc power without intermediate combustion or thermal cycles.

Take, for example, the fuel cell power section intended for use in first-generation power plants. It combines hydrogen and oxygen to produce water and electric power. The cell consists of a phosphoric acid electrolyte sandwiched between two electrodes. A hydrogen-rich fuel passes one electrode; an oxygen-rich gas—air—moves by the other. With the help of catalysts, the hydrogen at one electrode splits into hydrogen ions and electrons, which move in separate paths toward the oxygen, where they combine in the production of water. In this migration, the hydrogen ions pass through the electrolyte, and the electrons through an external circuit. The movement of the electrons through the circuit creates dc current.

A single cell produces between 0.6 and 1.0 Vdc. Current levels depend on the rate of cell reactions and the area available for these reactions. To increase voltage to the levels necessary for large-scale power generation, the individual cells are assembled into filter-press configurations, or stacks. These stacks are capable of generating 250–500 Vdc at power ratings of 200–500 kW. The stacks are connected in series or parallel to produce megawatts of power at 2000–3000 Vdc. This makes up the new plant's power section.

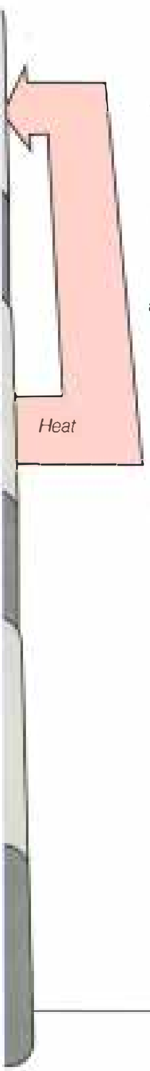
Fuel cells destined for commercial applications generally use air as the source of oxygen; other cell parameters—electrolyte, operating temperature, and fuel—may vary. However, the cell's electrolyte dictates certain temperature and fuel restrictions, and vice versa. A phosphoric acid electrolyte, for example, demands an operating temperature between 150 and 200°C. Large quantities of carbon dioxide, which may be present in the fuel, will not interfere with cell performance, but carbon monoxide might; so the amount of that substance in the fuel must be kept to a very low percentage. Other electrolytes require other operating temperatures and fuel streams. For instance, alkaline fuel cells operate at 25–125°C and cannot handle carbonaceous impurities in the fuel or the oxidant (air); those impurities react with the electrolyte, affecting performance negatively. Molten carbonate fuel cells, on the other hand, operate at 600–700°C. They will accept fuel streams with large quantities of carbon dioxide and carbon monoxide, as those substances are used in the cell's electrochemical reactions.

First-generation fuel cells use phosphoric acid electrolytes. The more ad-



vanced, second-generation fuel cells, which attempt to extend fuel capabilities, improve endurance, and lower cost, use molten carbonate technology. The molten carbonate fuel cell is still about five years behind the phosphoric acid cell in technological development.

The fuel cell power section is only one part of the fuel cell power plant. To plug into existing utility grids, the fuel cell must use utility fuel and produce ac power. Therefore, the complete power plant must include a fuel processor and a power conditioner. The processor converts a utility fuel, such as naphtha, to the necessary hydrogen-rich gas. The power conditioner converts dc power to the ac power compatible with the utility system's bus. For instance, the New York City demonstrator will convert the 4.8 MW dc power it produces to 4.5 MW ac power.



To fit into existing utility grids, the fuel cell must use utility fuel and produce ac power. Therefore, the complete power plant will include a fuel processor and a power conditioner in addition to the power section. The processor converts utility fuel, such as naphtha or coal-derived fuels, to the requisite hydrogen-rich gas; the conditioner converts dc power to ac power compatible with the utility bus. The New York City demonstrator, for example, will convert 4.8 MW dc power to 4.5 MW ac power.

Benefits and bonuses

The fuel cell power plant promises to be everything a power plant should be, and then some. Because it is not a thermal machine, the fuel cell is not limited by the Carnot cycle. It therefore offers the potential for higher conversion efficiencies and greater fuel conservation than conventional thermal generators are likely to achieve. First-generation fuel cells would have efficiencies of 38–40%, second-generation fuel cells, 45%. In contrast, the efficiency of conventional fossil-fueled generators is in the range of 28–38%. As cell technology advances, these efficiencies are bound to increase, according to Fickett. Also, since fuel cell efficiency is related to individual cell performance rather than generator size, small power plants will be just as efficient as larger ones.

As an added bonus, fuel cells produce reject heat appropriate for making steam or hot water. Therefore, cogeneration with fuel cells is a definite possibility for utilities interested in supplying district heat or industrial process heat. Since fuel cells can be sited close to population centers, the reject heat can be delivered economically to the user. Fickett comments that use of a fuel cell power plant's reject heat could increase its overall efficiency to as high as 90%.

Besides being more efficient than conventional generators, fuel cell power plants maintain their efficiency over a wide range of loads. Whereas conventional power generation equipment is most efficient at rated power and markedly less efficient at part power, the fuel cell power plant is nearly constant in efficiency from 25 to 100% of its rated power output. The fuel cell could therefore be used in a load-following mode, which would permit utilities to dispatch their conventional intermediate or peaking generators at maximum efficiencies. Another good reason to use fuel cells for load following: the cells are quick to respond to load changes. The 4.5 MW demonstrator, for example, will respond within 15 seconds to load changes between 25 and 100% of rated power.

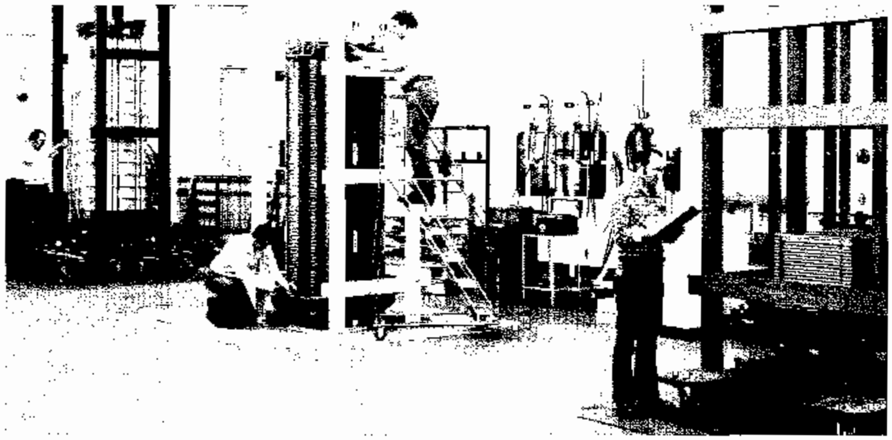
Since fuel cells have no combustion cycle, emissions other than carbon dioxide, air, and water are minimal. Those that do occur originate mainly in the power plant's fuel processor. SO_x emissions will be less than 0.045 g (0.0001 lb) per million Btu and NO_x emissions less than 9 g (0.02 lb) per million Btu if petroleum or clean coal–derived fuels are used—at least an order of magnitude below federal standards. Other good-neighbor characteristics: the fuel cell power plant is expected to be quiet and will not need makeup or cooling water.

Because of their environmental acceptability, fuel cell power plants can be easily sited, particularly near load centers. This dispersibility defers the need for new transmission and distribution investments, including line, substation, and right-of-way costs. A fuel cell next door also reduces the power losses inevitable during transmission.

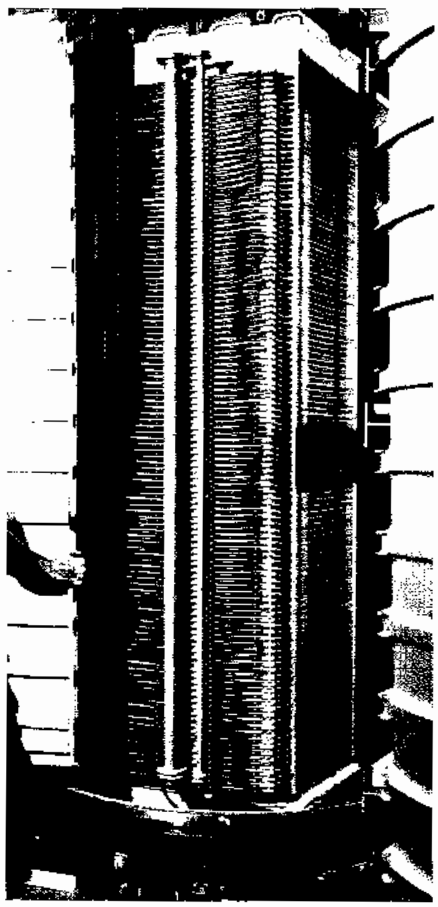
Modularity is yet one more benefit. Virtually all power plant components—fuel processor, power section, power conditioner, control system—will be incorporated into factory-fabricated, mass-produced fuel cell modules. These assembly-line techniques are expected to reduce costs, lead time, and field construction. Once a manufacturing system is established, the time lag from order to completed installation of a power plant would be about 24 months. Additional modules could be added relatively quickly to match increases in demand.

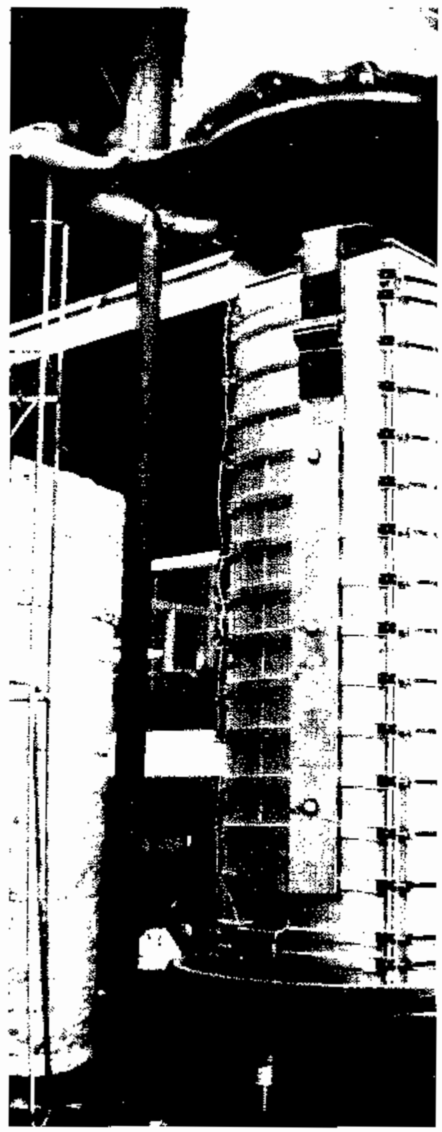
With all these unique attributes, fuel cells should be able to play an important part in electric utility systems. Of special near-term interest are power plants in the 5–25-MW range, to be dispersed as needed for efficient load-following duty. Recovery of reject heat should allow these plants to supply thermal energy as well. And over the longer term, fuel cells could even be integrated with coal gasifiers to function as central station baseload power plants in the 150–600-MW range.

Gas utilities, too, have designs on the fuel cell. With help from the Gas Research Institute, these utilities are actively pursuing smaller fuel cell power plants in the 25–200-kW range. These plants could be installed in commercial or residential buildings and integrated with existing natural gas transmission and distribution systems. Again, these plants could be equipped to recover reject heat, thereby supplying both electric and thermal energy.



UTC technicians assemble individual fuel cells into filter-press configurations, or stacks, to obtain the voltage levels necessary for power generation at the New York City demonstrator. Each stack houses 456 cells. Twenty completed stacks will be connected in series-parallel arrangement, and incorporated into power section modules to be trucked to the downtown site. Modularity, just one fuel cell benefit, will cut back on field construction.





Favorable forecasts

Critics frequently single out questionable fuel availability as a fuel cell drawback. Understandably, the electric utility industry might hesitate to invest in an oil- or gas-fueled technology as the nation moves toward coal and nuclear power. Still, it must recognize that the era of oil and gas is not over. While EPRI forecasts that 80% of the country's electric energy in the year 2000 will be produced by coal and nuclear, at least 10% will still be generated by petroleum and coal liquids and gases. The different fuels have different roles: coal and nuclear will be appropriately assigned to baseload duties; oil and gas, which can be used for a quick response to load changes, will be largely reserved for intermediate and peaking duties. EPRI projects that about 300 GW of oil- or gas-fueled capacity will be in place by 2000 (compared with 170 GW in 1976) to satisfy these cycling needs. Oil will also be called on as a swing fuel, making up unexpected increases in demand or shortfalls in capacity when coal or nuclear plants cannot be installed fast enough. The fuel cell would seem to be the technology of choice for a nation that must be careful about how it uses its limited petroleum and natural gas resources. And in the longer term, the fuel cell would serve to use coal-derived fuels with the highest possible efficiency —a key goal, considering the high cost these fuels will have.

An old curiosity

Although the fuel cell is a modern energy technology option, it is an old concept. It was invented in 1839 but remained little more than a curiosity until the early 1960s, when hydrogen and oxygen fuel cells were developed for use on the Gemini and Apollo spacecraft.

A rush of fuel cell activity followed as companies tried to adapt the fuel cell to more down-to-earth applications, including automobiles and central power stations. By the mid-1960s, some 50 U.S. companies were investigating fuel cells. Progress, however, was slow, and it became apparent that long-term research and development, not a series of sensational breakthroughs, was necessary to harness the fuel cell for truly commercial uses.

By 1968 fuel cell interest was dwindling; most programs had been eliminated or severely pruned back. One firm, Pratt & Whitney Aircraft (now Power Systems Division, United Technologies Corp.), and a group of gas and gas-electric utilities continued a major joint fuel cell program. They initiated the TARGET (team to advance research for gas energy transformation) program in 1967. This effort was aimed at developing phosphoric acid fuel cells for on-site residential and commercial applications, notably the conversion of natural gas to electricity and thermal energy for heating and cooling. As a result of this program, over sixty 12.5-kW power plants were field-tested in 1972–1973, and a 40-kW power plant with reject heat recovery was developed and demonstrated in 1975. The TARGET program has now moved into a product improvement and evaluation phase that could result in the testing of fifty 40-kW power plants between 1979 and 1981. This effort has funding from DOE and the Gas Research Institute.

Electric utilities step in

Along the sidelines, the electric utility industry had been eyeing the fuel cell. In 1971 the Edison Electric Institute (EEI), United Technologies Corp. (UTC), and a group of electric utilities began evaluating the benefits that the fuel cell could bring to the industry.

Significant benefits were identified, and in 1972 the Fuel Cell Generator-1 (FCG-1) program was mounted by UTC and nine utilities. The goal of the program was the development of a 26-MW, first-generation phosphoric acid power plant for commercial service by 1980. Operational targets included a capital cost of $350/kW in 1980 dollars (the stated goal was $185/kW in 1972 dollars), a heat rate of 9000–9300 Btu, a 40,000-hour stack life, and the ability to run on naphtha. In the same year, the industry also began an advanced, second-generation fuel cell technology effort to provide still lower costs, better efficiency, and expanded fuel capability for commercial fuel cell applications in the mid- to late 1980s.

A 1-MW pilot FCG-1 plant was demonstrated successfully in 1976–1977 at UTC's South Windsor, Connecticut, facility. The plant, while not in the packaged, modular form these plants will ultimately take, confirmed that a naphtha-fueled unit could provide electricity to a utility bus, while meeting heat rate, load-following, emissions, and other operational requirements established by the utilities.

However, it was evident that the 1-MW test would not provide enough evidence to confirm the provisional orders that had supported the effort. It would be necessary for utility personnel themselves to get hands-on experience with a larger package operated in a utility network.

By then, money had become a problem. The support required to carry this effort through to commercial introduction of large electric utility power plants was beyond the capability of the private sector. The investment was too high; the payback period too long. The program's proponents turned to the government and EPRI for help.

They got it. In 1976 ERDA (now DOE) and EPRI joined the FCG-1 effort, resulting in a $60 million program to design, fabricate, and test one 4.5-MW ac module of the FCG-1 power plant in 1979–1980. Consolidated Edison Co. of New York, Inc., was chosen as the host utility, and a downtown site in New York City was selected for the demonstration. Site preparation recently began.

The 4.5-MW demonstrator is expected to tie up the loose ends left by the 1-MW pilot plant with respect to the suitability of the fuel cell for utility service. Unlike the smaller plant, the 4.5-MW unit will be fully packaged, with virtually all components organized into modules. Plugged into Consolidated Edison's grid, the demonstrator will be operated by utility personnel, not UTC engineers. The plant's downtown location is expected to verify the fuel cell's unique siting claims. Data on the fuel cell's emissions, noise levels, and general acceptability to its neighbors will be developed. Economic advantages in the form of transmission savings, voltage control, load following, and system reliability will be determined. The program will also verify the FCG-1's operational claims, including those on heat rate, power quality, transient response, and startup-shutdown characteristics.

The only FCG-1 targets the demonstrator is not expected to meet are capital costs and cell stack endurance. Those problems are likely to be solved, however, by 1982, the date when the performance of the demonstrator is expected to be confirmed. Specifically, EPRI and DOE are considering funding a program to improve the first-generation cell stack. If successful, this effort would allow capital costs in production quantities to approach the desired $350/

kW and increase cell stack endurance to the required 40,000 hours.

Critical juncture

At this critical juncture—1982—the first-generation fuel cell power plant could be technologically ready to take its place in the electric utility grid. But this is also when the real difficulties of commercialization begin. The first fuel cell power plants off the assembly line will not cost $350/kW, according to Fickett; they can be offered at that price only after some 500–1500 MW worth have been mass-produced in a factory. More likely the first unit will cost about $1500/kW, with the cost of subsequent units decreasing by about 15% for each doubling of quantity, following a typical product learning curve. The eighth unit, for instance, should therefore cost $920/kW. However, the worth of these units to an electric utility will be somewhere between $330 and $600/kW, depending on such factors as how severely a utility's siting options are restricted.

Even in the best of times, it is unlikely a utility would invest $1500/kW for the first unit of an as yet immature technology. Today, the financing problem is compounded by uncertainties over the national energy policy, future electricity demand, utility rate structure, and fuel supply. If demand wobbled, if petroleum sources dried up, if the federal government adopted a no-oil-imports policy, a utility too quick to buy a fuel cell power plant could get caught with some expensive equipment, useful only at a later date, if at all. Given these circumstances, "today's electric utility industry just isn't a good customer for new energy technologies," admits Fickett. "They're not in a position to take risks with a new technology."

Nor are manufacturers likely to underwrite the 1500-MW learning curve. They could be stuck with vacant factories, unusable spare parts, and workmen to turn away.

Who, then, can help assume the formidable risks that new energy technology commercialization entails? Since the ensuing benefits extend beyond the utilities and the manufacturers and accrue to society as a whole, reasons Fickett, it is appropriate for the federal government to assist the private sector in the commercialization process.

Unfortunately, while the government recognizes the need to encourage new energy technologies, it lacks commercialization experience, according to Fickett. DOE's commercialization office is now making tentative ventures into that area, addressing technologies ready for commercialization, as well as incentives and mechanisms that would expedite the process. In the case of fuel cells, a DOE task force is evaluating various alternatives, including commercialization, for DOE participation beyond the 4.5-MW demonstrator. Congress is also considering supplemental DOE funding, earmarked to assist commercial introduction of the FCG-1.

Downtown Manhattan: future home of the 4.8-MW dc fuel cell demonstrator. Host utility, Consolidated Edison Co. of New York, Inc., has already begun site preparation at this 35,000-ft^2 lot. The power plant itself is expected to occupy only about 25% of that space; the remainder will permit easy access to the plant for demonstration activities.

No promises

At this time, however, solid promises of grants, price supports, product warranties, or any other mechanism that would help usher the fuel cell into the marketplace have yet to materialize. Even if the federal government does decide to assist commercialization, it could be a difficult proposition because UTC is the only fuel cell manufacturer in evidence. The government must be careful not to place any firm in a position that could eliminate competition from other companies at a later date.

To support the government's fuel cell effort, utilities have considered formation of a commercialization corporation. The activities of such a technology-user group could range from promoting the needs and benefits of fuel cells to the purchase of fuel cell systems.

All these plans, however, require time—time for the government to explore commercialization, time for the utilities to rally. Meanwhile, the fuel cell trail is in danger of growing cold. Fickett fears that unless an effective way to commercialize the fuel cell is developed within the next year or two, private industry may be forced to scuttle the entire first-generation effort. Some $200 million has been invested to date in the development of fuel cell power plant technology. It would make no sense, Fickett concedes, to continue funneling money into a technology—however promising—that has scant hopes of ever seeing commercial service.

Risk in the Pursuit of Benefit

In a wooded setting in Seattle, EPRI's Advisory Council explores the risks to environment and health from energy production.

"Every morning we're awakened by the clock radio to hear reports of a new risk—from unsafe tires to red dye in meat," observed Joseph Coates of the congressional Office of Technology Assessment.

"The scope and speed of technology development is heightening awareness and concern over risk," Coates added when delivering what was considered the most provocative talk at EPRI's annual Advisory Council Summer Seminar.

Held this year at the Battelle Conference Center in a relaxed, wooded park in Seattle, the four-day conference on environmental and health aspects of energy production was attended by some 75 participants and interested observers. Discussion topics ranged from the health effects of fossil fuel combustion through the economic implications of environmental protection to the ethical aspects of risk-benefit analysis.

Coates said that in becoming a major source of research funds the federal government has indirectly become a chief source of knowledge. Also, it has become a main disseminator of information, in which function Coates charged, "The government is a disaster. You can't get an even-handed account from government. In fact, government has become a major propagator of uncertainty." In this connection he cited, in general, the rulings of the Occupational Safety and Health Administration.

"Sometimes there is a conflict among government risk managers," Coates asserted, "and their responses are often inadequate." He spoke of a hearing in Utah held by a government regulatory agency that was intended to elicit public testimony. He said the regulators responded to the public witnesses "like leftovers from Mount Rushmore." Not very responsive.

Coates found particular fault with the agencies responsible for the regulation of nuclear power. He said the Atomic Energy Commission (AEC) and its successor agencies "have failed to tell the public in a timely way what was known and what was needed to be known about nuclear energy. The worst enemy of nuclear power has been the nuclear establishment itself. The government generally carries on a bittersweet relationship with the facts, telling the facts in a way that government managers think the facts ought to be heard."

Tailored information

Coates's strong views prompted a barrage of replies from the conferees. Walter Marshall, deputy chairman of the United Kingdom Atomic Energy Authority, allowed that Coates's remarks were "quite provocative," but he disagreed that "the AEC had not been forthcoming." Marshall granted that there is a difference in style between regulatory agencies in the United States and Great Britain. "U.S. agencies tend to wrap meaningless language around the facts," he noted, adding, "but I do not believe the AEC was trying to conceal the facts." Marshall went on to say, however, that the nuclear establishment in the United States "has tended to be too analytical and has not taken into account the public's feelings or perceptions about nuclear power."

Coates's rejoinder to Marshall was that there was no lack of "information" from the AEC. "The government dumps tons of data on the public," he said, "but much of the information is useless. It needs interpretation. Information is no good if it is not understandable."

William Nierenberg, director of Scripps Institution of Oceanography and a former Advisory Council member, drew laughter when he said, "It's unfair to single out the AEC. Every regulatory agency is less than forthcoming."

Merril Eisenbud, director of the Laboratory for Environmental Studies at New York University Medical Center and also a former member of the Advisory Council, defended the AEC for doing "a good job." Said Eisenbud, "I don't think it's the responsibility of government to make information easily available and clearly understandable to the public. Agencies such as the AEC (now part of DOE) should not interpret their own reports. That should be done by a third party."

Joseph Swidler, a prominent Washington attorney and a former chairman of the Federal Power Commission, who was instrumental in founding EPRI, said he was familiar with the regulatory hearing in Utah that Coates referred to. He commented, "In the highly judicialized decision-making process that regulatory agencies work within, it is especially difficult for regulators to be responsive when dealing with a public that doesn't know what it wants. Pressure group influence makes it difficult for public agencies to determine what the public really wants." He added that "the town meeting approach to making single-issue decisions often reveals a misinformed public." He offered as an example of public misinformation his witnessing an antinuclear demonstration in the San Francisco Bay Area where the demonstrators were claiming that the utility involved "owned" the Nuclear Regulatory Commission.

Chauncey Starr, EPRI vice chairman, agreed with Coates that "regulatory agencies have tended to tailor their decisions to fit their own interests."

Full disclosure

In his own presentation on risk-benefit analysis, Starr pointed out that the decisions made by a society on how it allocates its resources determine the number and quality of that society's social benefits. And there is a continuous stream of such decisions that must be made, almost always accompanied by uncertainty or risk. "Risk-benefit analysis is designed to guide the decision maker in the direction of the most beneficial choices for society," Starr explained.

He noted that in the United States "the balance between social goals and individual rights is continuously shifting by virtue of legislation and court decisions, the balance itself representative of a public value system. A method is needed for interpreting consensus social values, relating trade-offs between various social objectives. Risk-benefit analysis is a method for dealing with some of these trade-offs, those in which risks are significant factors."

Starr stated, "Past societal risk-taking has been based on *perceived* risks and benefits. We now have evidence that these perceptions do not correlate with

Radford: "Calculated risks do not put nuclear power at a disadvantage as far as public health is concerned."

statistical risk estimates. The success of a society in achieving its goals is determined in part by the degree to which perceptions reflect reality. To the extent that perceptions lag behind reality, resource misallocations will result."

He made note of a necessary step for decision making in a democracy—full disclosure of the decision makers' interpretation of values and risks, including the risks of all options under consideration. Said Starr, "Only through the feedback obtained from these disclosures do we avoid the institutionalization of minority values. We deserve to know in whose interest those decisions are being made. And we need assurance that all identifiable consequences of any action have been fully considered."

Bringing a fresh, intriguing viewpoint to the discussion of risk-benefit analysis was Margaret Maxey, associate professor of bioethics at the University of Detroit. She called for a refocus of the concept of hazards and a revision of the notion of risk, the methods used to measure probabilities, and the criteria that determine social acceptability of risk.

"There are ill-considered and needless problems that have resulted from limiting the concept of risk to negative consequences of human activities," she said. "This exclusive focus misrepresents the fundamental fact that all human activity entails risk-taking, and its primary motivating force is the foreseen and intended benefit that can be gained or lost by the activity." Maxey continued, "In any concrete situation, what is actually at risk is the benefit to be gained or lost. If risk assessment is to reflect real conditions, it ought to be primarily a measure of the probability of benefit acquired or foregone, and only secondarily a measure of the unwanted and unintended harm entailed." Current risk assessment methods, she claimed, pay "distorted attention" to hazards.

"The trouble with specialized hazard identification and increasingly sensitive assessment methods," Maxey continued, "is that they leave untouched the central managerial problem: action in the face of

Coates: "The scope and speed of technology development is heightening concern over risk."

Starr: "We need assurance that all identifiable consequences of any action have been fully considered."

and despite uncertainties. Uncertainty rather than the benefit or harm of outcomes is the index for the decision maker."

Maxey noted that "hard technology is so established and taken for granted that there is no longer any question about its acceptability. So technology has not needed to account for itself." She sees our technologies as "the embodiment of profound human values, of human aspirations not to capitulate to or remain at the mercy of the caprice of nature, and of a determination to extend human well-being on a global scale for the first time in human history." She believes technology assessment that "reduces itself to mere risk analysis and cost-benefit estimates and fails to make explicit the ethical values and principles embodied in technology development is a travesty."

Maxey offered criteria for assessing safety. "Because safety is not an intrinsic property that some product or system can and should possess but a value judgment based on personal and social priorities," she said, "a sensible guideline for allocating public monies would be this: When cost-risk-benefit ratios make it clear that a point of diminishing returns on investment of time and money has been reached by comparison with other potential hazards, then the particular product or process under scrutiny is 'safe enough.'"

Risk guidelines

In presenting summary data and guidelines relating to health risks from electricity generation, Cyril Comar, director of EPRI's Environmental Assessment Department, promised that he would oversimplify. By way of general oversimplification, Comar said that "large risks ought to be banned, small risks ignored, and in-between risks should be studied." He offered these guidelines:

- Eliminate any large risk that carries no benefit or is easily avoided

- Eliminate any large risk (about 1 in 10,000 per year or greater) that does not carry clearly overriding benefits

- Ignore for the time being any small risk (about 1 in 100,000 per year or less)

- Actively study risks that fall between the above-cited limits with the view that the risk of any proposed action should be weighed against the risk of not taking that action.

Comar presented a list of examples of 1 in 100,000 risks, among them the possibility of liver cancer from eating 400 tablespoons of peanut butter, lung cancer from smoking 10 cigarettes, accidental death from traveling 600 miles by car or 4000 miles by plane.

Among other statistical data presented, Comar gave figures on the estimated risk of premature deaths in 100,000 risks from cancer or respiratory disease as the result of exposure to emissions from a 1000-MW coal-burning power plant compared with the same capacity nuclear fueled plant: 2–100 from the coal plant; 0.01–0.2 from the nuclear plant. He observed that the public appears to be more fearful of cancer than of respiratory disease, and consequently there is greater public concern over the possible effects from nuclear power plants than from coal-fired plants, despite the statistical evidence.

Leonard Sagan, manager of EPRI's Biomedical Studies Program, commented his experience suggests that "people are more concerned with reducing pain and suffering than they are with prolonging life. And nuclear power is associated in the public mind with cancer from radiation, which would cause pain and suffering. So public fear of nuclear power appears to be connected with fear of pain and suffering from cancer rather than with a conscious desire to prolong life."

The success of the English in reducing air pollution in Great Britain and the resultant decline in chronic bronchitis and other respiratory diseases was reported by Patrick Lawther, director of air pollution research at St. Bartholomew's Hospital Medical College in London. Lawther, who laced his talk with humor (including Monty Python quips), noted that the disastrous London smog of 1952, partially created by air pollution and causing some 4000 deaths, was so thick and pervasive that cinemas closed because infiltrating smog obscured the screens. There has been a steady reduction in air pollution since the mid-1950s when British authorities started banning the burning of soft coal, with a corresponding falloff in the incidence of respiratory ailments.

In a group of chronic bronchitis patients Lawther has been studying for many years, he has noted a steady improvement in their condition, which he credits to a reduction of particulate matter in the ambient air. Although he traces the main cause of chronic bronchitis in his patient group to respirable particulates, Lawther pointed out that particulate matter has a complex composition, and he illustrated his point with slides that showed the microscopic particulates varying greatly in size and shape.

Lawther stressed the point that the British have achieved cleaner air "without regulatory ambient air standards. It has been done simply by regulating the kind of fuels burned." Lawther was confident that present air pollution levels in Great Britain are not a significant cause of disease.

Criteria and standards

The process by which the Environmental Protection Agency (EPA) arrives at its criteria documents was discussed by Richard Dowd, director of EPA's Science Advisory Board. EPA's scientific credibility, Dowd said, rests on this advisory panel of some 80 scientists grouped into a half-dozen committees who review and determine the scientific soundness of criteria documents before they are published. Dowd gave an example of the review process in the case of EPA's criteria document on lead, a toxic substance. The advisory panel subcommittee charged with passing on the document rejected it as inadequate on first review in January 1977. The revised version was judged an improvement, but still not adequate when reviewed again in June that year.

The science advisers offered suggestions for improvement that EPA incorporated in the third draft, which after further changes was approved and published in October 1977.

Dowd explained that the criteria documents are not themselves standards. "Their purpose is to describe the probable effects of exposure to a given toxic substance at specified dosages. They are an important part of the standard-setting process." These documents should contain the latest scientific data, he stressed, adding, "The prime concern of EPA in regulating hazardous substances is health effects, not economics." But he noted, "There needs to be a reasonable time gap between discovery of evidence of potential adverse health effects from a substance and the setting in motion of regulatory action." Time is often an economic factor.

Dowd told the conferees that the Toxic Substances Control Act of 1976, which gave EPA its mandate to regulate toxic materials, "has the potential for changing the standards ball game, because EPA will now be looking at pollutants it hasn't investigated before." He cited hazardous air pollutants such as polycyclic organic materials (POMs) and coke oven emissions as examples.

Comar asked Dowd how EPA goes about screening out "bad science." Dowd replied that he questioned the "bad" characterization of some of the science. He saw the problem rather as "bad application of science that could result in bad policy."

Starr reflected the feeling of many of the participants when he asked Dowd, somewhat rhetorically, why EPA "does not go back to Congress and seek to change the National Environmental Policy Act to make it more workable."

Edward Radford, professor of environmental epidemiology at the University of Pittsburgh, commented that "everyone had high hopes for EPA, but disappointment has followed. For all its criteria documents, EPA hasn't come up with new evidence on which to base any real changes in air quality standards."

Radiation and cancer

Radford's own talk on the biological effects of radiation was preceded by a brief, slide-illustrated history of radiation and of our knowledge of its powers to heal and to harm. The presentation was by Eisenbud, one of the early industrial health and safety specialists in the country.

Radford reported on a mass of data on health effects of radiation, primarily cancer induction, from a worldwide study by the United Nations Scientific Committee on Effects of Atomic Radiation, a similar study that focused on the United States by the National Academy of Sciences committee he chairs, and other sources. Among the groups in the studies are survivors of the Hiroshima and Nagasaki atomic bombs, Swedish and American uranium miners, and patients receiving radiation treatment for breast cancer, mastitis, and spinalitis.

Definite conclusions are difficult to draw, Radford observed, as there are so many variables. Among other things, the effects of radiation depend on the kind of radiation, duration of exposure, age of the person irradiated, level of dosage, and existing ailments at time of exposure. Radford said that analysis of the growing mass of data supports the long-recognized fact that "radiation is an effective agent for producing cancer in humans. And new information, much of it obtained since 1971, strongly suggests that radiation at low dosage produces cancer."

Comar, previous chairman of the National Academy of Sciences committee Radford now heads and a current member of the committee, noted, "There is still controversy over cancer production at levels near background." He added, "Calculated risks, using upper estimates of effects from recent data, do not put nuclear power at a disadvantage compared with coal burning as far as public health is concerned."

Radford further stated that researchers are now able to differentiate and compare the effects of different types of radiation—alpha as compared with gamma rays, for instance. He added, "I think we will be in a position to make some biological sense out of all this in time."

Other speakers at the conference included Ellis Cowling, professor of plant pathology and forest resources at North Carolina State University, who characterized his topic, acid rain, as "a dominant feature of man-induced change in the environment and a new arena of conflict." Cowling has been calling for a nationwide network of acid rain monitoring stations. "We need a monitoring system to tell us what's coming down from the atmosphere," he said, "and a government that cares what happens to it after it falls."

Joseph Rosenbaum, a consulting metallurgist for the U.S. Bureau of Mines, discussed the hazards, constraints, and controls in uranium mining and milling. The dimensions and technological solutions to the problem of nuclear waste disposal were dealt with by Allison Platt, manager of nuclear waste technology for Battelle, Pacific Northwest Laboratories. Oceanographer Charles Keeling of Scripps Institution of Oceanography reported on what is known, not known, and speculated about the global problem of the increasing levels of carbon dioxide in the atmosphere. The effects of power plant cooling systems and how to put waste heat to work were treated by Charles Coutant, an aquatic ecologist and leader of the power plant effects project at Oak Ridge National Laboratory.

On the fourth and final day, the role of the federal government in setting environmental policy was discussed by Robert Trumbule, head of the environment division of the Congressional Research Service. Fred Hahn, assistant director of the Office of External Affairs in the Department of Ecology, State of Washington, gave his views on the role of state government in matters of environmental policy, and Lewis Perl, vice president of National Economic Research Associates in New York, reviewed the economic implications of environmental protection.

EPRI Inventions

The fundamental aim of EPRI's patent policy is to foster the commercial availability of inventions resulting from research.

As a center of research and development in the public interest, EPRI has assumed an obligation to make the results of its work available to the public. Publishing research reports is often sufficient. But EPRI's research yields more than information. Sometimes it yields a new process or device that can increase the availability of electric power, make its production and delivery more efficient and less costly, or reduce or eliminate potential environmental problems.

What to do with such potentially useful inventions poses a policy question. Since EPRI and its members are not manufacturers and marketers of such advances, why not simply dedicate them to the public? Wouldn't this satisfy the need for public availability?

Henry Darius, EPRI's corporate secretary, explains why EPRI seeks patent protection for its more promising inventions. As Darius points out, "Theoretical availability of an invention is not the same as true commercial availability." To the average consumer, for example, having the recipe for a chemical process, such as a coal liquefaction process, is not the same as being able to buy the liquefied fuel from a commercial supplier. If no one is manufacturing and marketing a new device or process on a commercial scale, it is not really available to all who could benefit from it directly or indirectly.

Consequently, EPRI believes it has a responsibility to encourage commercial development of its inventions rather than leaving their development to chance. Carrying out this responsibility is the main objective of EPRI's patent program. This policy also implies specific benefits for EPRI, its members, and the public at large.

Incentive to commercialize

The marketplace has shown that an invention in the public domain is often of little commercial interest. No business wants to risk the large sums usually needed to develop an invention commercially only to find that the new product, once perfected, is being freely copied by competitors. For example, suppose Company A is considering investing several millions of dollars to develop a new type of electric storage battery invented by EPRI and dedicated to the public. Company B could enter the market, copy the battery down to the last detail, and then sell the battery for less than Company A because it would have no development costs to recover.

Imagine, in contrast, that EPRI invents such a battery, patents it, and then licenses Company A to manufacture and sell it. This license, which can give Company A certain protections against poaching by unlicensed rivals, would provide Company A with greater incentives to make the new battery commercially available.

Quality control

A second benefit of the EPRI patent program is quality control. After EPRI's staff and its contractors have put many hours of high-quality work into developing a new technology, EPRI generally wants to see appropriate quality standards maintained in development, manufacturing, and marketing. As the holder of patent rights, EPRI has the opportunity to build certain quality safeguards into its licensing arrangements.

Exchange opportunities

A third advantage of seeking patent protection for EPRI's inventions is the bargaining power it provides when a certain process or device is only one link in a manufacturing chain. For example, suppose that Company A wants to manufacture EPRI's new battery but cannot do so without using a special metal alloy patented by Z Corporation. EPRI might be able to gain rights to Z's patented alloy in exchange for rights to one or more of EPRI's own inventions. EPRI could then offer Company A a more complete and hence more commercially viable licensing package.

Defensive protection

Patenting an invention is also a way of making sure that no one else can gain exclusive control. There is a potential danger that another company could apply for a patent on that invention and then block public access to its use. For example, the patent holder might choose to withhold it from the market because it would threaten sales of his own established product line. Or he might offer it only at a prohibitively high price. In either case, the consumers could lose their right of true access to EPRI's research.

Royalties

The fifth benefit of EPRI's patent program is the royalty income that may be generated.

EPRI seeks relatively modest royalties from its licensing program because EPRI's members represent a major market for its inventions. These members and the rate-paying public helped to fund the research that made the inventions possible. Also, EPRI's low royalties support the fundamental aim of making its research results widely available.

The commercial outlook

Some EPRI inventions have already reached the marketplace. The May 1978 issue of the *EPRI Journal* (p. 12) covered the story of EPRI's sensor response-time hardware for nuclear power plants, a device that has now been licensed for commercial production and sale. Similarly, the high-intensity ionizer promises to be one of the more significant breakthroughs in EPRI's research so far. When combined with a conventional electrostatic precipitator, this device can greatly increase the efficiency and lower the costs of particulate collection from stack emissions, especially those from coal-fired plants. Commercial use of the high-intensity ionizer can help achieve the twin national goals of greater utilization of coal and maintenance of clean air.

Through the careful encouragement of commercial development, other EPRI inventions also promise to benefit both the electric utility industry and the public. Yet EPRI's licensing effort is not without certain restrictions.

Restrictions on licensing

Because EPRI carries on research in the public interest, the results of its work, including its patents, must be made available to the public on a nondiscriminatory basis. This means that EPRI ordinarily will not grant one company a license for a certain patented invention and refuse licenses to others.

As mentioned earlier, this presents a practical difficulty: a licensee will usually be more eager to bear the financial risks of developing a new EPRI-invented product if the licensee's rights to that invention are exclusive, at least for a limited period of time. If other licensees can obtain the same rights, then the first licensee—unless it possesses special knowledge or other proprietary rights—will have no security, even temporarily, against poaching by its market rivals. The upshot, at least where major development investments are required, is that some potential licensees will probably be discouraged from entering the market under a nonexclusive license, a fact that could impair EPRI's ability to encourage the commercialization of its inventions.

However, if the granting of an exclusive right is the only practicable manner in which an invention can be utilized to benefit the public, then granting an exclusive license may be proper, at least for a period of time sufficient to enable the licensee to recover a substantial portion of his development investment.

Inventions now available

The first step in EPRI's licensing effort is a public announcement of the invention's availability. After each new EPRI patent application is accepted for filing by the U.S. Patent Office in Washington, the *Journal* will publish a notice of availability and provide a brief description of the invention.

The list on page 58 includes all the EPRI inventions that are now available for licensing. Of the total 226 inventions, patents have been issued for 34; patents are pending for 192. ■

EPRI Patents

ELECTRICAL SYSTEMS

AC Overhead Transmission

A Method for Forming Zinc Oxide-Containing Ceramics by Hot Pressing and Annealing
U.S. patent pending (KD0657-01-02)

A Setter for a Ceramic Body and Methods of Formation and Use
U.S. patent pending (KD0657-01-06)

A Voltage-Limiting Composition and Method of Fabricating the Same
U.S. patent pending (KD0657-01-04)

Chemically Activated Switch
U.S. patent pending (KD0281-02-09)

Circuit Interrupter Using a Minimum of Dielectric Liquid
U.S. patent pending (KD0478-01-02)

Circuit Interrupter Using a Dielectric Liquid with Energy Storage
U.S. patent pending (KD0478-01-03)

Combustible Gas-in-Oil Detector
U.S. Patent No. 4,058,373 (KD0748-01-01)

Current Interrupter Electrode Configuration
U.S. patent pending (KD0564-01-03)

Current Interrupter for Fault Current Limiter and Method
U.S. patent pending (KD0281-02-10)

Current-Limiting Circuit Arrangement
U.S. patent pending (KD0654-01-01)

Explosively Activated Fault Current Limiter
U.S. patent pending (KD0281-02-07)

Fault-Current-Limiting Resistor
U.S. patent pending (KD0281-02-01)

Filled Polymer Electrical Insulator
U.S. patent pending (ED1203-76-55)

Hermetic Quick Connection and Seal for Coupling Low-Pressure Systems

High-Voltage Overhead Electrical Transmission Cable Protected from Wet-Environment Corona Losses
U.S. patent pending (ED0068-76-47)

High-Voltage Plain-Break Circuit Interrupter
U.S. patent pending (KD0655-01-04)

High-Voltage Two-Stage Triggered Vacuum Gap
U.S. patent pending (KD0754-01-01)

Improved Current Limiter Vacuum Envelope
U.S. patent pending (KD0564-01-08)

Improved Fault Current Limiter
U.S. patent pending (KD0654-76-36)

Method and Apparatus for Sensing the Clearance of Fault Current on an AC Transmission Line
U.S. patent pending (KD0281-02-02)

Method for the Nondestructive Testing of Voltage Limiting Blocks
U.S. patent pending (KD0657-01-01)

Repulsion Coil Actuator for High-Speed, High-Power Circuits
U.S. Patent No. 4,086,645 (KD0564-01-09)

Structurally Improved Rod Array Vacuum Interrupter
U.S. patent pending (KD0754-01-03)

Temperature-Sensing Device
U.S. patent pending (KD0479-01-01)

Tiered, Convoluted, Shielded Insulators
U.S. patent pending (ED1203-75-16)

Vacuum Arc Current-Switching Device
U.S. patent pending (ED0476-76-28)

Vacuum-Arc-Switching Device With Internal Shielding
U.S. patent pending (KD0564-01-02)

Vacuum Envelope for Current Limiter
U.S. patent pending (KD0564-01-04)

Vacuum Interrupter Configuration
(ED0564-76-43)

Voltage Regulator Utilizing a VAR Generator With Half-Period Averaging and Saturating-type Firing Angle
U.S. patent pending (KD0750-01-02)

DC Transmission

Electronic Current Transducer for High-Voltage Transmission Lines
U.S. patent pending (KD0668-01-02)

Light-Activated Semiconductor Device Package Unit
U.S. patent pending (KD0669-01-01)

Method and Means for Trapping Particles in Enclosed High-Voltage Electric Bus Apparatus
U.S. Patent No. 4,029,892 (KD0213-01-06)

Multigate Light-Fired Thyristor and Method
U.S. patent pending (KD0669-01-07)

Package for Light-Triggered Thyristor
U.S. patent pending (KD0567-01-03)

Particle-Trapping Elbow Joint for Enclosed High-Voltage Electric Bus Apparatus
U.S. Patent No. 4,029,890 (KD0213-01-13)

Particle-Trapping Sheath Coupling for Enclosed Electric Bus Apparatus
U.S. Patent No. 4,029,891 (KD0213-01-08)

Particle-Trapping Sheath Coupling for Enclosed Electric Bus Apparatus
U.S. Patent No. 4,042,774 (KD0213-01-15)

Rapid Response Generating Voltmeters
U.S. Patent No. 4,054,835 (KD0213-01-16)

Self-Protection Against Breakover Turn-On Failure in Thyristors Through Selective Base Lifetime Control
U.S. patent pending (KD0669-01-02)

Stab Connector for Enclosed Electric Bus Apparatus
U.S. Patent No. 4,082,933 (KD0213-01-12)

Thyristor Device With Self-Protection Against

Transformer Cascade for Powering Electronics on High-Voltage Transmission Lines
U.S. Patent No. 4,087,701 (KD0668-01-01)

Distribution

Current Limiting Fuse Construction and Method
U.S. patent pending (KD0428-01-03)

Current-Limiting Fuse With Resinous Arc-Quenching Filler
U.S. patent pending (KD0428-01-02)

Electrical Apparatus
U.S. patent pending (KD0930-01-05)

Overpressure Protection for Vaporization-Cooled Electrical Apparatus
U.S. patent pending (KD0930-01-12)

System for Detecting Foreign Particles and Voids in Plastic Material and Method
U.S. patent pending (KD0794-01-01)

System for Detecting Foreign Particles or Voids in Electrical Cable Insulation and Method
U.S. patent pending (KD0794-01-02)

Vaporization-Cooled and -Insulated Electrical Apparatus
U.S. patent pending (KD0930-01-14)

Vaporization-Cooled Electrical Apparatus
U.S. patent pending (KD0930-01-11)

Vaporization-Cooled Electrical Apparatus
U.S. patent pending (KD0930-01-15)

Vaporization-Cooled Electrical Apparatus
U.S. patent pending (KD0930-01-21)

Vaporization-Cooled Electrical Inductive Apparatus
U.S. patent pending (KD0930-01-17)

Rotating Electrical Machinery

A Stored-Field Superconducting Electrical

Improved Superconducting Hybrid Magnetic Flux Pump
U.S. patent pending (ED0563-75-15)

Method and Apparatus for Cooling a Winding in the Rotor of an Electrical Machine
U.S. patent pending (KD0429-02-02)

Multiphasic Pump for Rotating Cryogenic Machinery
U.S. patent pending (KD0429-01-02)

Sliding Support for a Superconducting Generator Rotor
U.S. Patent No. 4,092,555 (KD0429-01-01)

Spiral Pancake Winding for Two-Pole Electrical Machine, Specifically, Turbine Generator
U.S. patent pending (KD0429-01-06)

Superconducting Generator and Method
U.S. patent pending (KD0429-01-09)

Superconducting-Generator Thermal-Radiation Shield Having Substantially Uniform Temperature
U.S. patent pending (KD0429-02-01)

Underground Transmission

Backfilling Material and Method of Preparation Thereof
U.S. patent pending (KD7841-01-01)

Cutter for Corrugated Pipe for Flexible Gas Insulated Transmission Line
U.S. Patent No. 4,078,304 (KD7837-01-01)

Cutter for Helically Corrugated Tube for Flexible Gas-Insulated Cable
U.S. Patent No. 4,063,355 (KD7837-01-03)

Evaporation-Cooled Transmission Line System
U.S. Patent No. 4,091,230 (ED7834-75-12)

Extruded Sheath Section for Compressed-Gas-Insulated Transmission Lines
U.S. patent pending (KD7840-01-02)

Improved Transmission Line Breakdown Voltage
U.S. patent pending (ED7835-75-08)

Sodium-Filled Flexible Transmission Cable
U.S. Patent No. 4,056,679 (KD7837-01-02)

Termination for Stranded Cable
U.S. patent pending (KD7837-01-05)

Welded Joint in Segmented Sheath for Compressed-Gas-Insulated Transmission Lines
U.S. patent pending (KD7840-01-03)

Multiprograms

Arc Spinner Interrupter With Chromium Arcing Contact
U.S. patent pending (KD0661-01-07)

Arc Spinner Interrupter With Contact Follower
U.S. patent pending (KD0661-01-06)

Hybrid Power Circuit Breaker
U.S. patent pending (KD0661-01-01)

Moving Contact for Localized Gas-Flow Arc Spinner-type Interrupter
U.S. patent pending (KD0661-01-05)

Thin Arc Runner for Arc Spinner Interrupter
U.S. patent pending (KD0661-01-03)

FOSSIL FUEL AND ADVANCED SYSTEMS

Air Quality Control

Apparatus and Method for Ionizing Gases, Electrostatically Charging Particles, and Electrostatically Charging Particles or Ionizing Gases for Removing Contaminants From Gas Streams
U.S. patent pending (KD0386-01-01)

Assembly for and Method of Sampling Particle-Laden Fluids and a Cascade Impactor Used Therewith
U.S. patent pending (KD0414-01-01)

Convective Heat Transfer Steam Boiler for Fuels of Low Energy and Ash Content
U.S. patent pending (ED0265-75-07)

Focusing Electrodes for High-Intensity Ionizer Stage of Electrostatic Precipitator

Field-Testing a New Planning Concept

A new utility planning model developed by EPRI is designed to deal with future demand uncertainty. Sixty Northwest utility representatives tested and refined it at a workshop in Portland, Oregon.

More than 60 representatives from public and private utilities in the Pacific Northwest met in Portland, Oregon, July 26 to take a close, critical look at a new utility planning concept developed by EPRI's Energy Analysis and Environment Division. They were there to test and refine a planning model designed to deal with future demand uncertainty.

When planning future capacity in today's social and economic environment, electric utilities are venturing deep into uncharted territory. They are challenged by a bewildering number of unknowns headed by uncertain demand. Others include unknown fuel supply conditions, escalating fuel prices, lengthening lead times for installation of various electricity generation systems, financing uncertainties, technological changes, increasing environmental concerns, and political considerations.

At best it is a hazardous journey. To help anticipate some of the perils inherent in mapping the course, EPRI, working closely with utility planners, has developed the innovative planning model described in the May 1978 issue of the *EPRI Journal* (pp. 6–11).

Differences

Although the new concept complements conventional planning, there are a number of variations. For example, it does not attempt to establish generating requirements for a specific demand for a given year. Instead, it establishes requirements for a probable range of demand. Planning lines or curves that plot capacity requirements over time are replaced by open "fans" that represent a probable range of future demand.

"Since utilities are faced with more uncertainties each year in their system planning, we have tried to build a balanced model that treats many of those uncertainties," explains Jerry Karaganis, former project manager in the EPRI Systems Program. (Karaganis now manages modeling and economic research for the Edison Electric Institute.)

The new approach puts a heavy emphasis on the planning reserve margin, which is the extra generating capacity that must be available to ensure overall adequacy of the electric system. It does not call for the highly detailed scheduling that is characteristic of conventional capacity planning models. As a result, the EPRI model is more adaptable to computer use. "We model toward the simple side to keep costs down," says Karaganis.

The new system simulates the sequential decisions that utilities must make to carry planned additions from initial studies through licensing to actual construction and startup. It enables utilities to track these decisions on a yearly basis and thus review and revise their planning when necessary. A modular design allows specific parts of the model to be expanded to suit the characteristics of a particular utility system.

How does it work?

It looks good on paper, but how will it work out in the real world, facing real utility planning problems? Will it be accepted by utility planners, who have compiled a very good track record over the past six decades?

The answers to these questions and others are being generated by taking the model to utilities and getting their reactions and their ideas.

"The ideal way for us to generate new software technology for the industry is to work directly with utilities to build the product," Karaganis says. "For those utilities that have not participated in a project, the best way to transfer technology is through workshops. These afford us an opportunity to get immediate feedback. They function as instantaneous software pilot plants. Then, when the product is refined, we distribute it to the rest of our members through reports and computer tapes."

The Portland workshop was cohosted by the Bonneville Power Administration (BPA) and Pacific Power & Light Co. (PP&L). Before the meeting, BPA put EPRI's new planning model on its computers and applied it to the demand forecasts of the West Group area, a large region within the Western Systems Coordinating Council. The range of least-cost planning reserve margins suggested by the EPRI model compared favorably with the capacity expansion recommendations of the previously completed

West Group planning study. "The results of both systems were well within the same ball park," according to Karaganis.

The EPRI model was run on a large and diverse region, rather than a one-utility system, to provide a broader example that included utility operating environments familiar to all the workshop delegates. Karaganis explained, however, that the model is particularly well-suited for individual utility use.

Reactions

There was plenty of feedback. Reactions varied from very favorable to very skeptical. Many thought the new model was too simple and therefore could not be accurate. In a way, they were right because this model is not designed to suggest a specific planning reserve margin. Its purpose is to describe a range of probable reserve margins. Within its range, it proved to be accurate.

In the West Group utility area, hydroelectric modeling is very complicated. It was pointed out that this portion of the EPRI model was in need of modification. Such is the workshop debugging process.

"We don't conduct workshops to constant applause," Karaganis says. "These are not lecture sessions. They are designed to generate an interchange of ideas . . . to help us get the bugs out of the new concept. To do this we try to apply our model to systems with which the participants are familiar to encourage them to take shots at it. We all benefit from such exchanges."

A large part of the afternoon was devoted to two panels. One covered the special characteristics of modeling hydroelectric energy sources. The other dealt with the intricacies of modeling uncertain demand.

Increased understanding

Karaganis noticed that the understanding of the new model increased substantially as the day wore on—as the workshop participants aired their concerns and became more familiar with the system.

"We are indebted to all our workshop delegates for their participation and their inputs, but particularly to BPA for developing and presenting the workshop case study that was used and to PP&L for hosting the meeting," Karaganis said.

Workshops were held with the New York Power Pool and the New England Power Pool in May 1978. They, too, proved very productive.

What's next? There will be more workshops, as needed. There will be a final report describing the model and utility reactions at the workshops and from the subsequent use of the model by utilities on their own systems. Computer tapes of the model with working examples are now available through EPRI's Energy Analysis and Environment Division.

Then on to the next phase, when the model will be used to estimate the effects of both demand (kW) and total electric energy (kWh) needs on facility expansion decisions. ■

Key workshop planners: (from left) Clifford Watkins, Bonneville Power Administration; Nancy Bord, Pacific Power & Light Co.; and Jerry Karaganis, former project manager in the EPRI Systems Program. Workshop panel: Don Hoffard, Bonneville Power Administration; Michael Warwick, Pacific Power & Light Co.; Lloyd Meyers, The Washington Water Power Co.; David Hoff, Puget Sound Power & Light Co.; and Tom Keelin and Edward Cazelet of Decision Focus, Inc., utility industry planning consultants.

Margaret Maxey: The Ethical Eye

A bioethicist shares her intriguing intellectual vision on the ethical dilemmas of nuclear waste disposal.

Margaret Maxey is an intense person with passionately held views, vigorously expressed.

"If the public understood that all the radioactive waste that would be generated by nuclear reactors producing electricity to the year 2000 would constitute one ten-millionth of a percent of the total toxic elements naturally occurring in the earth's crust," she has said, "then the problem would be seen for what it is—belonging in the land of Lilliput!"

Grounded in scholastic philosophy and disciplined by Jesuit training at Creighton and St. Louis universities and the University of San Francisco, with a doctorate in Christian ethics from Union Theological Seminary, Maxey is an educator in the relatively new field of bioethics. An associate professor of bioethics at the University of Detroit, she has written and lectured extensively and is a consultant on the ethical considerations of nuclear waste management. Maxey, a recent addition to EPRI's Advisory Council, presented a paper on risk and ethics that stimulated considerable interest at the Advisory Council's summer seminar in Seattle. She took time out between sessions for a *Journal* interview. Although new to the Council, Maxey says she is "impressed by the sensitivity of EPRI management to the concerns expressed by the Advisory Council. This is actually a responsible way in which the public interest is being represented in a very open and, I think, influential manner."

"Evidently, the public has yet to comprehend the fact that safety is not an intrinsic property, measured by achieving zero risk."

Bioethics defined

Bioethics does not lend itself to simple definition. Maxey describes ethics as "a systematic philosophical analysis of moral value judgments and choices," while bioethics, she explains, is concerned with "a total system of conditions affecting the public health and safety of living things, primarily human beings."

Maxey believes that "because of the awesome range and power with which human actions may affect the global environment for generations, traditional neighbor ethics—expressed in such values as justice, truthfulness, respect for individual rights—is simply inadequate to define criteria for the human good." Thus the need for a total-system bioethics, she contends, that relates the natural world to the man-made world. And within that system is what is known as public ethics, from which flow the ethical criteria for decision making.

Unlike social ethics, which deals with the proper ordering of human communities and with shaping long-term changes in social policies, public ethics, according to Maxey, must meet a different set of requirements: Public ethics must deal with a specific problem calling for a particular public decision; that problem must be pressing and must be quickly resolved; and the required decision must not be intended or expected to change the social order.

Identifying policy options, then defending or criticizing them, and finally ranking those options in some order of ethically preferable choices are among the tasks confronting those concerned with public ethics. The ranking of policy alternatives "necessarily involves assessing risks against benefits, weighing social and economic costs against benefits, and balancing a hypothetical against a verifiable erosion of the quality of life," notes Maxey.

"Far from being merely crass utilitarian trade-offs," she stresses, "these exercises in human judgment are a necessity for responsible, ethical decision making. To the extent that politics is the art of the possible, public ethicists endeavor to practice the art of discerning the morally preferable among the practical possibilities. It remains to be seen how these sometimes conflicting choices relate to likewise conflicting assessments of technology and its effect on the environment."

Ethics and radioactive waste

Maxey cites nuclear power technology as a prime example of a current problem whose alleged moral and ethical issues are causing heated debate and confusion among the public. What Maxey sees as "the environmental crisis mentality" constitutes the main issue that needs to be dealt with: How are we to recover and maintain some perspective, some corrective in public perception, that will introduce a balanced judgment about alleged hazards from radiation sources in our present cultural climate of crisis?

"The nature of the nuclear waste problem is neither unique nor unprecedented. We have always lived with toxic elements in our environment."

Maxey points out, "If unacceptable risks to our environmental quality were to be measured in terms of the half-life or rate of decay of toxic elements or their potential for lethal dose commitments to a population, then we would have long since undertaken permanent geologic burial of mercury, lead, arsenic, chromium, and chlorine, whose half-life is infinite." And she goes on to say that the radioactive waste problem stems not from scientific or technological considerations but "from public misperceptions of the risks involved and the ease with which those misperceptions have been exploited by those who have chosen to politicize the nuclear energy option of this nation."

Maxey has joined the controversy over radioactive waste with characteristic verve and intellectual discipline. Her expertise has led to her work as a consultant on the ethical aspects of nuclear waste disposal with the University of California's Lawrence Livermore Laboratory and Teknekron, Inc., a Washington, D.C., energy consulting firm. Maxey's published articles and studies in the field include "Radwastes and Public Ethics: Issues and Imperatives," "A Bioethical Perspective on Acceptable Risk Criteria for Nuclear Waste Management," "Nuclear Energy Politics: Moralism vs. Ethics," and "Radiation Protection Philosophy: Bioethical Problems and Priorities."

In the interest of restoring some balance to a public perception of alleged hazards, Maxey offers four precepts:

First, the degree of risk from any biohazard must be measured in terms of clearly defined conditions under which exposure can be calculated. The index of risk is not mere presence, but rather the likelihood of exposure.

Second, the risk cannot be said to exist unless or until a potential biohazard is able to enter into, travel along, and remain unobstructed and undiluted by environmental pathways to life.

Third, any potentially adverse health effects must be defined in relation to a significant dose received by individuals. If any upper numerical limit to dosage can be set, it should be an ambient radiation standard for specific occupational fields that exist where individuals can be monitored for any noteworthy health effects. If a dose in relation to ambience is high, it is measurable and controllable. If it is low, it is lost in the background.

Fourth, future populations will not make intentional intrusions on an underground repository; individuals will. Individuals would be exposed to a source of radiation, not populations.

Not safety alone

Maxey observes, "Evidently, the public has yet to comprehend the fact that safety is not an intrinsic property, measured by achieving zero risk. It is a subjective, relativistic, evolving, shifting judgment based on each person's current value priorities. The public can never divest itself of risks. It can only judge their acceptability. There are as many judgments as there are people and priorities."

As Maxey sees it, "The problem of radioactive management is only symptomatic of a much deeper problem: How is the public decision-making process to be made more ethically responsible in serving the common social good? How can it provide a more just and balanced protection of the general public's health and safety? How can a corrective be applied to an inherently deficient social mechanism—the regulatory agency?"

A consensus must be reached on the answer to the fundamental question: How much safety are we willing and able to pay for? "If we are to avoid excessively costly and destructive policy decisions made by regulatory agencies, decisions that are in conflict with the common good of the many, the public must be educated to reallocate the financial and social costs of safety. Zero risk and absolute safety are indeed costly illusions."

Maxey concludes, "The nature of the nuclear waste problem is neither unique nor unprecedented. We have always lived with toxic elements in our environment, and they have not been sequestered with the skill and planning applied to radioactive wastes.

"As an ethical imperative, criteria for acceptable risk must avoid two potential extremes: capitulation to the requirements dictated by a vocal minority whose values and priorities neglect basic necessities of the living majority; and excessive preoccupation with imaginable risks to future generations whose claim on the intellectual and moral responsibility of existing persons has not yet been clearly defined. Man does not live by safety alone. The ultimate challenge is to rediscover what else we live by."

The real target

Maxey perceives that the real purpose of many of those organized against nuclear energy is to dismantle the corporation as a seat of power. "What animates environmental and consumer advocacy movements," she says, "is really a drive to reform our entire society so that somehow the corporation will disappear from the face of the earth."

And she sees the electric utility industry, because of its pervasiveness and our dependence on electric power, as "a lightning rod attracting those who are critics of technology" and as the target of those seeking to quash the corporation. "To look at the struggle over nuclear power in any other light," Maxey says, "is to miss the central issue." ■

At the Institute

Fuel Cells

During a recent task force meeting of the EPRI Energy Management and Utilization Technology Department, members viewed the fuel cell facility of United Technologies Corp. in South Windsor, Connecticut. UTC's William Lueckel (second from left) explains the details of one of 20 fuel cell stacks being readied for the 4.8-MW fuel cell demonstration, which is planned for late 1979 in New York. Looking on (left to right) are Paul Robb, Potomac Electric Power Co.; (Lueckel); Task Force Chairman Orin Zimmerman, Portland General Electric Co.; Sid Naylor, Boston Edison Co.; and John Kekela, Ohio Edison Co.

Computer Workshop

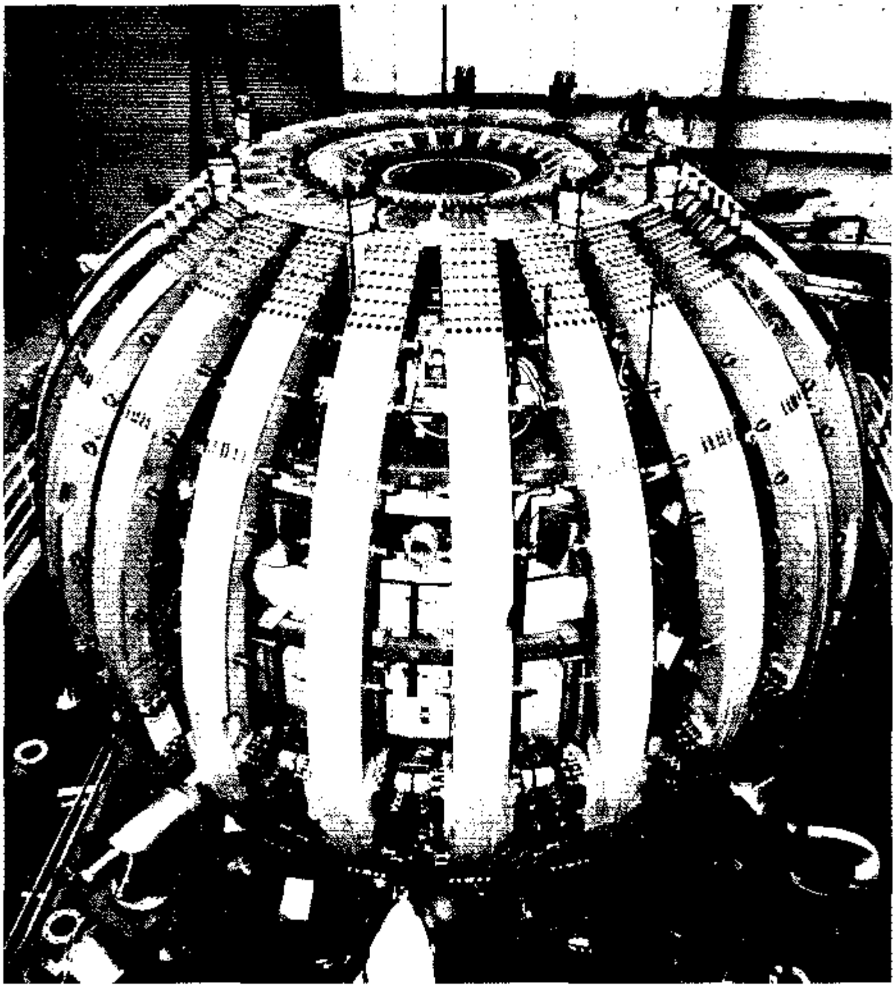
Representatives of utilities and equipment manufacturers and Stanford graduate students attended a recent workshop on the BIGIF computer program. This program, developed by Failure Analysis Associates (an EPRI contractor), predicts the lifetime of cracked structures in power plants. During the workshop, which was cosponsored by EPRI and Stanford University, Philip M. Besuner of FAA explained the result of a BIGIF calculation on a turbine rotor crack to L. Erik Titland, Baltimore Gas and Electric Co. (foreground); Dave Burns, Washington Public Power Supply System; Michael Kolar, EPRI program engineer; A. P. Rochino, General Public Utilities Service Corp.; and Sri K. Sinha, Consolidated Edison Co. of New York, Inc.

Pressure Vessel Group

Some 37 experts on nuclear pressure vessels and piping recently attended the semiannual meeting of the Pressure Vessel Study Group at EPRI headquarters in Palo Alto, California. Participants included experts from Germany, France, the United Kingdom, Japan, and the U.S. Nuclear Regulatory Commission, as well as representatives from reactor vendors and universities. Discussing the results of recent experiments on the pressure vessel safety research being conducted by Karl Kussmaul and coworkers are (from left) Dietmar Strum, Staatliche Materialprüfungsanstalt, Stuttgart, Germany; Theodore Marston, EPRI; Karl Kussmaul, Staatliche Materialprüfungsanstalt; and Robin Jones, EPRI. The meeting also featured discussions of national pressure vessel research programs in the United States and the United Kingdom. Progress was made toward increased research cooperation, program coordination, and data exchange among the participants, reports EPRI Program Manager Karl Stahlkopf, who organized the meeting.

Doublet III Dedicated

The world's largest operating magnetic confinement device, Doublet III, which was designed under EPRI support and built and operated by General Atomic Co. for DOE, was dedicated in September at GA headquarters in San Diego. The $30 million fusion research machine is designed to achieve (probably in the early 1980s) the physics conditions necessary for a practical fusion reaction that can be used for electric power production. Doublet III, which looks like a bulging birdcage, weighs about 500 tons, with most of its weight in copper coils. It is 4.9 m (16 ft) high and 5.8 m (19 ft) in diameter.



Project Highlights

Process Converts Sulfur Dioxide From Stack Gases Into Sulfur

A new process for converting SO_2 from power plant stack gases into potentially marketable sulfur is being demonstrated at a utility coal-fired boiler in West Germany, EPRI announced recently.

The $4.1 million demonstration effort is being funded by EPRI, the Federal Republic of Germany, and contractors Foster Wheeler Energy Corp., Deutsche Babcock AG, Steag AG, and Bergbau-Forschung GmbH.

The demonstration plant uses activated carbon to remove SO_2 from the gas and then employs a process called Resox (a registered trademark of Foster Wheeler Energy Corp.) to convert the SO_2 to elemental sulfur.

In the Resox process, a stream of concentrated SO_2 is passed through a bed of crushed coal at 649–816°C (1200–1500°F). The SO_2 reacts with the coal to form elemental sulfur and CO_2. Like other sulfur-producing processes, Resox eliminates the production of sludge and associated disposal problems. (Sludge is a by-product in conventional cleaning of stack gases from fossil fuel power plants.)

Though other sulfur-producing processes also eliminate the production of sludge and associated disposal problems, Resox has an advantage in that it uses coal rather than natural gas to reduce the SO_2. Natural gas is thus conserved for higher priority uses, such as home heating.

"The Resox process is part of EPRI's program to develop a sulfur-producing process that is both competitive with the least costly desulfurization methods used today and free of most environmental drawbacks," reports EPRI Program Manager George Preston.

He adds that EPRI plans to demonstrate a sulfur-dioxide removal process in combination with Resox on a commercial scale by late 1983. One of the aims of the EPRI program is to develop a simple process that has long-term reliability.

The demonstration work is being done at a utility plant in Lünen, West Germany, because of the availability of a concentrated SO_2 stream from the SO_2 removal system previously developed at the site by Bergbau-Forschung.

Large-Scale Demonstration of Coal Liquid

The nation's first large-scale combustion demonstration with a synthetic liquid fuel made from coal began in mid-September at a generating station of Consolidated Edison Co. of New York, Inc.

Under an EPRI contract, KVB, Inc., of Tustin, California (a subsidiary of Research-Cottrell), is performing an engineering and emissions assessment during the combustion of solvent-refined coal distillate (SRC-II) at the host utility's 74th Street station in Manhattan. Consolidated Edison, a cofunder, is coordinating KVB's activities.

Studying SRC-II's combustion performance and emission characteristics is important because these are two major factors that affect the eventual commercialization of this fuel, reports EPRI Project Manager William Rovesti. One of the ways researchers will study these characteristics is by making comparison tests with petroleum fuel. Researchers will burn about 4000 barrels of the synthetic coal liquid during the several days of testing.

Consolidated Edison's Chairman of the Board Charles Luce, who was instrumental in the formation of EPRI and is a member of its Board of Directors, says, "The development of SRC-II technology is a very important national program in the interest of the country, the electric utilities, and our millions of customers. As a potential alternative to conventional petroleum fuels for use in utility boilers, SRC-II—a low-ash, low-sulfur product—could lessen U.S. dependence on imported oil."

The Consolidated Edison demonstration burn follows smaller-scale EPRI tests with SRC-II at the Alliance Research

EPRI Negotiates 44 Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP209-3	Maintenance of Stack Gas Emission Control Coordination Center and Inquiry Service	1 year	30.0	Battelle, Columbus Laboratories *T. Morasky*
RP323-3	Key EPR Design Tasks, Phase 2	18 months	580.0	General Atomic Co. *D. Paul*
RP929-2	Geothermal Reservoir Assessment Techniques	26 months	41.8	Stanford University *V. Roberts*
RP984-2	Vibration Analysis of Rotating Auxiliary Machinery	17 months	133.0	Kenneth Medearis Associates *J. Dimmer*
RP1034-1	Cycling of High-Pressure-Steam Power-Generating Units With Drum Boilers	18 months	564.7	Tennessee Valley Authority *J. Parkes and J. Dimmer*
RP1079-1	Baseline Data on Utilization of Low-Grade Fuels in Gas Turbine Applications	1 year	563.0	Florida Power & Light Co. *R. Duncan*
RP1180-8	Impact of Future Environmental Regulations	7 months	29.9	Radian Corp. *S. Baruch*
RP1187-2	High-Reliability Gas-Turbine Combined-Cycle Development	1 year	545.0	Westinghouse Electric Corp. *R. Duncan*
RP1260-4	Evaluation of the Use of Ozone in Cooling Towers	4 months	15.0	Brown & Caldwell *R. Jorden*
RP1263-1	Disposal of Polychlorinated Biphenyls and PCB-Contaminated Materials	5 months	186.8	SCS Engineers *D. Golden*
RP1266-5	Assessment of Current Nondestructive Tube Inspection Techniques	8 months	49.7	The Reluxtrol Co. *J. Dimmer*
RP1319-3	Advanced Cooling Techniques: Full-Scale Engine Demonstration, Phase 1-U	2 months	70.0	United Technologies Corp. *A. Cohn*
Nuclear Power Division				
RP506-6	Integration of Enrichment Program Reports	4 months	9.1	COE Associates *M. Lapides*
RP1167-2	Chemistry of Corrosion-Producing Salts	31 months	279.0	Babcock & Wilcox Co. *T. Passell*
RP1167-3	Denting Simulation Studies	3 years	147.2	Centre Belge d'Etude de la Corrosion *T. Passell*
RP1175-3	Transuranics and Other Radionuclides in Gaseous Effluents From LWRs	1 year	55.4	LFE Environmental Analysis Laboratories *H. Till*
RP1175-4	Transuranics and Other Radionuclides in Gaseous Effluents From LWRs	1 year	39.2	Science Applications, Inc. *H. Till*
RP1229-1	Hydraulic Investigation of a 4 × 6 Rod Bundle	1 year	123.7	Babcock & Wilcox Co. *D. Cain*
RP1233-1	Probabilistic Reactor Safety Studies	2 years	1252.2	Science Applications, Inc. *G. Lellouche*
RP1233-3	Probabilistic Accident Analysis—ATWS	2 months	52.2	Babcock & Wilcox Co. *G. Lellouche*
RP1246-1	Acoustic Monitoring of Power Plant Valves	2 years	300.0	Technology for Energy Corp. *G. Shugars*
RP1253-2	Breeder Reactor External Fuel Cycle	9 months	40.0	General Electric Co. *R. Williams*

Center of Babcock & Wilcox Co. in June and earlier tests by Gulf Mineral Resources Co. at the KVB laboratory in Los Angeles.

SRC-II is a direct coal liquefaction process in which a coal-derived solvent and hydrogen react with coal to transform it into a solids-containing liquid product, which is then distilled and condensed into a liquid fuel. The SRC-II process was developed by Gulf under DOE sponsorship and is owned by the government. The fuel, which is being supplied for the test program by DOE, was produced at a pilot plant operated by Gulf near Tacoma, Washington.

SRC-II is an outgrowth of direct coal liquefaction technology, which originally developed SRC-I, a clean-burning solid fuel produced from coal. SRC-I was burned in a demonstration at Georgia Power Co. in 1977.

The current demonstration is envisioned as one of a series using liquid and solid synthetic fuels as they become available from processes now under development by EPRI, the government, and industry.

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1254-1	Analysis of the Thorium-Fueled Core in the Indian Point-1 Reactor	1 year	98.8	Babcock & Wilcox Co. *W. Eich*
RP1320-1	LWR Sensitivity Analysis Using Advanced RETRAN Models	2 months	20.0	Nuclear Associates International, Inc. *J. Naser*
RP1324-1	Evaluation of Pipe Whip Analysis Capability	4 months	27.6	Hibbitt & Karlsson, Inc. *H. Tang*
RP1330-1	Radwaste Evaporator Pretreatment by Ultrafiltration	16 months	75.0	TERA Corp. *A. Miller*
RP1330-2	Radwaste Evaporator Pretreatment by Ultrafiltration	16 months	128.0	Walden Division of ABCOR, Inc. *A. Miller*
RP1330-3	Radwaste Evaporator Pretreatment by Ultrafiltration	5 months	49.3	ABCOR, Inc. *A. Miller*

Electrical Systems Division

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP797-2	Computer Simulation of Faulted URD Cables	1 year	61.1	Georgia Institute of Technology *T. Kendrew*
RP1205-1	Research on Geomagnetic-Induced Currents	2 years	50.0	Minnesota Power & Light Co. *J. Porter*
RP1291-1	Advanced Thyristor Valve Development	3 years	1000.3	General Electric Co. *I. Vancers*
RP1353-1	Reliability Indices for Power Systems	2 years	261.4	General Electric Co. *M. Bhavaraju*
RP1355-1	Design of Multiprocessor Structures for Simulation of Power System Dynamics	11 months	50.0	Northwestern University *D. Koenig*
RP1360-1	Fault Analysis in Gas-Insulated Equipment	2 years	388.0	Ontario Hydro *V. Tahiliani*
RP7840-3	Three-Conductor Gas Cable Field Demonstration	42 months	581.1	Westinghouse Electric Corp. *J. Shimshock*

Energy Analysis and Environment Division

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP862-12	Lidar Measurement of Pollutants in the SURE Program	7 months	129.6	SRI International *G. Hilst*
RP1104-2	Economic Value to Consumers of Electricity Supply Reliability	13 months	68.0	Resource Planning Associates, Inc. *R. Riley*
RP1109-3	Modeling Support for Adirondack Lakes Acidification Study	18 months	99.8	Tetra Tech, Inc. *R. Goldstein*
RP1145-2	Scenarios for the Introduction of Light Electric Vehicles	10 months	39.0	University of California at Berkeley *A. Lawrence*
RP1147-2	Labor Relations and Coal Production	13 months	37.0	Brophy Associates, Inc. *J. Chamberlin*
RP1148-1	Development of Information Base for Technology Status	11 months	185.8	TERA Corp. *J. Chamberlin*
RP1212-2	Electrical Loads for Specific Industrial Processes: Response to Cogeneration Incentives and Time-of-Use Pricing	14 months	300.4	Gordian Associates, Inc. *A. Lawrence*
RP1215-1	Effects of Natural Gas Curtailments on Industrial Demand for Electricity	5 months	170.0	Resource Planning Associates, Inc. *L. Williams*
RP1300-2	Regional Data Base for Support of Electricity Supply Projects	14 months	146.1	Boeing Computer Services, Inc. *R. Riley*

Washington Report

District Heating: Translating the Swedish Experience

Enthusiastic about its own successful experience with district heating systems, Sweden would like to spark similar interest within the U.S. energy community and boost bilateral trade. In October a group of Swedish industry, trade, and government officials held district heating workshops in six U.S. cities. Included in the program was discussion of a DOE-funded study on a district heating plan for the cities of Minneapolis and St. Paul.

An underlying theme of the workshops was that the United States could realize energy savings, as well as economic and environmental benefits similar to those enjoyed by Sweden, if the use of district heating is expanded in this country. Although a number of U.S. energy officials question whether exact comparisons can be made because of economic, institutional, and technical differences between the two countries, workshop attendees exhibited considerable interest in Sweden's approach to the technology.

District heating is not unknown in this country. In fact, the world's first district heating plant was built in 1877 in Lockport, New York. Today, however, the technology accounts for less that 1% of total U.S. energy demand. In contrast, many northern European countries have accelerated their use of the technology in the past 25 years.

District heating involves the centralized production of heat energy and its distribution through pipes to provide space and hot water heating for homes, businesses, and industries within a certain area. In the United States, the heat is distributed as steam; in Sweden, hot water. District heating can be part of a cogeneration process, a technological enterprise of increasing popularity with administration officials and one singled out for favorable comment in President Carter's April 20, 1977, energy message. When district heating is included in cogeneration, both heat and electricity are produced at the same central plant.

At the first district heating workshop in Washington, D.C., on October 10, DOE Under Secretary for Commercialization Jackson Gouraud welcomed the Swedish visitors and assured the attendees that his staff would be trying to "get a handle" on district heating by further analysis of opportunities for wider use of the technology in this country. A task force headed by Gouraud has just completed identifying various technologies judged as top candidates for commercialization, and although district heating was not included on the list, cogeneration was.

Economics as prime mover

Throughout the workshop, Swedish speakers stressed the economic incentives for district heating. "Cold economic factors have been the prime mover for the development of district heating in Sweden and for the design and operation of combined heat and power plants," stated Pär Hollertz, Stal–Laval Turbin Ab. Officials admitted that Sweden has been forced to look for economic energy technology because of its heavy dependence on imported fossil fuels. In 1977, for example, Sweden imported 75% of the energy it consumed. Oil is the predominant fuel used for heating. "Interest in district heating was therefore awakened in Sweden at a very early stage," commented Bertil Köhler of Ab Energikonsult.

Speakers stressed that district heating is economic because of its overall efficiency and its opportunities to run on a variety of fuels. Carl-Erik Lind of Sweden's National Board of Industry told workshop attendees that the practical efficiency for district heating systems is about 80%, calculated on a fuel's net heat value. This efficiency applies both to heat-only and to cogeneration systems. Lind compared this with a 50–70% efficiency for most individual oil-fired boilers heating one-family houses or apartments.

District heating systems can run on fuels other than costly oil and natural gas. In the United States, that might mean coal or perhaps even nuclear power. In Sweden, it might mean heavy fuel oil rather than light fuel oil.

Cost, however, can be an initial obstacle to district heating development, the Swedish experts admitted. "The crucial point for district heating from the profit point of view is the cost for distribution and the distribution heat losses," said Lind. The distribution costs have to be kept below a certain level for district heating to be economic.

Tomas Bruce, a utility official from the City of Södertälje Energy Authority, explained that distribution costs depend heavily on the load density of a potential district heating area. Low-density areas require an extensive—and thus expensive—distribution system. "It is therefore natural," he noted, "that district heating is most advantageous in high-density urban developments." In Sweden, downtown high-rise buildings offer good possibilities for the introduction of district heating, whereas single-family houses are less favorable. New buildings offer better economic prospects than older structures because of the expense involved in retrofit. "In Sweden, district heating systems always start in new, built-up areas or in remodeled city core areas," said Erik Wahlman, Theorell & Martin Energikonsulter Ab.

Step by step

Because of the initial expenses involved in building the distribution system and because costs drop as more customers are connected to the system, Sweden has adopted a step-by-step approach to district heating.

"To start small and build up in modular sizes has proved to be the key to success," said Pär Hollertz. In the early days of a system, when the load is relatively small, mobile boilers provide heat for the customers in a given area. Although compact and relatively inexpensive (and therefore desirable in early stages), these boilers are not as efficient as the more permanent ones. As the number of subscribers to a system increases, large hot water boilers of a more permanent nature are built. Later, when demand justifies, a large cogenerating plant may replace the heat-only boilers.

A final step may be district heating on a wider, regional basis, supplied by cogeneration plants run on nuclear power. This progression from small, portable boilers to large permanent plants postpones the heavy financial investment in a district heating system until there are sufficient subscribers to support it. Each step helps to raise capital for the next larger investment.

The Swedes believe that standardization is a key to keeping costs down. Hollertz reported that turbines in three sizes—26, 45, and 100 MW (e)—are used in most cogeneration district heating plants.

New products have also been a cost-saving factor. Swedish industry representatives described such products as flexible pipes made of temperature-resistant plastic and insulation composed of polyurethane.

Environmental advantages rank side-by-side wih economics in justifying district heating systems, the Swedish experts emphasized. Among the environmental benefits listed by Lind were more efficient supervision of the emissions; dilution of emissions by using taller stacks; opportunities for installing more efficient air-cleaning equipment; special supervision of operation; possibilities to use waste heat from industries; and fewer oil-transporting trucks on the streets.

Sweden had a ready-made institutional pattern for handling the organization of district heating when it was first introduced into the country. Although electric power is produced by about a dozen major power utilities, its distribution within urban areas is controlled by municipalities. These community-owned enterprises serve about 70% of all electric consumers, and they produce and distribute hot water also. It was natural, therefore, for district heating to be a municipality function. Today there are some 55 district heating utilities, all community-owned.

The Swedish government has supported the expansion of district heating systems through various legislative and funding actions. Even before the oil crisis increased the economic attractiveness of energy conservation, the government subsidized a major portion of the costs for subscribers to connect to a district heating system. Various measures enacted since then have increased government support. As an incentive for subscribing to a system, Peter Margen of Studsvik Energiteknik Ab reported, Swedish district heating utilities offer consumers rates that equal the lowest cost of alternative suppliers.

Twin Cities system

Margen presented perhaps the most salient address of the workshop in terms of district heating application in the United States. Margen's company (formerly Ab Atomenergi) is conducting a DOE-funded study coordinated by Oak Ridge National Laboratory on techniques and possibilities for introducing district heating on a large regional scale in the Twin Cities area, Minneapolis–St. Paul, Minnesota. Although the final study results are not expected until later this year, Margen reported interim findings that regional district heating holds great promise for the Twin Cities area.

The Twin Cities area exhibits many attributes that render it suitable for district heating, he explained. Its cold climate and concentrated downtown areas offer a large potential load. The area currently depends heavily on natural gas and oil for heating, and these fuels will become increasingly scarce and costly. Coal-fired generating facilities with units suitable for cogeneration exist nearby. There is some tradition for district heating the area (three small steam-based systems), but these systems are not so extensive as to strongly influence future technology. Also, local authorities and utilities have shown a desire to improve fuel use and reduce air pollution.

The interim plan prepared by Studsvik for the Twin Cities calls for a district heating system that would meet 83% of the heat demand from the densest parts of both cities, including downtown sections, commercial and apartment house areas, and nearby sections of two-family homes. The system would also meet 70% of the heat demand from less-dense residential areas in nearby suburbs with one-family houses.

The system would distribute hot water produced from existing electricity-generating equipment converted for co-generation and from new, heat-only boilers. Initially, hot water pipes would be laid under the dense downtown area and expanded outward. Development would be parallel in both Minneapolis and St. Paul, and eventually the systems would be integrated.

The interim results of Studsvik's cost-benefit analysis show that district heating could save the two cities between $55 million and $207 million in areas of dense population over the 1981–2000 period, depending on interest rates and fuel price escalation. In these same areas, the interim results also indicate a fuel savings of 57 million barrels of oil and natural gas.

Fees and rates

Margen identified several institutional issues that are being studied by U.S. teams. He said local permit fees for pipe laying or production plant operation could become an obstacle to the healthy growth of the system and recommended that the fees reflect the benefits of district heating in terms of fuel conservation and environmental protection. These same considerations should be acknowledged when rates for consumers are set so that consumers are not penalized economically by connection to the new system.

In general, however, the Swedish expert found the interim results very encouraging: "If the economics are as good as they appear from the studies made to date, the rest is really merely a question of good will, give and take in negotiations, and common sense."

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

SOLAR HEATING AND COOLING

In seeking to maximize energy displacement (substitution of renewable for scarce sources) in individual buildings, many solar heating and cooling (SHAC) experiments have neglected the associated impact on utility load factors and economics. The potential for widespread, near-term introduction of solar heating and cooling of buildings, coupled with the potential for positive or adverse effects on load factors, makes SHAC an area of great importance to the electric utility industry. The residential and commercial sectors use about 25% of the nation's total energy, most of which is for space comfort control and water heating. Current EPRI projections indicate that SHAC might become competitive in the 1980–1985 time frame, and by 2000 the market penetration of solar systems could reach 10% of total space heating and cooling of buildings (2% of U.S. energy consumption). Reports from U.S. government agencies and their contractors have given even higher estimates—some as high as 20–25%. Some states are promulgating laws whose objectives are to reach those levels of penetration. Many SHAC systems will use electricity as their auxiliary energy source.

The SHAC subprogram of EPRI's Solar Program has been structured to examine the impact of widespread SHAC application on electric loads and on utility cost of supply and consequent rate levels. The principal objectives of the subprogram are to:

- Develop and demonstrate "preferred" systems, components, and modes of operation
- Evaluate the impact of SHAC applications on electric utility planning, operations, and economics
- Provide government solar energy programs with information about solar–electric utility interface requirements

The subprogram incorporates a step-by-step approach to accommodating energy load shifting as well as energy displacement. Topics include energy conservation in building design, improvements in SHAC technology, use of integrated energy storage and off-peak power for load management, and solar augmentation. Using analytic and experimental approaches, EPRI aims to develop computerized tools and data to help utilities identify what the preferred SHAC equipment configurations are for their individual service territories.

A configuration qualifies as preferred if it minimizes the customer's costs for his total energy needs and allows the utility to manage its load in a way that results in reduced capacity requirements. Such a configuration of solar, storage, and conventional equipment takes into account that the load center (residential or commercial) is an integral part or extension of its supporting utility systems.

Figure 1 shows the major components of a residential heating, ventilating, and air conditioning (HVAC) system. It shows that there

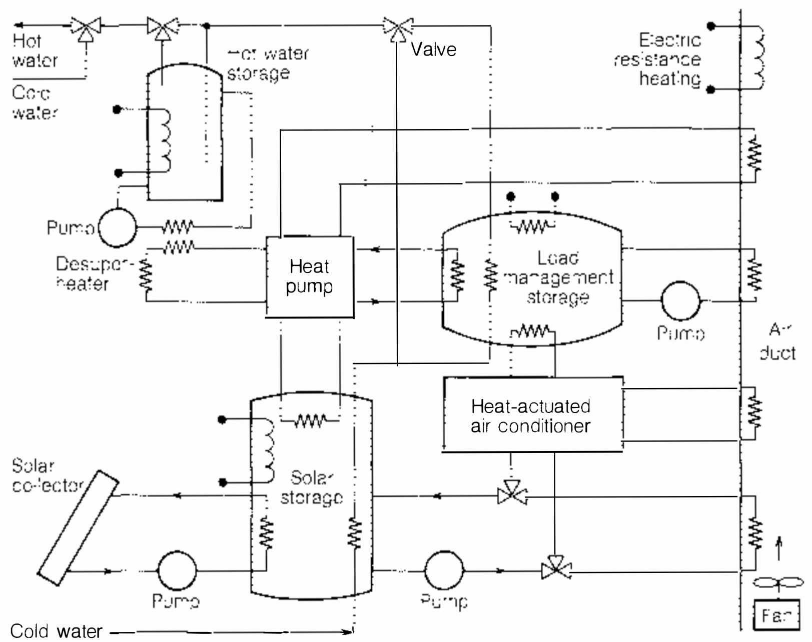
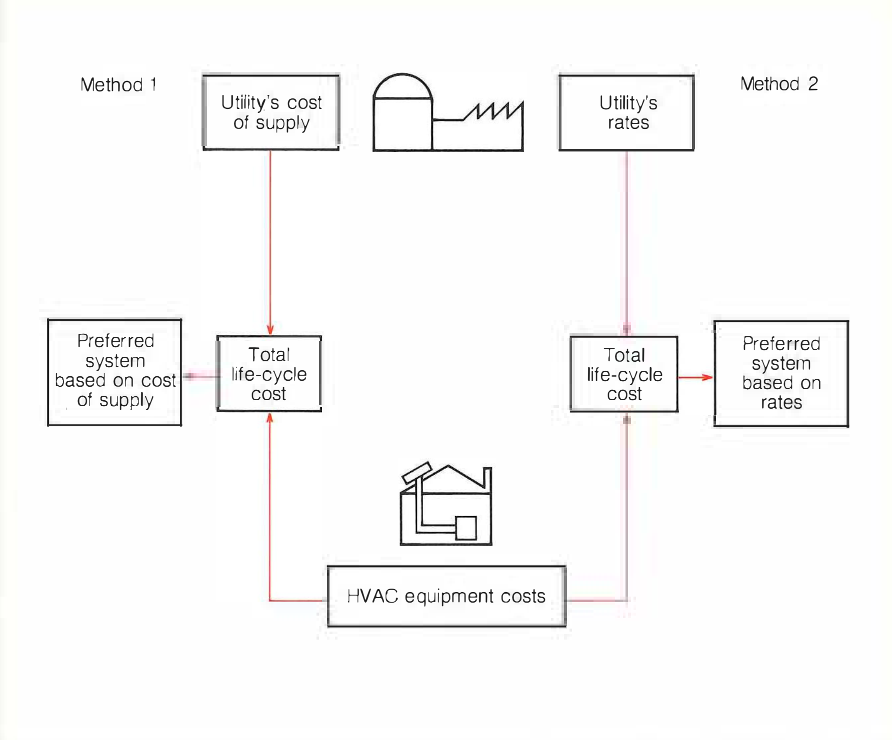


Figure 1 Generalized schematic of a residential, solar-augmented heating, ventilating, and air conditioning (HVAC) system. In practice, many options exist for combining the elements shown—use of more than one heat pump and more or fewer storage tanks, for example.

are scores of possible combinations and configurations of the components. For example, the system could use an integrated tank rather than separate tanks for solar and load-managed storage, or individual heat pumps could be used instead of the multimode unit depicted. Collector area, storage volume, piping sizes, and circulating-fluid options are other variables. The amount of insulation in house walls, ceilings, and floors, the extent of window area, and the mode of wall construction all help determine the needs for space heating and cooling. It is no small task to decide on the particular solar system configuration that best meets the needs of a building in a given climate condition.

Fortunately, the decision process lends itself to automation. Arthur D. Little, Inc. (ADL) has developed a computer program that analyzes the impact of specific SHAC system configurations on buildings typical of those in a utility's territory (RP926). The program—EPRI Methodology for Preferred Solar Systems (EMPSS)—is available for such an analysis. Factoring in utility economic data, the program analyzes SHAC options on the basis of both a utility's rate schedule and its cost-of-supply data. This feature, depicted in Figure 2, allows the user to determine whether a current or planned rate structure will adequately cover the utility's cost of supplying supplementary energy to its solar customers. This capability makes the EPRI-developed computer code unique among those available for solar simulations.

Figure 2 There are two methods available to the EMPSS program user for determining the preferred solar system configurations—one based on the utility's cost of supply and the other based on the utility's rates. In this way, EMPSS can assist utilities in examining possible rate alternatives.



There are many computer programs available for analyzing SHAC systems. Some have even incorporated simplified economic analyses to help the homeowner determine the payback period—the time it takes for energy savings to equal equipment costs. Some of these programs, as well as more sophisticated analytic codes, have been developed for the federal government and are in the public domain. These codes (TRNSYS, F–CHART, SOLCOST) are widely used by solar equipment distributors to help them size the components for particular applications.

However, none of these programs examine the questions of utility interface and economics. Little is known about the assumptions used in these codes or about code limitations. ADL is exploring these and other features of the many simulation programs available, including EMPSS (RP1269). A document summarizing the characteristics and capabilities of the simulation programs currently in widest use will be published.

Figure 3 shows how EMPSS works. The utility supplies information about its loads, rates, and cost of supply; individual thermal descriptions of building types; and a description of the SHAC or conventional HVAC system being studied. A weather tape, containing information on temperature, wind, and sunshine, is then used to determine the heating and cooling loads of the building and any weather-sensitive components of the utility's load. Available solar energy (or energy from storage, if specified) is used to meet the comfort needs of the building. If there is a deficiency, electric backup energy is used to meet the needs.

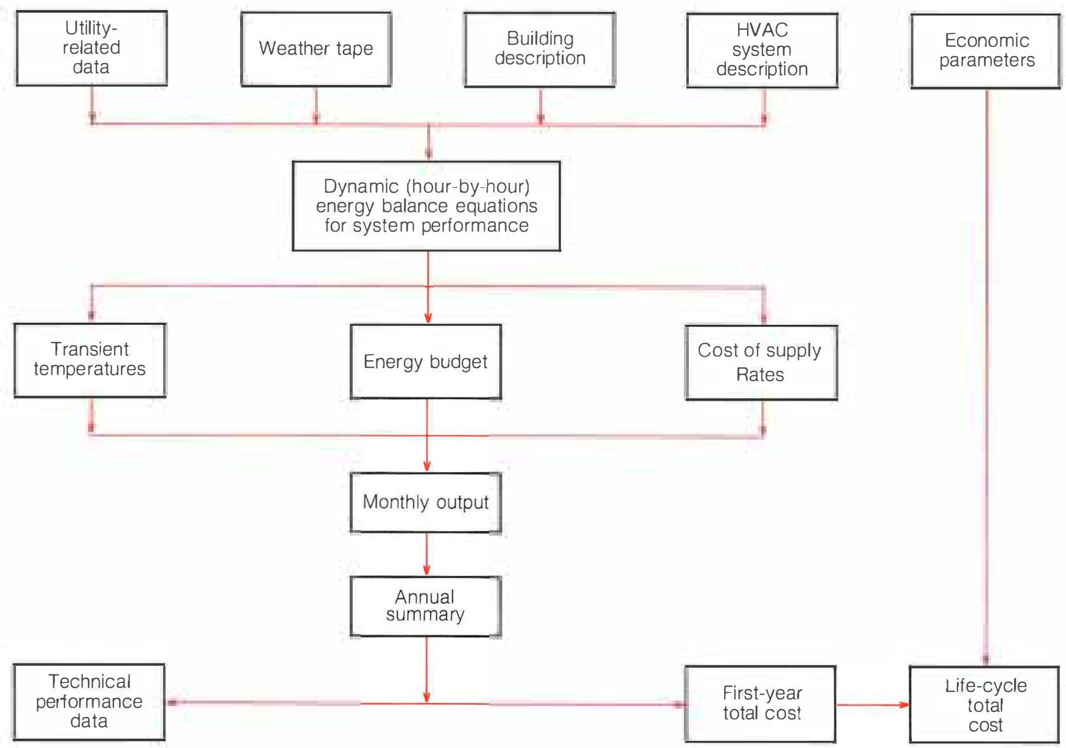
Program outputs include a summary of the performance of the SHAC equipment and a summary of all the energy demands and supplies. These are the usual outputs. EMPSS also provides an hourly summary of the building's electrical requirements for meeting the peak heating and cooling load experienced in a given month and gives the same information for the utility's peak load day in that same month. Finally, EMPSS provides an annual summary of the performance of the equipment and a monthly calculation of the cost of the customer's electric energy, based on rates and on the utility-provided cost-of-supply data. Included with this summary is economic information that allows life-cycle costs to be calculated. Capital costs for equipment are also included as inputs to the program.

More than 50 utilities have expressed interest in using EMPSS. Because of the program's multiple options for data entry and exit, the utilities plan to use it for a wide variety of studies. Those mentioned most frequently include studies of the impact of load management technologies on system loads, analyses of solar technology options, rate structure design studies, and load-forecast modeling studies. The flexibility of the EMPSS program will allow its use for these and other types of studies.

A residential project (RP549) will provide data that will be used to check the computer predictions, which are based on the models used in the computer code. Models will be updated as necessary, so that the predictive capabilities of the program will be enhanced. Similarly, using EMPSS in the detailed definition of the experiments (as was done in earlier phases) will probably help to eliminate early problems in the data analysis and gathering systems in use in the experimental projects.

A tape or card deck copy of the computer

Figure 3 Flow of information through the computer program EMPSS.



program is available. Two reports are also available to explain the program's uses. One (ER-770) summarizes the project and the features of the computer code, explaining in general the capabilities of the program. The other (ER-771) contains the documentation for the program and serves as the user's guide for the code. It describes in detail the data inputs and outputs, the models, and the simulation processes.

Some member utilities have expressed an interest in contracting directly with ADL for study work. Such arrangements can be made with ADL by contacting Dan Nathanson, (617) 864-5770. *Project Manager: James Beck*

COMPRESSED-AIR ENERGY STORAGE

New methods of energy storage for electric utilities are the focus of research efforts under way in the thermal-mechanical energy storage (TMES) subprogram of the Energy Storage Program. Part of this subprogram addresses further developments in compressed-air storage (CAS) that could use conventional or near-term technology to reduce or eliminate the need for burning oil during peak load periods.

The TMES subprogram is designed to facilitate utility evaluation and development of underground pumped hydro (UPH) and CAS plant concepts; selectively develop and assess thermal energy storage (TES) for power plant applications; and selectively assess and develop advanced CAS systems. This subprogram also includes low-level efforts to explore new concepts and to improve existing technologies—for example, investigation of possible improvements in conventional hydroelectric generation and evaluation of the potential for low-head hydroelectric generation.

The TMES subprogram is concerned primarily with accelerating the commercialization of near-term schemes for UPH, CAS (coupled with combustion turbine systems), and sensible-heat thermal-energy storage. These first-generation technologies appear to have significant technical and economic promise for near-term applications. The subprogram also includes specific supporting studies and experiments on limiting technical problems.

In addition, advanced TMES concepts are being investigated that could have significant performance or cost advantages over the first-generation technologies. Prime candidates are advanced versions of CAS that would eliminate the need for oil to reheat the stored air on discharge, either through storage and reuse of the heat of compression (adiabatic CAS) or through use of coal as the heat source during expansion.

CAS is familiar to many utility engineers because the concept originated in the 1940s, even though it is only now being applied. A CAS plant uses the main components of combustion turbines but in a modified cycle in which compressor and turbine operate at different times. Air is compressed during off-peak periods by motor-driven compressors and is stored underground. When power is needed, the air is released from its store, heated in a combustion chamber, and then expanded through the turbine, which drives the generator (Figure 4). Compressed air can be stored in three different types of underground structures: caverns in competent rock (man-made or natural), caverns in salt (solution-mined or excavated), and porous underground formations (aquifers).

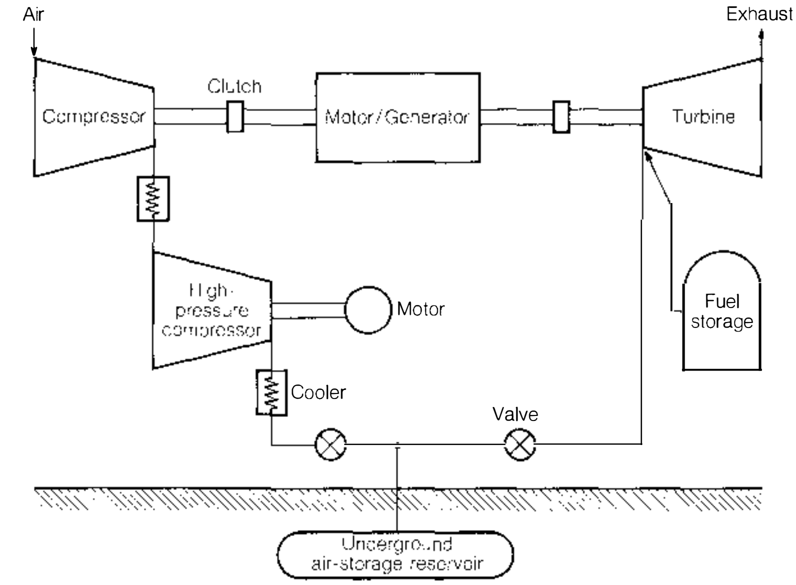
Early feasibility studies (RP737, TPS75-618) concluded that major uncertainties were best addressed in preliminary engineering-design studies. EPRI and DOE are currently cosponsoring three separate design teams, each led by a utility company. The design studies (RP1081) will help utilities to make decisions on plant construction, to better define technical and cost uncertainties (both subterranean and surface), to establish broadly applicable analysis and design methodologies, and to identify the research and development needed to advance the first and following generations of CAS and UPH.

The utilities leading these efforts are: Potomac Electric Power Co. (Pepco), Middle South Services, Inc. (MSS), and Public Service Co. of Indiana, Inc. (PSI). Support for subcontracted work comes from EPRI and DOE (Pepco is also investigating UPH in parallel with its effort on CAS). Each of the project teams is using one of these alternatives. Pepco is investigating competent rock sites, MSS is looking at the use of salt caverns, and PSI is examining the use of aquifers for air storage.

CAS is not a pure energy storage system, as oil is burned during the generation phase. It is, however, effective in reducing on-peak oil consumption. Typical operation of a CAS plant should require a charge-to-discharge energy ratio of less than 0.8 (less than 0.8 kWh of electrical energy expended on compression for every kWh generated). In addition to the electrical energy input, the fuel heat rate (oil burned during the generation phase) will be close to 3800 kJ/kWh (4000 Btu/kWh).

In first-generation CAS concepts, the heat of compression is removed by compressor intercoolers and rejected to the environment. This is a thermodynamic penalty for the cycle and necessitates the combustion of distillate fuels to raise the air temperature before expansion through the turbine. An alternative and less well developed concept is to use some method of thermal energy storage that would permit storage and recovery of the heat of compression. Returning the stored thermal energy to the air prior to its expansion through the turbine can re-

Figure 4 In a conventional first-generation compressed-air storage (CAS) plant, low-cost nighttime energy is used to compress air, which is then stored underground. In the generation mode, oil is used to heat the stored air prior to expansion through the turbine that drives the generator.



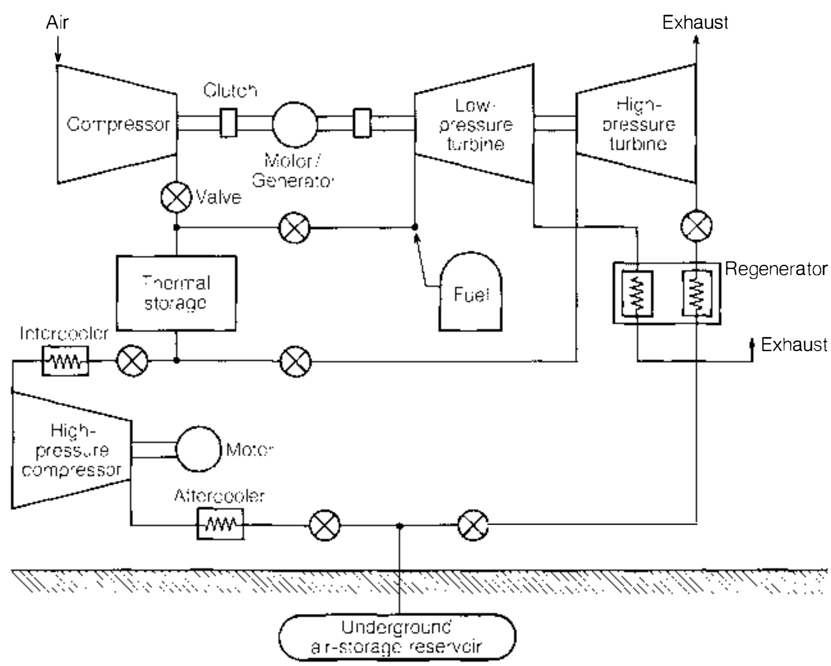


Figure 5 In a hybrid thermal energy storage–compressed-air plant, the thermal energy store acts as a compressor intercooler during the charging mode and as a regenerative air heater on discharge.

duce or eliminate fuel requirements. This and other concepts for reducing—or, if possible, eliminating—the need for reheating the expanding air with oil are currently being assessed in EPRI's TMES subprogram.

Of particular interest is the joint effort with England's Central Electricity Generating Board (CEGB), which is showing through conceptual design level analysis that storage and recovery of heat from a compressor in a CAS cycle can be effective in reducing the fuel heat rate of a CAS plant (RP1083). In particular, a hybrid (thermal storage plus some combustion) scheme has recently been developed by the CEGB team in which an intermediate-pressure TES is installed between the low-pressure and high-pressure compressors during charging (pumping) and before the low-pressure combustion during generating (Figure 5). As the exhaust of a low-pressure compressor would typically be 2 MPa (20 atm), the TES could consist of a pebble-bed heat exchanger (RP788) with aboveground pressure vessels of either steel, concrete, or cast iron, containing fireclay or cast-iron pebbles. With such a configuration, development requirements are substantially reduced. Such a hybrid CAS–TES scheme might achieve a fuel heat rate of 2600 kJ/kWh (2740 Btu/kWh) and a ratio of electric charge energy to discharge energy of 0.96. It appears that the second-generation CAS option could become technically feasible and economically attractive in the 1980s. *Program Manager: Thomas Schneider*

NO_x CONTROL TECHNOLOGY

Passage of the Clean Air Act Amendments of 1977 has increased regulatory attention in controlling nitrogen oxide (NO_x) emissions from coal-fired power plants. EPRI has initiated a program to assess the technology and associated costs of various forms of NO_x control. Primary emphasis has been on the cost-effective combustion modification method. Laboratory research has yielded NO_x levels of ~150 ppm (about 0.20 lb per million Btu) for representative bituminous, subbituminous, and lignite coals. Research on the more costly postcombustion approach is currently being initiated to assure that utility operating requirements and costs are accurately defined before widespread application of these technologies is mandated.

It is possible that a major future constraint on the use of pulverized coal for power generation will be emissions of NO_x. Relatively minor changes in burner designs and boiler operating procedures (e.g., staged combustion and low excess air) have been applied to satisfy the New Source Performance Standards for NO_x. Refinements of these procedures will probably be applied in response to the standards recently proposed by the Environmental Protection Agency (EPA) for coal-fired steam generators, although questions regarding furnace tube corrosion and potentially toxic by-products, such as polycyclic organic matter, are as yet unanswered. However, EPA is considering lowering NO_x standards even further: EPA research goals of 200 ppm NO_x in 1980 and 100 ppm in 1985 have been established for pulverized-coal steam generators.

For obvious economic reasons, the emphasis for NO_x control at EPRI has been on the combustion modification method. A $3 million cost-shared project is under way with Babcock & Wilcox Co. (B&W) to develop a low-NO_x combustion process for coal-fired utility boilers. A lower priority has been placed on postcombustion alternatives because of the substantially higher costs involved and the likelihood of major reliability impacts.

Low-NO_x combustion process development

The major problem in trying to achieve low NO_x levels from coal is similar to that encountered with sulfur—the nitrogen organically bound within the coal molecules is the source of the emissions. Were this fuel-bound nitrogen not present, such control technologies as wind-box flue gas recirculation and staged combustion would be adequate to reduce NO_x to very low levels. However, the fuel-bound nitrogen does not necessarily result in a solid by-product like its sulfur counterpart, which can leave scrubber sludge, sulfuric acid, or even elemental sulfur that somehow must be disposed of. There is a considerable amount of fundamental data indicating that the fuel-bound nitrogen may be reduced to innocuous molecular nitrogen by manipulation of the combustion chemistry.

The fundamental process for converting fuel-bound nitrogen to N_2 is fuel-rich combustion. However, it is unlikely that this can be accomplished by modification of current staged-combustion techniques with conventional burners. The conversion is more likely to require a completely new burner technology that can provide the proper temperature, time, and stoichiometry for low NO_x. The system must physically isolate the fuel-rich combustion process from the secondary-air injection zone to maintain an overall oxidizing condition in the boiler. One approach is the primary combustion furnace (PCF) concept proposed by B&W. Pulverized coal is introduced into a conventional B&W dual-register burner with less air than is required for complete combustion. All resemblance to existing burners ends at this point. The extended length of the combustor provides the necessary residence time to partially oxidize the coal and permit the N_2-producing reactions to occur. There is also heat removal along the combustion chamber to avoid slagging. Secondary air is added at the exit of the primary combustion furnace to bring the combustion products to oxidizing conditions for the balance of their passage through a conventional convective section.

To date, the development of the low-NO_x combustion process has been performed at 4×10^6 Btu/h. These tests evaluated the process variables necessary to accommodate low NO_x without losing acceptable combustion characteristics. Major parameters such as heat removal, residence time, and quantity of air in the primary combustion furnace have been defined. Results to date show that under optimal conditions, NO_x levels of 150 ppm can be achieved at the laboratory scale. The PCF is now being scaled up to 50×10^6 Btu/h. This research will confirm the NO_x and combustion process variables determined in the earlier work and evaluate material requirements, mechanical design, and longevity. Results of the 50×10^6 Btu/h tests can be extrapolated to typical full-scale utility burner ratings ($150–200 \times 10^6$ Btu/h).

Cost estimates provided by B&W for this technology put new-unit costs at $5/kW. While this figure must be regarded as preliminary, the attractiveness of the combustion control approach is obvious when one considers that postcombustion control techniques for new units are currently being estimated at $30/kW and up.

Postcombustion low-NO_x studies

While the major effort on NO_x control at EPRI is focused on the cost-effective combustion control approach, considerable research activity by EPA is concentrated on the postcombustion alternative. An EPA contract has been signed with UOP, Inc., to study the potential for simultaneous dry NO_x and SO_x control, and another EPA study, with Hitachi Zosen, will investigate catalytic NO_x control. Both projects will be run at a 0.5-MW pilot plant scale.

EPRI projects in this area include economic and feasibility assessment studies (RP983) with Battelle, Columbus Laboratories; Stearns-Roger, Inc.; and Tennessee

Valley Authority. EPRI is also managing the design and installation of a 2-m^3/s (5000-scfm) catalytic NO_x pilot plant (RPs 1256, 835). These tests will emphasize investigation of the practical aspects and cost implications of integrating such a device into an operating power plant. Key factors that must be addressed include startup/shutdown requirements, load following, NH_3 carryover, catalyst plugging, catalyst erosion, and undesirable by-product emissions. The NH_3 carryover poses some especially difficult operating problems, since it can lead to air preheater deposition and corrosion, blinding of baghouses, NH_3 emissions, sulfate emissions, and formation of visible plumes. Consideration of these factors will significantly increase the cost of applying post-combustion NO_x controls. It is hoped that accurate cost information will be useful to regulatory bodies in making informed decisions. *Program Manager: Donald Teixeira*

COAL-CLEANING TEST FACILITY

At its August meeting, the EPRI Board of Directors authorized the detailed design, procurement, construction, and operation of a coal-cleaning test facility (RP1400). This test facility is needed to develop improved unit operations that optimize Btu yield and demonstrate the potential of existing and improved unit operations for upgrading a variety of utility coals. The conceptual design is complete and a utility site is being selected (RP1030-5).

By 1985 the U.S. utility industry will be spending well over $1 billion a month for coal. Over one-third of this coal could be cleaned at the mine. With current cleaning practices, up to 20% of the raw-coal Btu is rejected in the refuse, and by 1985, if current cleaning practices continue, the Btu in the waste will have been enough to have supplied ten 1000-MW plants. The coal-cleaning subprogram is aimed at reducing that potential loss while producing the quality product the industry will demand.

The goals of the coal-cleaning test facility are to:

- Develop improved unit operations that optimize Btu yield and coal quality for both eastern and western coals
- Demonstrate the potential of existing and improved unit operations (arranged into optimized flow sheets) for upgrading a variety of utility coals

The test facility, designed as a small, integrated coal-cleaning plant capable of washing 4–20 t/h of a variety of steam coals, will fill a gap that now exists between the bench or test-stand R&D results and commercialization. By use of diverters and piping changes, up to 50 possible commercial flow sheets can be simulated. The facility is both flexible and integrated. The physical arrangement allows any new unit to be bolted into the structure and connected at its proper point in an integrated flow sheet. No such facility now exists in the United States, although the need has been recognized for several years. The facility will be uniquely capable of meeting the following utility goals for steam coal-cleaning development:

- Reduce coal-cleaning costs
- Develop improved technologies for utility priorities (e.g., sulfur and ash reduction, lower unit cost)
- Provide a basis for coal-cleaning plant specifications
- Test new coals for cleanability
- Provide a basis for writing tighter purchase specifications for coal quality
- Produce clean coal for testing
- Determine influence of unit operation on subsequent operations
- Provide feedstock of uniform size and quality for coal conversion development

Coal cleaning is a low-capital-cost method of upgrading coal and can meet many utility needs. As a result, coal cleaning is now applied to 65 million t/yr of utility coal, and the rate is expected to increase to 300 million t/yr by 1990. The advantages of coal cleaning include increased plant availability (coal-related boiler problems are a major cause of outages) and reduced plant maintenance costs for pulverizers, tubing, dust collectors, and air heaters. Coal cleaning will aid utilities in complying with environmental regulations and will eliminate the need for a scrubber in some existing plants. About 60 million t/yr of utility coal in the United States can be cleaned to meet state implementation plans without the use of scrubbers. Coal cleaning can reduce the sulfur dioxide removal efficiency requirements on scrubbers because the revised New Source Performance Standards will give credit for coal cleaning in meeting the requirement for percentage removal of SO_2. It can also reduce fugitive dust and acidic leachate from coal piles and extend the life of ash and sludge disposal systems. In addition, a low-cost trade-off in a nonattainment area may be provided so that a new plant can be built. Also, units derated by severe slagging may be operated at capacity by using cleaned coal.

The goal set for the coal-cleaning subprogram is the development of technology that will reduce the delivered cost of clean coal by 5–10%. The estimated savings in coal costs to the industry could exceed $400 million a year by 1995.

A conceptual design for the test facility has been completed by the Birtley Division of Sverdrup & Parcel and Associates, Inc. (RP1030-5). The estimated capital cost is $4.03 million with an estimated annual operating and maintenance cost of $750,000. The test facility will be sited near a utility coal-fired power station presently being selected.

The coal-cleaning test facility provides an important tool by which the coal-cleaning R&D objectives of the utility industry can be achieved. Unit operations developed in various EPRI projects at bench and test-stand scales will be developed to near-commercial scale at the test facility (RP1030 and RP1338). Thus the facility is an integral part of the coal-cleaning subprogram, which involves additional expenditures of $15 million in the period 1979–1983 to meet the objectives of EPRI's coal-cleaning subprogram.

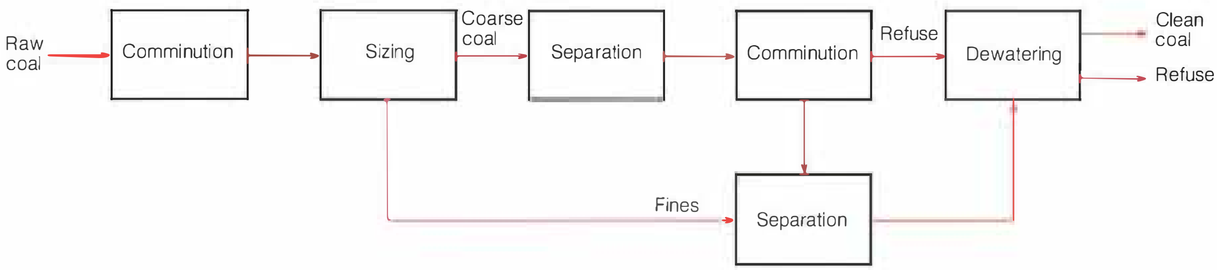
Although the costs and benefits must be assessed on a site-by-site basis, the net benefit can amount to $20 million a year or more for a 1000-MW (e) plant.

Planning for the project has involved input of information from 25 coal-burning utilities, 8 engineering and equipment supply companies in the field, and 3 universities. The facility will probably become the national center for coal-cleaning R&D and will have more projects each year than can be effectively handled. Advisory groups have therefore been organized to provide input for the selection process.

Figure 6 indicates the relationship between the various unit operations involved in coal cleaning and indicates the options that may be evaluated at the test facility.

The preliminary test plan for the first two years of operation (1980–81) includes dewatering of fine refuse and coal; cleaning of fine coal with heavy-media (e.g., magnetite and water) cyclones, water-only cyclones, and froth flotation; mechanical comminution; and instrumentation. *Project Manager: Kenneth Clifford*

Figure 6 The various unit operations in the coal-cleaning test facility can be used in 50 possible arrangements via diverters and piping changes. The lower section of the figure shows options that may be evaluated.



Comminution	Sizing	Separation	Comminution/Separation	Dewatering
Mechanical crushing	Dry screening	Heavy-media cyclone separation	Tabling Flotation	Disk filtration Centrifugation
Closed-circuit mechanical crushing Wet crushing Chemical comminution	Wet screening High-efficiency screening Pneumatic classification	Organic or inorganic true heavy-media separation Hydroclone separation Recrushing/recycling of middlings (coal and ash)	Hydroclone separation True heavy-media separation Elevated-temperature hydroclone separation Chemical cleaning	Oil agglomeration Pressure filtration (at ambient temperature) Pressure filtration (at elevated temperature)

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

FAST BREEDER BLANKET FACILITY

A fast breeder blanket facility has been designed, constructed, and licensed for operation (RP514). The facility uses a californium neutron source to drive the converter regions, which modify the neutron spectrum in such a way that the spectrum incident on a blanket that surrounds the converter regions is very similar to the spectrum incident on the blanket of a large liquid metal fast breeder reactor (LMFBR). An extensive experimental research program will be pursued on various blanket configurations with the objective of reducing the uncertainty of prediction of blanket physical behavior during the course of its life in the reactor.

Nuclear fission will probably play an important role in providing energy for industrialized and developing countries in the future. The only naturally occurring fissile material, ^{235}U, is found in the low proportion of 0.7% in natural uranium. Therefore, ^{235}U can be produced economically only from high-grade uranium ore. Though high-grade ore is in short supply, the fertile isotopes ^{238}U and ^{232}Th are available in abundance. Thus, large-scale production of nuclear energy, over a period of many decades, requires the conversion of fertile nuclei to fissile ones. This conversion is carried out in converter reactors (e.g., LWRs, D_2O-moderated reactors, or high-temperature gas-cooled reactors). Converter reactors can stretch the uranium supply by recycling the generated fissile material. However, only through breeding (i.e., through enhanced conversion that produces more fissile fuel than is consumed during power generation) can the abundant fertile material provide energy for centuries on a world scale.

The most efficient technical realization of the breeding process is in the fast breeder reactor (FBR), especially its sodium-cooled version, the LMFBR. An FBR comprises a core, in which most of the power and most of the neutrons are produced, and a blanket surrounding the core, in which the neutrons leaking from the core are captured to produce a substantial part of the breeding.

In the United States most of the experimental and theoretical neutron and gamma-ray physics research on LMFBRs has been directed toward resolution of uncertainties in the design and performance of LMFBR cores. Consequently, inaccuracies in the prediction of the important physics parameters of the blanket (breeding, gamma heating, and so on) have been much larger than those of the core. Much of the experimental work has been performed on critical assemblies—zero power reactor (ZPR) and zero power plutonium reactor (ZPPR)—which have simulated the core and the blanket composition with small plates of fissile, fertile, structural, and coolant materials. There are few data on the physics parameters and on the neutron and gamma spatial and spectral distributions in geometric blankets similar to those employed in actual LMFBRs (i.e., blankets containing rods of blanket material). Also, because of their design, the ZPR assemblies cannot provide good data at long distances from the core.

Because the gamma rays from the core are preferentially absorbed in the blanket, LMFBR blankets generate a considerable fraction of their power from gamma absorption. The prompt and delayed gamma rays carry about 14% of the energy generated in fission, and the spatial distribution of gamma absorption heat in the blanket is different from that of the fission heat. The fissile buildup and heat generation over the life cycle of the blanket has a complex spatial and time dependence. The uncertainties in the spatial heat generation rate may force reactor designers to overcool the blankets and reduce plant efficiency, which is an economic disadvantage for the expected long-term operation of an LMFBR. The uncertainties in the temperature distributions lead to uncertainties in the prediction of structural loads that are caused by thermal stress deflections and bowing during the life of the blanket.

Accurate prediction of neutron, gamma, fission, and ^{238}U capture rate distributions is difficult because of the changing nature of the neutron spectra in the relatively thin (~40-cm; 16-in) blankets sandwiched between the core and the radial reflector. The calculation methods, which employ neutron cross sections based on equilibrium spectra, have led to poor comparisons with reaction rate distributions measured in the ZPR and ZPPR blankets.

A fast breeder blanket facility (FBBF) has been designed and constructed to perform experimental and theoretical research leading to a reduction in the uncertainties associated with the prediction of the important physics parameters and of the thermal and structural behavior parameters for LMFBR blankets over their life cycle (RP514-1). The data gathered in the FBBF will be employed to help in the design of LMFBRs for superior performance and assured safety.

RP514 is sponsored in cooperation with DOE. The fuel for the facility, in the form of about 11,000 UO_2 rods of 4.8%, 1.3%, and 0.7% (natural uranium) enrichment, was obtained from DOE under loan arrangement. In addition, the 10^{10}-neutron-per-second ^{252}Cf source that will provide the neutrons in the FBBF was loaned by DOE to Purdue University. Purdue Research Foundation is the contractor on this EPRI–DOE cooperative project, with work performed by professors and students of the School of Nuclear Engineering. The principal investigators are K. O. Ott, F. M. Clikeman, P. J. Fulford, R. C. Borg, and R. H. Johnson.

The FBBF is neither a reactor nor a critical facility. It was designed to be safe (highly subcritical) under all conceivable conditions, including complete flooding. The facility has been secured, and the license for construction and operation has been obtained from NRC.

The FBBF was designed to provide as close a simulation as possible of the blankets in a large LMFBR. Neutrons from the source feed into two converter regions, which modify the neutron spectrum in such a way that the spectrum incident on the blanket that surrounds the converter regions is very similar to that of a large LMFBR. Various blanket configurations can be simulated.

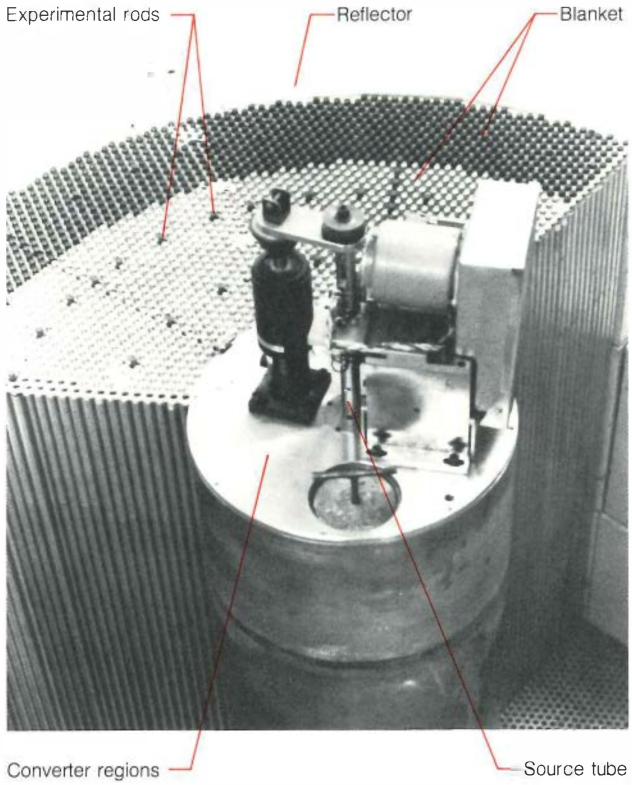
Figure 1 shows the major components of the FBBF, which is located in a concrete structure in the basement of the Physics Department at Purdue. The ^{252}Cf neutron sources normally reside in an underground storage cask. The sources are strung together in the source tube to form a pseudocosine line source. The source tube is raised by a motor drive inside a source guide tube with inside diameter (ID) of 38 mm (1.5 in) and outside diameter (OD) of 58 mm (2.3 in). Surrounding the source tube are two converter regions enclosed in a sealed steel tank. The inner converter is contained in an annular cylindrical can of welded 316 stainless steel, with 59-mm (2.3-in) ID, 320-mm (12.6-in) OD, and 1.09-m (42.9-in) height. The converter is composed of tightly packed 4.8%-enriched UO_2 rods with boron carbide powder in the interrod spaces. The outer converter region is contained in the sealed annular cylindrical tank with ID of 329 mm (13 in) and OD of 443 mm (17.5 in). This converter is composed of 4.8%-enriched UO_2 pins on a 17.9-mm (0.7-in) pitch and uses unequal-sided hexagonal cans filled with frozen sodium in the interrod gaps.

The radial blanket region is the annular volume between the outside of the sealed converter tank and the inside of the reflector region. The initial blanket loading consists of approximately 6000 natural uranium blanket rods of 15 mm (0.59 in) OD, which are located on a pitch of 17 mm (0.67 in). The blanket rods have aluminum or stainless steel secondary cladding. A small number of blanket rods are removable for experimental access. At these sites, the top grid plates are drilled out to the full pin diameter plus a clearance.

The reflector region is 152 mm (6 in) thick and is composed of about two-thirds mild steel and about one-third salt (NaCl). Steel plates and salt are contained in steel cans, which are bolted together to form a continuous annular zone.

The initial blanket has been loaded with natural uranium rods in aluminum and steel cans. The reaction rates for various foils (material samples) are presently being measured. The research program includes measurements of reaction rate distributions, gamma energy deposition distributions in the thermoluminescent detectors, and neutron spectrum distributions, among others. Slightly enriched fuel rods will be employed to simulate plutonium buildup in the LMFBR blankets. Analysis of the measurements will be carried out concurrently, and new methods of analysis will be developed when necessary. *Project Manager: Bal Raj Sehgal*

Figure 1 Close-up of the fast breeder blanket facility with a 120°-sector blanket loading about 1 m thick. The 443-mm-OD, 1.09-m-high sealed cylinder in the center contains converter regions.

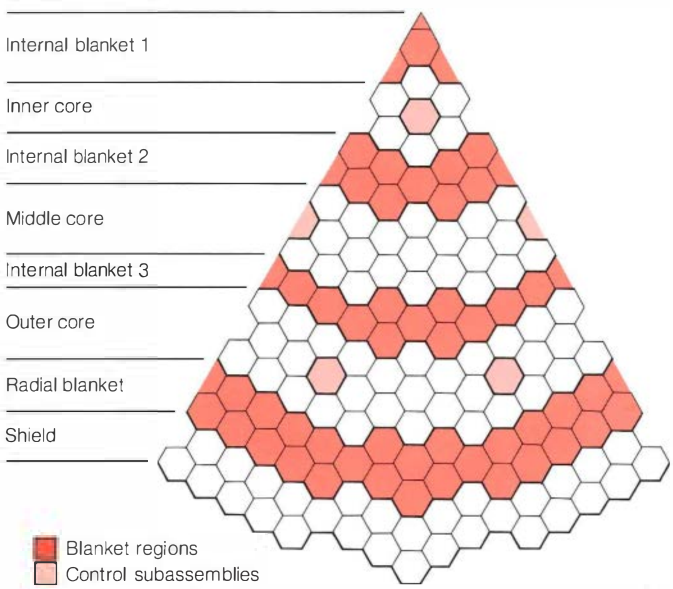


OPTIMIZATION OF HETEROGENEOUS LMFBR CORE DESIGNS

Heterogeneous core designs are being optimized with respect to breeding ratio, doubling time, sodium void reactivity, power-tilting phenomena, power-to-flow ratios, and so forth. Cores capable of producing enough thermal power to generate 1000 MW (e) are being considered. Both central blanket and central core configurations are being evaluated. The approach being taken is to impose a constraint on the maximum allowable sodium void reactivity and then to evolve design concepts that maximize core performance, breeding, and reliability.

The purpose of this work (RP620-25), being done in the Applied Physics Division of Argonne National Laboratory, is to develop optimized heterogeneous LMFBR core designs that will maximize breeding and core performance, given safety-related design constraints. Heterogeneous cores are defined as those containing blanket subassemblies within the matrix of fuel subassemblies (Figure 2). Such an arrangement has a potential for improved plutonium breeding. In addition, the design results in a lower sodium void coefficient of reactivity. This provides an added margin of safety against a rapid power increase caused by voiding sodium during the highly unlikely event of an accident initiated by simultaneous pump coastdown and failure of the

Figure 2 Heterogeneous core layout for a central blanket configuration (60° sector).



plant protection system. If such an accident occurred, the fuel pins, which would not be adequately cooled, would eventually melt, and core disruption would result. If the reactivity introduced from sodium voiding was sufficiently high and was introduced sufficiently rapidly, then considerable energy could be generated, thereby leading to a high damage potential.

The first phase of the three-phase study provided a critical analysis of a core-blanket complex sent to the various LMFBR Project Office contractors to provide them with guidelines for sizing components and structures designed in the course of development of their pool-type plant designs (RP620). The various core-related parameters were reviewed with respect to consistency in an integrated nuclear, thermal-hydraulic, and mechanical design. The analysis determined that the sodium void reactivity was significantly greater than the target design limit—namely, 2 dollars resulting from voiding the core. This corresponds to about 0.7% Δk (that is, 1 dollar corresponds to about 0.35% Δk in an oxide-fueled LMFBR). The core design thus needs further optimization with respect to core height, blanket thickness, pin sizes, and so on, while being subjected to a 2-dollar void reactivity constraint.

There was a significant shift in the power distribution (power tilt) toward the outer regions of the core. Thus the enrichment split, which measures the relative amount of plutonium present in the various core regions, needed adjustment. Great care must be taken in doing this, since power tilt is very sensitive to variation in enrichment in heterogeneous cores.

The nominal-peak linear heat rating for the end-of-cycle was excessively high in internal-blanket pins because of the large buildup of plutonium during the cycle. To avoid gross undercooling at the end of the cycle, it is necessary either to reduce the blanket pin sizes while increasing the number of blanket pins in a subassembly, or to provide added coolant flow through blanket assemblies.

The second and third phases have the specific goal of optimizing safety and breeding characteristics of large heterogeneous cores. In the second phase, now in progress, core height, blanket thicknesses, and fuel and blanket pin sizes are being optimized for layouts of the central blanket region and the central core region. This optimization is subject to a consistent set of nuclear, mechanical, and thermal-hydraulic design constraints. In addition, consideration is being given to such factors as the lower inlet plenum design, subassembly keys, duct design options, and control subassembly design to ensure proper integration of analysis and hardware design concepts. Thus far, it has been found that the greatest sensitivity of the sodium void coefficient is to the variation in core height. Of secondary importance is the sensitivity to variations in blanket thickness, number of internal blanket regions, and fuel pin size. The results of some screening calculations for these sensitivities are shown in Table 1 for central-blanket layouts with three core zones. The calculations were done for conditions that exist at the beginning of the equilibrium cycle. A comparison of cases 1, 2, and 5 shows a strong variation of sodium void reactivity with core height. Comparing cases 2, 3, and 4 shows a moderate variation of sodium void worth with thickness of internal blanket regions. It should be pointed out, however, that the effectiveness of this approach is limited by the increased sensitivity of power peaking to enrichment split.

Figure 3 shows the sensitivity of power peaking to changes in enrichment (as would occur during a fuel cycle) as a function of the degree of coupling. The three curves represent the same two-core central blanket region layout, but with different numbers of pins per subassembly. The larger the number of pins per subassembly, the greater the degree of decoupling between core regions and the lower the sodium void reactivity. From Figure 3 it is evident that the sensitivity to enrichment split is greater when core regions are decoupled than when they are highly coupled. The minimums in the curves denote the enrichment splits for which the peak fission densities are equal in the two core regions.

The results presented above, obtained from screening calculations during the second (current) phase, seem to be pointing toward the use of cores with relatively low heights and with relatively tight coupling between core fuel regions. Such designs would decrease both the sodium void coefficient and the variation of power peaking over a burnup cycle.

The third phase will involve detailed performance assessment of one or more of the most promising design concepts identified during the second phase. The following will be carried out in detail: nuclear, thermal-hydraulic, and mechanical design analyses; transient and safety analysis; startup analysis; power shape and reactivity control analysis; and assessment of instrumentation

Table 1
SENSITIVITY OF SODIUM VOID REACTIVITY TO VARIATIONS IN CORE HEIGHT AND INTERNAL-BLANKET THICKNESS

Case No.	Core Height (m)	Internal-Blanket Thickness (No. of assemblies)* IB1	IB2	IB3	Total-Core Sodium Void Reactivity (%Δk)
1	0.87	13	60	108	0.208
2	1.06	13	60	108	0.398
3	1.06	13	60	120	0.342
4	1.06	13	72	120	0.289
5	1.32	13	60	108	0.597

*IB1, IB2, and IB3 refer to the three internal blanket regions shown in Figure 2.

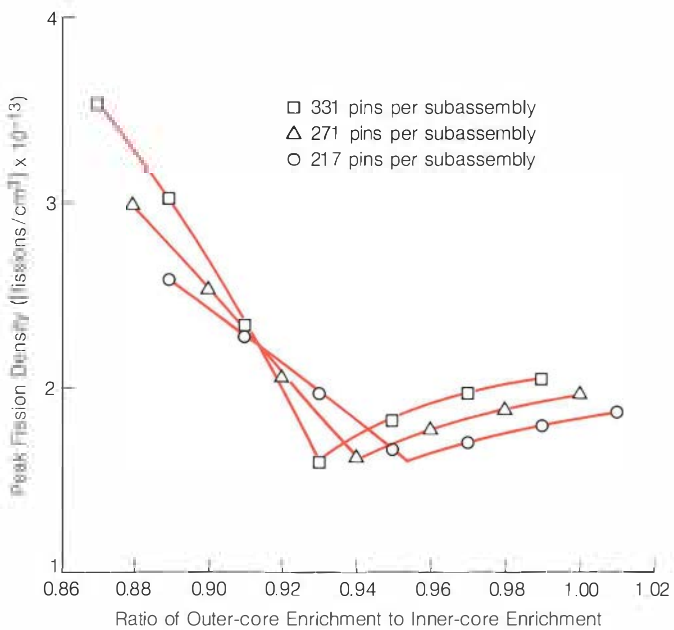


Figure 3 Sensitivity of power peaking to changes in enrichment. The greater the number of pins per subassembly, the greater the degree of decoupling between core fuel regions and the lesser the sodium void reactivity. The degree of power tilt occurring over a fuel cycle is measured by the change in peak fission density over the cycle. Such changes occur as functions of the variations of fissile enrichment with burnup, and the variations differ for each region. The more decoupled the core regions, the greater the sensitivity of power tilt to changes in enrichment split.

needs. Conceptual design of hardware will be carried out, including designs for the lower grid; fuel, blanket, and shield assemblies; core restraint system; and other core-related components. *Project Manager: Edward Fuller*

LWR EMERGENCY CORE COOLING SYSTEMS

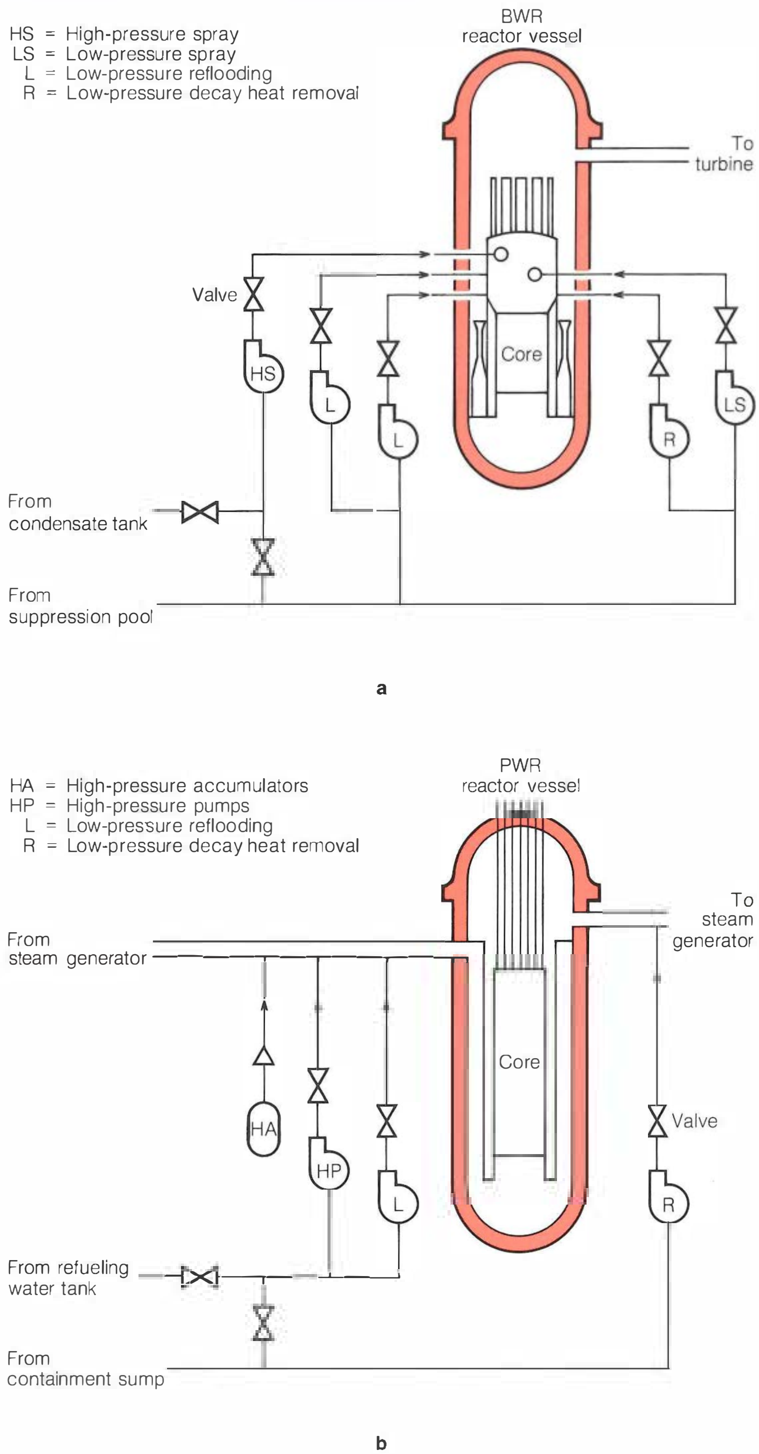
Understanding the performance of safety injection systems in LWRs is of considerable technical importance and provides further insight into the assurance of safety. The current R&D in this area, of which EPRI's efforts represent a significant part, is aimed at providing both basic data and systems-testing information. These are used to underpin the analytic methods needed to describe the complex thermal-hydraulic processes that may occur in a full-scale reactor. The trend is toward a more scientific basis of description that will permit better quantitative definition of present and future reactor operating and safety margins.

Historical background

EPRI is heavily involved in evaluating the performance of LWR emergency core cooling systems (ECCSs). All LWRs that currently generate power must include such a system, and ECCS performance and specifications are important in reactor licensing. These systems were designed specifically as an additional safeguard to ensure refilling and flooding of the reactor vessel following hypothetical failure of the primary circuit pipework. Although the probability of occurrence is low (estimates vary from 10^{-3} to 10^{-4} per reactor operating year), such a failure would cause the high-pressure coolant to discharge. A wide range of system failures with varying degrees of predicted severity may be postulated. The predicted probabilities and consequences are sensitive functions of the location, kinetics, and nature of those failures. The most extreme postulated failures could lead to some core exposure or a significant temperature transient for the reactor fuel. ECCSs are designed to safely mitigate and terminate this kind of transient and to provide for long-term heat removal.

The safety principles of diversity and redundancy are applied in design. In current reactors, the water supply for the ECCS is diversified (coming from accumulators, storage tanks, and suppression pools), and redundancy in delivery is ensured by using multiple pumping systems (Figure 4). Much controversy has centered in the actual per-

Figure 4 Typical emergency injection systems in current U.S. reactors. BWRs **(a)** use core spray and flooding injected inside the reactor vessel, whereas PWRs **(b)** use core flooding injected into the reactor pipework.



formance (effectiveness) of these systems in adequately cooling the reactor.

Quickly mounted small-scale experiments at the Idaho National Engineering Laboratory showed that significant quantities of ECC water might be entrained during depressurization and not reach the reactor core. Significant delivery of ECC water has been observed in all the subsequent experiments, which have used more relevant conditions. The experiments were criticized because of their small scale, and the program was redirected to the large loss-of-fluid test (LOFT) facility to study these effects at larger and more typical scale (60 MW [th]). Almost simultaneously, nonnuclear experiments at Oak Ridge National Laboratory on simulated fuel rod behavior during transients showed that clad swelling (ballooning) was possible under some conditions. It was postulated that this could significantly reduce the flow area available for ECC water in the more extreme transients.

Reactor licensing and R&D

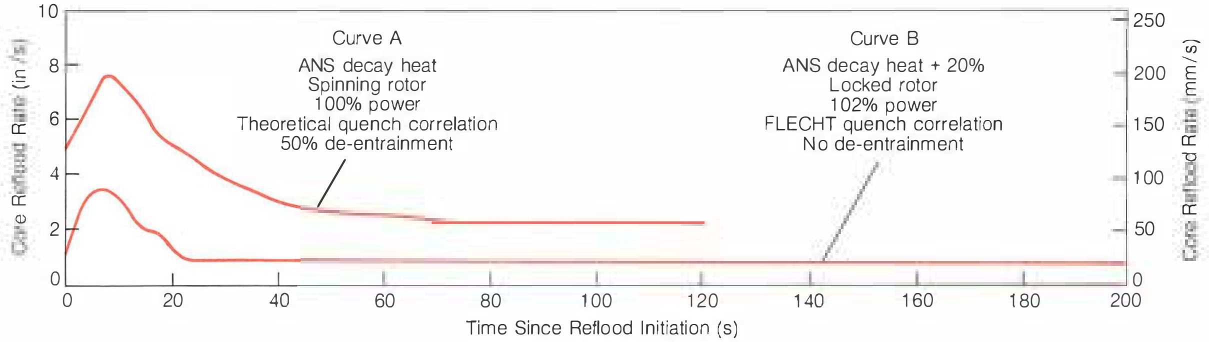
Information from this research was incorporated in reactor licensing requirements in an 18-month series of public hearings begun in 1972. These hearings specified:

- The models, methods, and correlations to be used in accident analysis
- The types of reactor accidents to be analyzed
- The limits on core temperature (currently ~1500 K) and degree of clad oxidation
- The interpretation of R&D results as applied to reactor licensing

Thus, political and industrial needs had a direct impact on scientific research and its application. The results of the hearings were embodied in the *Code of Federal Regulations: Title X, Energy,* Part 50, Appendix K, published in 1973; this code supplements the existing General Design Criteria and other regulatory requirements.

The general objective of Appendix K was to place an upper bound on core temperature to ensure both an operating safety margin (since core temperatures reached in an accident are related to initial core power) and due allowance for unknown or possibly poorly represented physical phenomena. Subsequent federal research (through NRC) and international efforts were then directed toward quantifying the safety margin. This led to the concept of "confirmatory research," intended to quantitatively confirm existing judgments and

Figure 5 Core reflood rates calculated using EPRI reactor code RAP. Curve A shows the enhanced effects of using assumptions that are more realistic than those required for the current licensing analyses, shown as curve B.



licensing margins. The federal program received about $100 million a year in funding. The effort, which involved national laboratories, government contractors, and universities, has ECCS performance as a central issue. The program involved full-scale bundle experiments, scaled investigations of blowdown behavior, and basic investigations of two-phase flow. Several large computer programs that use simplified models of the heat transfer and fluid flow are also under development.

The confirmatory research took place at about the same time that EPRI was formed. EPRI's initial involvement in this area was heavily influenced by these past events and by the need to bring a coherent utility voice to the debate on safety R&D. Since that time, EPRI has expended some $20 million over 5 years on this area and its related technology.

Current estimates of PWR core-reflooding rates, for example, now suggest values of 50–100 mm/s (2–4 in/s), compared with the 20 mm/s (0.8 in/s) or less that can be predicted for licensing purposes (Figure 5) by using the currently legislated analysis. Whereas these new values represent an apparent safety margin, translating this into a real safety benefit requires a continued R&D effort. Since no general theory for transient two-phase flow and heat transfer exists, the industry approach has been to generate empirical correlations directly from large-scale testing of prototypical components. These have then been applied in reactor calculations. Current efforts by NRC, EPRI, and others are aimed at providing a more fundamental analytic basis, both theoretically and experimentally. Only in this way can the credibility of the analysis be improved. Such an approach attempts to minimize the number of arbitrary adjustable constants (e.g., water droplet size, convective heat transfer, entrainment velocities) in the theoretical modeling while ensuring that the remaining constants are theoretically sound and are tested against a wide range of both basic and large-scale data.

The scientific questions

There are four fundamental questions to be investigated.

- What is the distribution of ECC water throughout the reactor vessel and circuit? (This is the so-called ECC bypass question in PWRs and the core spray distribution problem in BWRs.)
- Given this distribution, how fast is the reactor core quenched?
- Given this quenching rate, what is the heat removal rate (due to vapor and droplet flows) from the reactor core?
- With the cladding thermal history due to the above phenomena, what are the mechanical conditions of the cladding and fuel during and after the transient?

Strictly speaking, these questions cannot be considered separately. For example, when ECC water penetrates the core, boiling occurs, which generates steam. Venting of this steam and any entrained water from the core can occur either backwards through the injection water itself as a countercurrent flow or in the flow direction as a cocurrent flow. The pressure losses incurred can partially offset the hydrostatic head available to drive flow through the core, thus altering core flow rate and hence the steam generation rate. These pressure losses are relatively small and occur at very low pressures relative to the normal design conditions. The ability to predict these pressure loss components can have a relatively marked impact on the conclusions. In a PWR, venting occurs during blowdown through the upper plenum and steam generators; in a BWR, it may occur through the upper plenum during blowdown, in countercurrent flow with the spray system.

Experimental work

In current R&D at EPRI, three complementary types of experiments have been performed. Basic studies of single-tube countercurrent flow, quenching, and heat transfer are used to provide a fundamental data base (RP248-1). This work is used directly to test, improve, and upgrade heat transfer analyses. This basic heat transfer experiment has proved to be a severe test of current models, particularly for the film-boiling heat transfer. The work has recently been extended to include the effects of known flow transients. Basic countercurrent flow experiments are under way to resolve scaling uncertainties in extrapolating to reactors from LOFT, TLTA (two-loop test apparatus), and other ECC-bypass studies. These include air-water and steam-water studies to isolate the effects of condensation on momentum transfer (RP443) and the effect of viscosity and surface tension on countercurrent flow behavior (RP1160). The most recent work is an attempt to determine whether a geometry-independent correlation is applicable for characterizing the flow.

Few-rod and large-rod-bundle experiments have been undertaken to provide heat transfer data for known flow conditions. This approach eliminates the uncertainties and feedback associated with the overall system response. Some compromises are necessary in the bundle design. The largest bundle experiments use a single assembly of 64 or 161 stainless-steel-clad heaters to represent the many assembles of Zircaloy-clad fuel in LWRs (RP495 and RP959). This work is undertaken in conjunction with the reactor vendors (General Electric Co. and Westinghouse Electric Corp.) and NRC. A few-rod study at University of California at Los Angeles is investigating the difference between the thermophysical properties of heater rods and those of fuel rods (RP1118). The quenching rate for fuel is expected to be much faster than for the heaters currently used in experiments. Thus the steam generation feedback due to quenching affects core flow and must be correctly accounted for through appropriate theoretical analysis.

In large-scale systems tests, a significant portion of the reactor circuit geometry and layout is modeled at reduced scale. Both BWR and PWR studies have been undertaken, including study of depressurization effects. The results from this work indicate the presence of phenomena not previously accounted for, including residual two-phase flows during blowdown, flow oscillations during reflooding, and condensation near the ECC injection regions. Because these tests suffer distortion in scale, the results cannot be applied directly to power reactors; this can only be achieved by appropriate analytic modeling.

The results to date show that simplified equilibrium models are not uniformly applicable for flow description. Such models usually presume that steam and water behave as a continuum with equal phase temperatures. During ECC operation, the condensation process is governed by the large temperature difference between the injected water and the steam in the circuit, and the heat removal from the rod surfaces by the two-phase flow is governed by the large surface-to-fluid temperature difference.

Because of these large temperature differences, the processes cannot be considered as being in thermodynamic equilibrium. Hence explicit treatment of nonequilibrium phenomena in boiling and in condensation is necessary. Conventional heat transfer and pressure drop correlations are not uniformly applicable. Thus the objectives of new theories are to develop an adequate description of these phenomena without introducing undue complexity and to define a range of practical applications for the simpler models.

Theoretical work

The analytic attack has also taken three complementary routes. First, specialized theoretical models are being developed for ECC heat transfer and fluid flow. Such work stems from the need for detailed description of the two-phase flow structure and for an understanding of how this is coupled to the heat transfer (RP248). Local fluid conditions are calculated on an incremental basis along the heated surface. Because of the complexity of the flow (changing from single-phase liquid at the inlet to a dispersed two-phase flow with highly superheated vapor at the outlet), relatively sophisticated methods are incorporated. The models can be fitted to ECC data, but there are still uncertainties in the magnitude of the film-boiling heat transfer. Advanced two-fluid models are being developed to provide a more complete analysis (RP958 and RP443). These models are still in their early stages.

Second, simplified theoretical models are being developed for use in large-reactor codes. Because of the degree of reactor circuit detail, these analyses generally must simplify the treatment of the core heat transfer. Thus some specialized models are under development for the LWR systems code RETRAN (RP958). Nonequilibrium phenomena that occur during condensation are approximated by relaxation methods (characterization of the appropriate time scales for the process). Reflood two-phase flow is approximated by using an empirical approximation to heat fluxes in transient boiling. While these methods cannot be considered as exact, they do provide some guidance on the overall behavior.

Third, a simplified reactor code, RAP, has been developed at EPRI as a research tool and management guide. Sensitivity studies are performed with this method, and the code is continually updated as new results accrue from the program. This is an effective and necessary method of using and evaluating R&D results (Table 2).

Future efforts

Changes in reactor licensing for ECCSs can be foreseen as a result of the intensive R&D effort of the last few years. The initiative for such changes derives from institutional efforts and licensing actions. In support of such changes, future R&D efforts at EPRI are expected to concentrate on evaluating potential multidimensional effects in refilling and reflooding, improving the accuracy of nonequilibrium models for ECCS performance, and evaluating the applicability of currently proposed NRC experiments and tests (e.g., LOFT).

Substantial new information has been generated in recent years, and this input will probably continue for the next 2–5 years. This is expected to significantly influence industry strategy on changing the current licensing criteria. The following research accomplishments can be anticipated:

- Development and application of multidimensional nonequilibrium analysis
- Results from international R&D on PWR upper-plenum and large-bundle effects
- Results from R&D on BWR upper-plenum effects
- Resolution of scaling uncertainties on ECC bypass
- Completion of large systems experiments on PWR reflooding
- Improved estimates of safety margins
- Objective evaluations of alternative ECCSs

Current R&D has been aimed at resolving key uncertainties in ECCS performance. The results of this research imply that there are significant margins in current reactor safety limits, despite limitations inherent in the methodology. Quantifying these margins has proved to be no easy task. Further work aimed particularly at multidimensional phenomena in the core and reactor system is under way. It is to be hoped that this concentrated effort will lead to definitive resolution of the issues. *Program Manager: R. B. Duffey; Project Manager K. H. Sun*

Table 2
PROJECTS ON EMERGENCY CORE COOLING SYSTEMS IN LWRs

Area of Investigation	Physical Phenomenon	Project	Expected Impact of Results
ECC water distribution	Depressurization and two-phase flow	RP342, RP495, RP958	Nonequilibrium models required for condensation and discharge
	Critical flow	RP443, RP965	Initial experiments under way to quantify discharge rates
	Entrainment	RP248, RP273	Water entrainment incomplete in compartments outside primary system
	Condensation	RP294, RP341, RP443	Oscillations explainable by simple model
	Two-phase level and countercurrent flow	RP341, RP443, RP460, RP495	Property and geometry effects significant for scaling
Core quenching rate	Quench front propagation	RP248, RP341, RP959, RP1118	Local models necessary to quantify reflood rates
	Flow oscillations	RP248, RP287, RP341, RP959	Heat transfer enhanced
	Countercurrent flow	RP495	Condensation effects significant for ECC delivery rate to bundle
Core heat transfer	Decay heat	RP392, RP766, RP957	Current measurements ~80% of current licensing values
	Film boiling	RP248, RP495, RP959, RP989, RP1118	Quenching time reduced to enhance reflood rates
	Two-phase level	RP495, RP959	Increased heat transfer effects under investigation
	Condensation due to spray and flooding injection	RP341, RP495, RP959	Condensation coupled to system effects
Core mechanical conditions	Clad deformation effects on heat transfer	RP959, RP1118	Constitutive equations developed for validation of simpler models
	Oxidation	RP249, RP1118	Current licensing values high by ~10%

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

OVERHEAD TRANSMISSION

Galloping control by detuning

A continuing problem in line operation is the conductor motion known as galloping. Ontario Hydro has developed a detuning device that shows promise in limiting the detrimental effects of galloping on transmission lines, and an EPRI project now involves a field evaluation of this detuner on the lines of cooperating U.S. utilities (RP1095). The device is reasonable in cost and is installed on conductors at selected span locations (Figure 1) in much the same way as a conventional vibration damper or spacer is attached. A parallel but smaller evaluation program will be conducted in Canada by Ontario Hydro.

The detuner separates the conductor's natural torsional and vertical frequencies of oscillation. The prevailing theory is that if initiation of either torsional or vertical motion can be inhibited, galloping can be prevented. This technique differs from the damper concept, where the energy of an already galloping conductor is absorbed.

Most of the hardware for this year's tests was installed last winter at 54 test sites in the United States (at 26 utilities) and 6 sites in Canada. These sites include lines with single conductors, twin conductors, and four-conductor bundles, with voltages ranging from 12 to 765 kV (Figure 2).

During the past winter, galloping was observed on eight occasions at six U.S. sites and on five occasions at four Canadian sites. Data sheets were prepared, and in many instances movies were made of the lines in motion. Preliminary evaluation of the detuner's effectiveness has been mixed but nevertheless encouraging.

The project is scheduled to continue through mid-1980. More bundled-conductor test sites are expected to be used, and adjustments will be made on some lines where the detuners were improperly applied. *Project Manager: Phillip Landers*

Figure 1 Typical detuning pendulum as installed on single-conductor lines in the EPRI field-testing program. The data collection program is scheduled to continue until mid-1980.

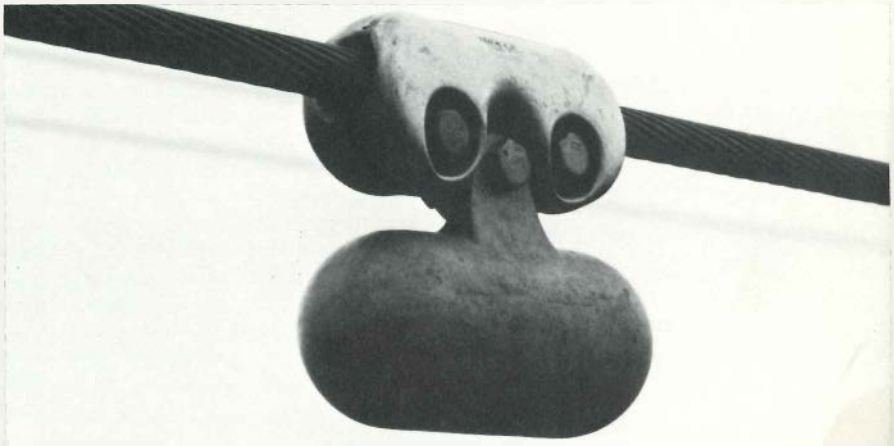


Figure 2 Field test sites for EPRI studies on control of transmission line galloping. Twenty-six U.S. utilities and Ontario Hydro (Canada) have installed detuning pendulums on lines that have a history of galloping.

Impact loads on overhead lines

Transmission design criteria that allow for the impact of broken conductors, ice release, and so on have eluded designers since transmission lines were first installed. The forces created by these events are dynamic and difficult to predict. There have been almost no empirical data on these problems.

The University of Wisconsin and GAI Consultants, Inc., have nearly completed an EPRI field-testing project to obtain the needed data (RP1096). A unique opportunity to test an existing line up to its design capacity was presented when Wisconsin Power and Light Co. decided to dismantle an existing 130-kV line to make room for a new 345-kV line on the same right-of-way. The University of Wisconsin conducted 23 tests on the line in November and December, 1977. These included loads induced by broken conductors, broken ground wires, and broken insulators. In a final destructive test, all six conductors of both circuits and both groundwires were cut simultaneously in an attempt to initiate a progressive collapse (cascade) failure of the line. Although the towers withstood this test without failure, valuable data were obtained on reactions of lattice tower structures during severe overload.

The instrumentation, provided by Engineering Research Consultants, included load cells, accelerometers, strain gages, and high-speed movie cameras. A new energy formula for predicting dynamic reactions has been developed by the University of Wisconsin, and the data from the field tests will be used to validate both the semi-empirical energy formula and the impact factors derived. The field test data will also be compared with dynamic forces predicted by tests performed on laboratory models by GAI (RP561). Preliminary data now show good correlation between predicted and measured results. All data will be analyzed and a final report will be issued by the end of the year. *Program Manager: Richard Kennon*

UNDERGROUND TRANSMISSION

Superconducting tape

A new process for manufacturing continuous lengths of superconducting Nb_3Ge tape, developed by the Los Alamos Scientific Laboratory (LASL), may lead to less expensive and more efficient underground transmission lines for the electric utility industry (RP7855). This tape is unique because it can operate at higher temperatures and current densities than any other known superconductor. Using the chemical vapor deposition process, LASL has fabricated the tape in lengths of up to 20 m (66 ft) in a configuration suitable for an ac power transmission line.

This material exhibits a transition temperature greater than 21 K and a critical current density greater than 2.5 MA/cm^2 at 14.9 K, as measured by passing current through an entire 7-m (23-ft) length of tape.

These characteristics, which are significantly superior to those of any other known superconductor, promise economic benefits in refrigeration and cryogenic envelope costs. Further work offers potential for high-current operation at temperatures above 14 K and for use of hydrogen rather than helium as the cryogen. *Project Manager: Mario Rabinowitz*

Fault location

Underground transmission cable is an effective power link only if it operates reliably. Loss of a circuit because of a fault is a matter of serious concern, particularly as the industry has increased the use of underground cable in urban areas, where dense loading makes reliability a problem.

High-pressure oil-filled (HPOF) pipe-type cable is the type most used by the industry at 69 kV and above. Unfortunately, faults in HPOF cable are probably the hardest to find, and fault locators designed for HPOF cable have so far been either inaccurate or time-consuming.

Because of the need for a fast, accurate method of locating faults, Hughes Research Laboratories is conducting an 18-month project to develop a fault-locating system that will identify and locate all types of faults on both solid-dielectric cable and paper-oil-insulated pipe-type cable (RP7874). The measuring technique developed will be based on the time required for a spark-gap impulse wave to travel from the faulted section to a terminal. *Project Manager: Thomas Rodenbaugh*

SUBSTATIONS

Fault data acquisition system

Analysis of large-scale disturbances on a power system often involves the frustration of waiting for complete and accurate information to be assembled. When data are finally collected, they are often unsatisfactory because they contain conflicting information from different sources. Furthermore, if historical operating data are needed for evaluation of a failure, it is difficult and often impossible to obtain them. For a demonstration project such as the prototype high-voltage direct current (HVDC) link in New York City (RP213), a complete, accurate operating history and detailed fault information are vital for evaluation of the new technology.

A fault data acquisition system (FDAS) has therefore been developed that will capture all pertinent fault data and produce a log of operational data. The FDAS has been built by Boeing Engineering & Construction, a division of Boeing Co. (RP213-3).

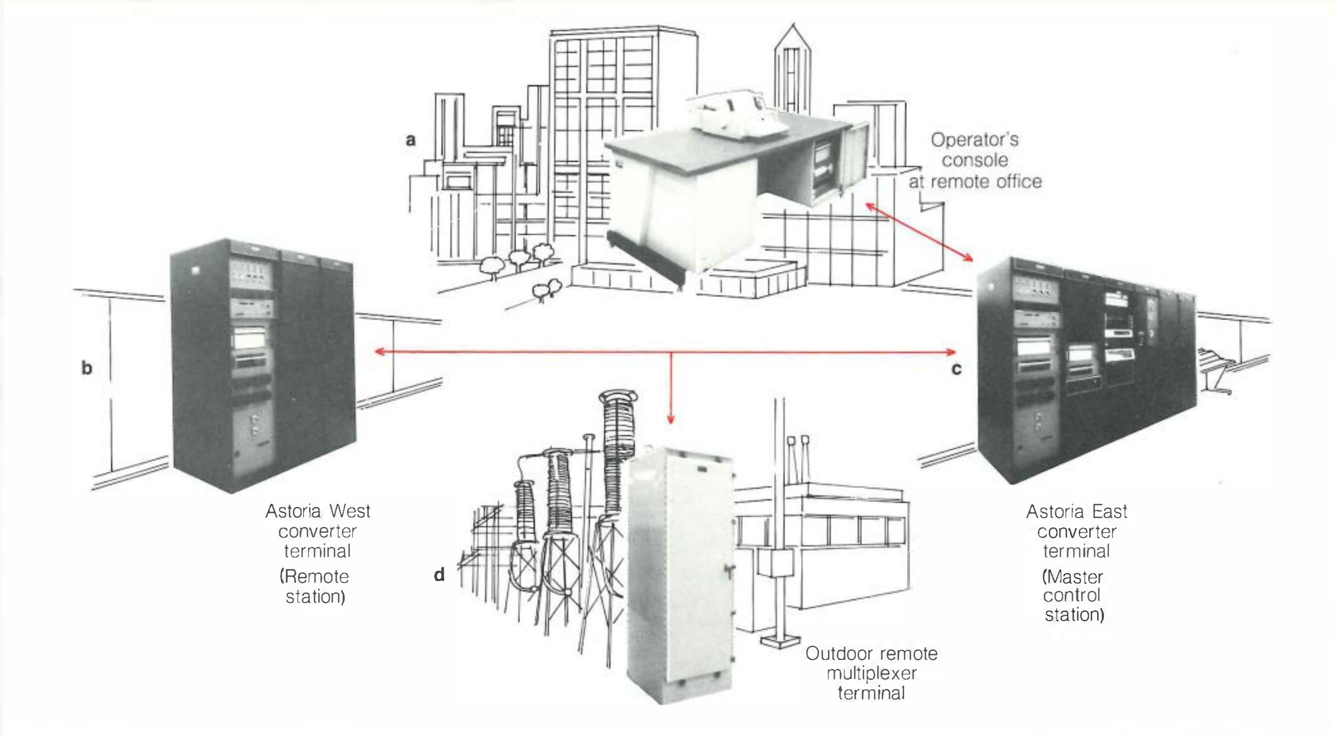
The system (Figure 3) has a master control station in the Astoria East converter terminal (the manned terminal) of the prototype HVDC link. A remote station is located in the Astoria West converter terminal. Since the two terminals are situated about 700 m (0.44 mi) from each other, a high-speed multiplexer system is used for most of the data acquisition. One of the five multiplexer terminal units used in the FDAS is located in the Astoria yard, close to a splice in the dc cable connecting the two dc terminals. The use of this remote multiplexing system has significantly reduced the cost of the data acquisition system. The fourth major assembly shown in the figure is an operator's console that is intended to be used by an operations or relay engineer at a remote office. The console has output devices that will produce a complete record of a fault from either terminal within a few minutes after the occurrence.

The FDAS will produce event records with millisecond time resolution and oscillographic data from 16 channels per station, each with 1.6-kHz bandwidth. This means 72,000 bits of data can be obtained for each second of operation. These data will be recorded on magnetic tape at the master station.

The FDAS has been built from standard, commercially available equipment. Siemens fault recorders, a Digital Equipment Corp. minicomputer, and a Boeing multiplexer system are the major components of the system. The three major R&D objectives have been to design a common time base for the system, to develop a data concentration method that can be used for transmission of oscillographic fault data, and to design the general system interfaces and their integration.

The system has been built to be expandable; only about half of the design capacity is used in the Astoria system. Since the data acquisition system is a subset of a Boeing-built control system, its expansion to incorporate control capability is relatively easy. The system configuration is modular, and a two-computer configuration, with one computer placed in each terminal, will be

Figure 3 Fault data acquisition system for the Astoria prototype HVDC link in New York City. The system will be used to acquire and route transient fault data and sequence-of-events information. It will also produce an operations log. The system comprises four major subsystems. The operator's console **(a)**, which is intended for a remote operations center, will provide a full fault record, including transient fault data, within minutes after a fault in either of the two converter terminals **(b, c)**. Also noteworthy is the use of a remote multiplexing system **(d)** in a substation for the first time. This feature minimizes the need for cables by placing the data acquisition terminals close to the equipment being monitored.



used. This is important because the HVDC terminals in a conventional HVDC transmission system are normally several hundred miles apart. With some additional effort, it should be possible to configure the system with dial-up lines for the fault data transmission. Dedication of communication lines for the infrequent fault data transmission would not then be required.

The output device selected for the transmitted fault records is a slow recorder of the same type used in each local fault recorder system. It is, of course, possible to replace this slow-speed recorder with a small computer that has a disk memory (or other large bulk-storage media). With this system it would be possible to perform computer analysis of the fault data, which could further enhance the fault analysis. This capability could be of significant value to system operators and troubleshooters in the future.

The system passed factory acceptance tests in August 1978 and will go through field acceptance tests before the end of the year. After that, the system will be used for evaluation of the prototype HVDC link during its five-year trial operating period. The FDAS itself will also be evaluated, particularly for fault data forwarding capability. *Project Manager: Stig Nilsson*

Passive hot spot detectors

Transformer designers have long wanted to measure the winding temperature of a transformer under load. However, no suitable temperature sensor exists that can be used without violating the dielectric integrity of the transformer. The sensor must be small enough to be placed in direct contact with the winding material, it must be capable of measuring temperatures above 200°C, and it must have complete electrical isolation between the winding and the instrument used for temperature readouts. Since presently used hot spot indicators are sometimes inaccurate, utility engineers are also looking for a hot-spot temperature-measuring device that can be used as an operational tool in addition to being used in laboratory testing of transformers. A direct-reading temperature sensor for transformer hot spot measurements is being developed by Westinghouse Electric Corp. at its Sharon Transformer Division (RP994-1). The objective is to develop a hot spot temperature sensor that uses passive components with lifetimes at least equal to that of the transformer. It is also desirable to avoid connection between the winding and the tank wall, but it is improbable that this goal can be met. Use of an ultrasonic signal transmission medium, which is dielectrically as strong as the insulating materials now used in transformers, is being pursued in this project.

The ultrasonic temperature sensor, which was developed for deep-level oceanic research, uses a small disk as the primary temperature-sensing component. The resonating frequency of the disk is a direct function of its temperature. The disk is excited through an ultrasonic transmission link made from a fiberglass strand. This causes the disk to vibrate, and the amplitude of the oscillation is sensed by a second fiber. The sensing fiber is placed so that when the sensor is excited near its resonant frequency, the feedback signal from the second sensor is at a peak. By calibrating the resonant frequency to a thermal scale, one can determine the temperature of the disk and therefore that of the winding. The feasibility of this method of temperature measurement has already been demonstrated, and the detailed design of the sensor is nearing completion. As stated before, the sensor has to be sufficiently rugged to survive installation in the winding and many decades of operation. This requires careful attention to packaging and installation details. The electronic equipment needed to convert frequency measurements to temperature readings is also being designed. When the remaining design problems are solved, the temperature sensor will be implanted in a new transformer and shipped to a utility for long-term evaluation. *Project Manager: Stig Nilsson*

Tuned-circuit fault current limiter

There are basically two types of fault current limiters: tuned-circuit and switched-impedance. EPRI has just completed a detailed design study of a novel, tuned-circuit current limiter that restricts current flow under fault conditions to as little as twice full-load current (RP654). In this tuned-circuit (controlled-impedance) device, a series impedance is tuned to 60 Hz during normal operation but is rapidly switched into a parallel-tuned resistive impedance during a fault.

The project included an analysis of the performance and cost of five circuit variations, one of which was optimized for a specific application. A complete paper design for an application specifically chosen by Consolidated Edison Co. of New York, Inc., was evaluated for performance and cost (EL857).

In this application, the effectiveness of the tuned-circuit current limiter was verified. Such a device is expensive in both initial cost and operation (because of high losses). However, should the designer of an electrical system need to split up a system to cope with increasing fault currents, a current limiter of this type would be ideally suited for application at a tie position where the normal current is extremely low and losses are therefore a minor factor. The initial cost of this device is related to its MVA rating, since the primary cost components are power reactor and capacitor costs. Thus the user is encouraged to specify a low MVA rating for such a current limiter. Fortunately, a bus tie is expected to carry significant power only in a contingency, when the available system short-circuit current is low; hopefully, this current will be within the rating of the installed equipment. During such a contingency, the device can be bypassed through a switch. If this current limiter were connected only when the available fault current exceeded the breaker interrupting capability—that is, during normal operation—system designers could specify a low-MVA (lower-cost) current-limiting device.

Of further concern is the significant space requirement for such a current limiter. If necessary, however, this device can be made more compact by employing techniques developed for the new generation of gas-insulated substations. In a separate EPRI project, compact capacitors are being developed for filters in dc converter stations, and that technology could conceivably be used for this application. Since such research is being pursued elsewhere, this project did not attempt to address the problem of size reduction.

This project has at least quantified the cost element and the size reduction, and therefore will serve as a tool to a system designer in evaluating the alternatives. Should the decision be to employ such a device, the final report will aid in specifying the equipment. *Project Manager: Vasu Tahiliani*

Ac harmonics

The successful application of HVDC transmission requires that harmonic currents be anticipated before they are injected into the ac system by dc converters.Once their size and effects are known, harmonics can be reduced through the use of appropriate filters. Although the ac system offers resistance to certain harmonics (which can be measured or calculated) the system's impedance varies with time, system growth, system status, line design parameters, and load and power requirements. Historically, assumptions used as bases for ac filter design and performance have been conservative to cover all contingencies. This results in less effective and more costly designs, primarily because the ac harmonic impedance characteristics are not precisely known.

There is a distinct need for better information on ac system harmonic impedances and for a way to calculate or test for these impedances under all anticipated conditions. Hence, a research project has been undertaken with General Electric Co. to measure harmonic impedances on a power system so that present analytic techniques can be modified to agree with field tests (RP1138). This will improve a utility's understanding of harmonic impedances on its ac system and lead to more effective design of protective filters.

As part of this 18-month project, monitors have been installed at the Celilo HVDC converter terminal on the Pacific Northwest–Southwest Intertie to measure filter overcurrents. These will be compared with calculated current levels as a first step toward modifying theoretical computations. Results should be available by mid-1979. *Project Manager: Narain Hingorani*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

INTEGRATED FORECASTING MODEL

A model of the U.S. energy sector has been developed by the Systems Program of the Energy Analysis and Environment (EAE) Division using submodels provided by EAE's Demand and Conservation Program and Supply Program. A network diagram of the energy sector is used to define the frequently complex links between the submodels. A preliminary base case for 1975–2000 has been run, and the model is currently being calibrated to actual data for 1975 and is being compared with runs of other energy models. The model will provide information to the Planning Staff for use in constructing an R&D overview.

The EAE Division is conducting a comprehensive program of supply, demand, and environmental research. Over the past few years, information about these three areas has been provided by the final reports of projects that focus on major sectors of the energy economy (e.g., EA-235, *Residential Demand for Energy,* and EA-496, *Economic Analysis of Coal Supply*).

A project was initiated to integrate much of this research into a single, internally consistent model, designed in particular to forecast energy prices and quantities (RP1108). It involves a joint effort on the part of researchers from the Supply, Demand and Conservation, and Systems programs of EAE and the consultant, Decision Focus, Inc. The model is sufficiently flexible to incorporate new analyses and to provide a setting for examining issues of particular interest to EPRI. As such, the model is intended as an ongoing analytic tool, which can be modified to suit the needs of EPRI researchers and planners. One such use will be to provide analysis and input to EPRI planners for R&D evaluations and planning decisions.

The integrated forecasting model represents the set of energy markets in the United States. It is composed of submodels provided by the Supply Program and the Demand and Conservation Program and a linking procedure provided by the Systems Program and Decision Focus. The current version of the integrated model is national because, for the most part, the submodels provided had been aggregated to the national level. The results provided by the integrated model offer more insights than do the individual submodels because the price and quantity assumptions in all submodels are consistent. Because of feedback relationships inherent in economic models, it is difficult to ensure this consistency without an explicit integrating framework.

Figure 1 is an illustrated network, which shows how the submodels were integrated. Once the submodels have been linked, a solution algorithm is used to determine the prices that balance supply and demand. At the bottom of the network, an initial estimate is made of the market clearing prices over time of each of the primary resources throughout the network.

As the network is traced upward along all paths simultaneously, interim prices are computed for the products by using submodels provided by the Supply Program. Components of the submodels describe the relationship between input and output prices. When the top of the network has been reached, interim prices of usable energy will have been computed for each demand sector in each region over time.

At the top of the network, a downward pass begins. The prices of usable energy are applied to the energy demand curves provided by the Demand and Conservation Program to determine the quantity of energy needed for each end use in each time period. The required quantities of materials are allocated to competing sources on the basis of submodels provided by the Supply Program. For example, the required quantities are adjusted to account for the thermal losses in energy conversion and transportation. When the bottom of the network has been reached, an estimate will have been obtained of the required quantity in each time period for each of the primary resources. If that quantity does not equal the quantity implied by the initial choice of price, a new price is chosen and the process is repeated. The estimates of production lead to new prices that are passed up the network and result in new demands that are passed down the network. This iterative process is continued until it converges—that is, until no significant changes in prices and quantities occur on two successive iterations.

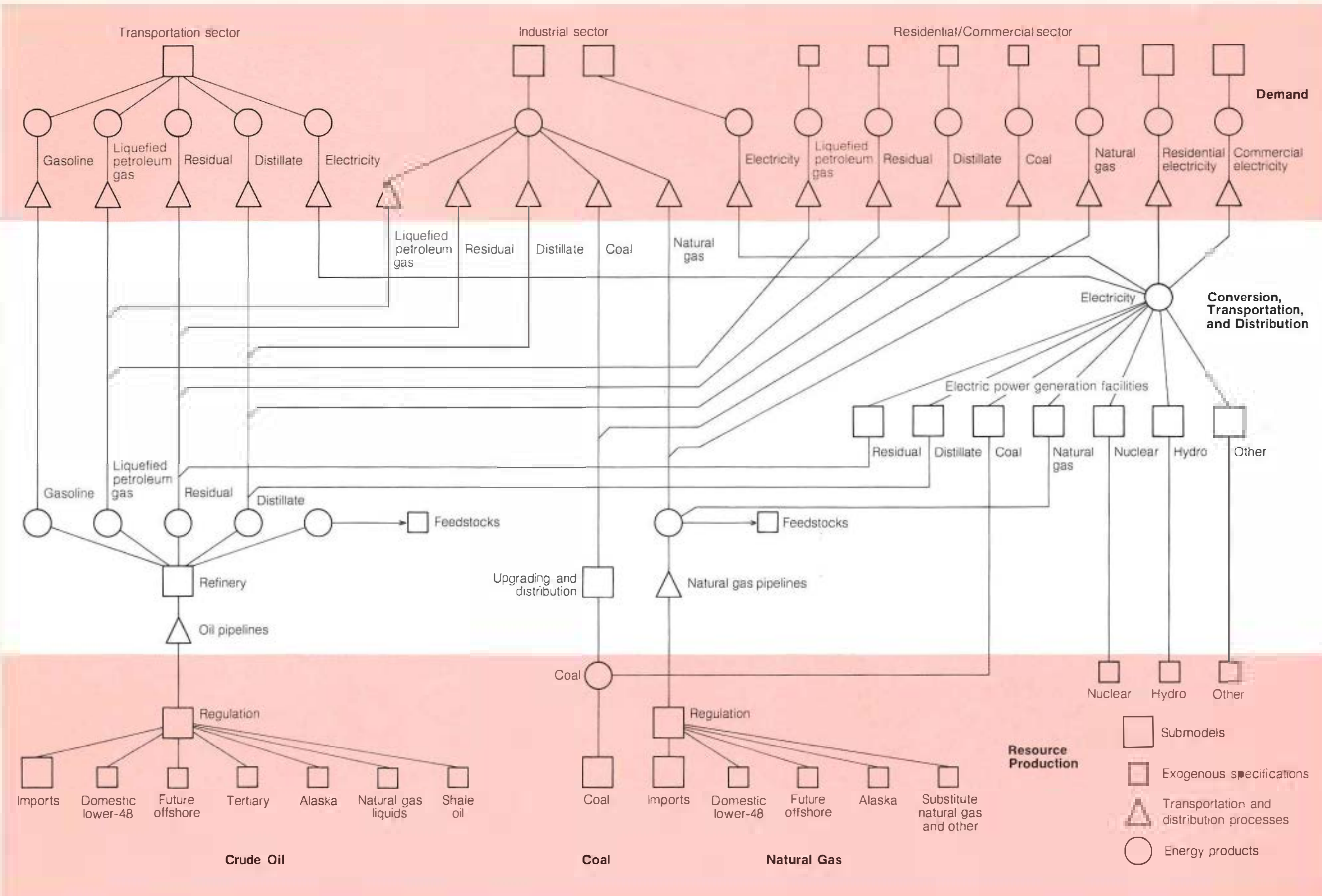
Demand submodels

The Demand and Conservation Program provided the computer model that produced the results contained in the publication *Demand 77* (EA-621-SR). This computer model was the basis for the demand submodels. A brief description of each of the submodels (residential, commercial, industrial, and transportation) is given here. *Demand 77* gives a detailed description of the methodological basis of each submodel.

Residential Electricity Demand This submodel is based on work by Taylor, Blattenberger, and Verleger (EA-235). In the residential submodel, state per capita kilowatthour sales are related to state lagged sales, personal income per capita, electric utility rates, natural gas prices, climate variables, and a state-specific constant. This submodel's major innovation is its treatment of the declining-block structure of electricity rates, which permits a more precise estimate of the responsiveness of consumers to the way electricity is actually priced. Because it includes a distributed-lag specification, the residential model also takes into account the fact that electricity consumption does not adjust instantaneously to changes in income and prices.

Commercial Electricity Demand This submodel was based on a reestimation made in RP333 of a specification by Mount, Chap-

Figure 1 This diagram of the U.S. energy system can be viewed on two levels. It can be seen as physical flows of energy products through the energy economy; it can also be viewed as representing the structure of the integrated forecasting model. In physical terms, the primary energy sources—oil, coal, and natural gas—are shown at the bottom of the network. These are transported and converted into other energy forms (middle section) and then distributed to the demand sectors (top section). For instance, the sources of natural gas at the lower right come together in the regulation area. The gas is transported by pipeline closer to the market. It is then delivered to various users, such as the industrial sector. In terms of the integrated model, submodels are grouped in regions on the network diagram. Thus, the analyst can visualize the links between submodels and input them into the computer program. After the submodels are linked, an algorithm is used to determine a set of prices and quantities that balances supplies and demands.



man, and Tyrrell. Like the residential model, it consists of a single equation that relates state kilowatthour sales to lagged sales, the price of electricity, the price of natural gas, personal income per capita, population, and a region-specific constant.

Residential-Commercial Petroleum and Natural Gas Demand The report *Demand 77* combined the residential and commercial sectors in dealing with petroleum and natural gas. The forecasts for these fuels are based on scenarios from *National Energy Outlook, 1976*, published by the Federal Energy Administration (FEA).

Industrial Energy Demand Industrial energy use is treated as a derived demand for factors of production. The specification is based on in-house research performed by the Demand and Conservation Program. The manufacturing sector is disaggregated into nine industries, which are modeled separately but on a national basis. The industrial model proceeds on a two-step basis. The first step forms separate forecasting equations for electricity and fossil fuels. The second step is to split the fossil fuel total into natural gas, petroleum, and coal components.

Transportation Energy Demand The forecast for gasoline demand uses a model developed for FEA. It takes account of total vehicle miles traveled, average miles per gallon for all gasoline-powered vehicles, and differences in mileage for vehicles of different vintages. The model also takes account of the retirement of vehicles over time and forecasts miles per gallon of new cars as a function of the price of gasoline and legislated efficiency standards. Consumption of other forms of energy in transportation depends to various degrees on time trends, prices, lagged consumption, and transportation activity levels.

Supply submodels

The Supply Program provided computer submodels to represent electric power generation, lower-48 natural gas supply, lower-48 crude oil supply, and coal supply (excluding metallurgical coal). Brief descriptions of these submodels are provided here. *Supply 77* (EA-634-SR) provides a more detailed description of the methodological basis for these submodels.

Electric Power Generation The submodel used for the electricity price forecasts (ELECTP) is a simulation code developed by the Supply Program. The structure of the submodel is as follows. Generation plant types are categorized as coal, oil, gas, nuclear, hydro, and other. For each of these types, the current capital costs, fuel prices, heat rates, load factors, and operation and maintenance costs are input to the submodel. The user also provides annual projected changes in each variable. The submodel calculates net annual additions to capacity, given initial capacities and exogenous growth in capacity for each plant type. Fuel costs are calculated by multiplying the number of dollars per million Btu by the heat rate for each plant type (except for nuclear, where a separate analysis provides exogenous input to the model directly in cents per kilowatthour). Annual capital charges are calculated by multiplying the capital cost by a fixed charge rate. Annual fuel consumption for coal, oil, and gas is calculated by multiplying generation for each plant type by the appropriate heat rate. Annual average electricity prices (revenues per kilowatthour) are computed from generation costs by the inclusion of transmission losses and transmission and distribution cost factors.

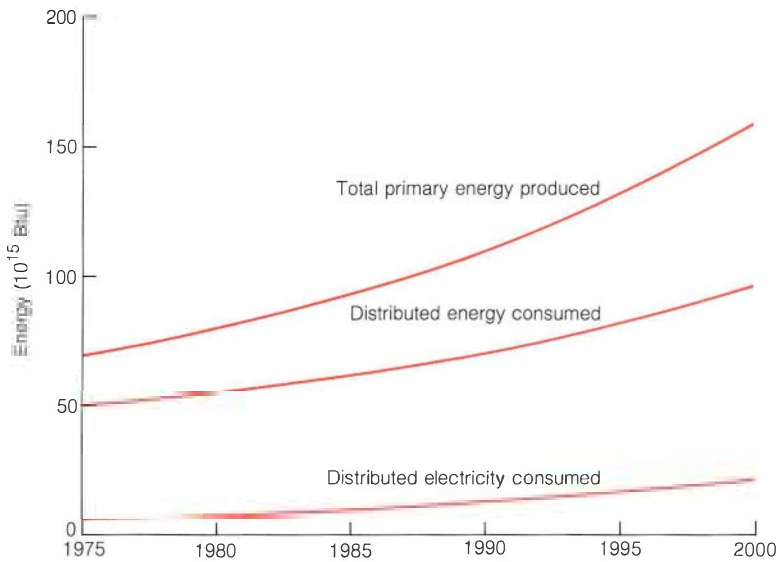
Lower-48 Natural Gas Supply The interim nonassociated gas submodel is a simple simulation model. It includes two types of gas, "new" and "old." For each type there are regulated price scenarios. This year's developments of new gas depend on last year's revenue from the sale of old and new gas. Production of old gas declines as reserves of old gas are depleted. Production of new gas is estimated as a sum of developments from previous years with depletion taken into account. Gas pricing is on an average basis and includes old and new gas.

Lower-48 Crude Oil Supply This submodel is structurally similar to that described previously for nonassociated natural gas production. There are three types of oil: upper-tier, lower-tier, and stripper. For each type there are regulated price scenarios.

Coal Supply In addition to these submodels, the Supply Program provided the computer code for a submodel of coal supply that had been developed in-house. This submodel relates the price of coal paid by electric utilities to the quantity of coal used by electric utilities. The relationship was estimated by statistical means, using indices based on production data, transportation cost, and end use. The national price and quantity of all coal are then calculated from the price and quantity to electric utilities.

Other Submodels Simple models of the oil refinery process and various transportation and distribution processes were constructed from information provided by the Supply Program to complete the integrated forecasting model. In addition, a simple model of oil and gas imports was constructed. In this version of the model, oil and gas imports fill in the gap between domestic supplies and demand, so that natural gas shortages were not modeled. The oil refinery submodel calculates the prices of gasoline, distillate, and residual by adding a refinery cost and maintaining a historical price ratio between the products. Each transportation and distribution submodel specifies a simple linear relationship between input and output prices. Both submodels adjust the quantity input to account for efficiency losses. The submodel for oil and gas imports allows the input of a supply curve specifying the price of imports for any given quantity.

Figure 2 Total use of energy in the United States. Primary energy includes coal, crude oil, and natural gas plus nuclear, hydroelectric, and other inputs into the electric generation sector. Distributed energy is the delivered energy for fuel and power uses and thus differs from primary energy by efficiency losses in converting energy from one form to another, transmission and distribution losses and uses, and use of energy products for raw materials purposes. Distributed electricity is the delivered electricity minus transmission and distribution losses.



Future research

Results for the base case run of the integrated model have been obtained. For instance, Figure 2 shows the quantities from 1975 to 2000 for total primary energy produced, total distributed energy consumed, and total distributed electricity consumed. Efforts are under way to calibrate the base case both to actual data for 1975 and to runs of other energy systems models. It should be kept in mind that the modeling effort has been under way for only six months and the current results are consequently preliminary.

In the continuation of the project, improvements will be made to the model in the areas of load shape, electric utility sector, and coal supply. These improvements will be guided by the desire to make this model useful for R&D assessment and will be based on on-going EAE work. Once these improvements have been incorporated, the model will be a useful addition to EAE's capability to provide information for the EPRI R&D overview. *Project Manager: Stephen Peck*

POLLUTANTS IN THE ENVIRONMENT

The basic objectives of the Physical Factors Program are to define the distribution of pollutants in the environment and to identify the utility industry's contribution to this pollution. The first objective is met principally through the identification, characterization, and monitoring subprogram, which supports research on analytic techniques, species identification, and measurement and monitoring. The second objective is handled through the transport and interactions subprogram, which focuses on reaction mechanisms, transport phenomena, and the ulti-

mate fate of pollutants. Data generated through the Physical Factors Program are often of direct use to EPRI's Ecological Effects, Health Effects, and Biomedical Studies programs. It is hoped that identifying the utility industry's contribution to pollutant levels will provide information that will be of value to regulatory and policy groups.

Most activities within the program concentrate on air quality problems related to conventional coal burning. However, a number of new projects are planned for 1979 that are related to solid waste and to coal conversion processes.

Monitoring projects

The principal project under way (RP862) is the Sulfate Regional Experiment (SURE). This project, whose field operations began in July 1977, will be completed by the end of 1979. Its goal is to determine the amount of regional, ambient sulfates contributed by utilities. This is to be accomplished by an extensive 16-month air quality measurement program in the Northeast that will attempt to relate ambient levels of sulfates to local emissions of their precursor, SO_2. The field program, comprising measurements from ground stations and airplanes, has operated according to schedule and with a high degree of efficiency (with regard to data capture).

The intensive period of measurements in summer 1978 was perhaps the most successful of the project. The 54 ground stations and two EPRI airplanes were supplemented by two airplanes from DOE's MAP3S program, which coordinated DOE research with that of SURE. A significant episode of high sulfate concentration was encountered during the intensive operation, and detailed data on the episode from both ground and air measurements have been gathered.

Project researchers have developed a set of high-quality data on the regional nature of air quality. The original hypothesis that high regional sulfate levels are strongly related to meteorological conditions seems to be holding up. Two distinct types of episodes can now be recognized. One is the classic, well-recognized episode in which long-range transport plays an important role in the movement of high concentrations of sulfates across a region. These transport episodes, which last 2–4 days and reach concentration levels of 20–40 $\mu g/m^3$, occur when humid, tropical air masses from the south and southwest are channeled northeastward along the Ohio Valley by the southerly movement of a cold front from the Great Lakes area.

A second type of episode seems to occur in the fall and is related to stagnant air conditions. In this type, a high-pressure zone over an SO_2 source area is blocked by a second high-pressure area over the North Atlantic, which prevents it from migrating. Such stagnant episodes can last from four to six days. A minor episode of this sort was recognized during SURE's intensive operation period in October 1977. Present plans call for SURE field operations to end in late 1978 and for 1979 efforts to center on data analysis and modeling.

A second aspect of the monitoring activity deals with routine measurement of the chemistry of rain as part of EPRI's interest in acid precipitation. For approximately the past ten months, Rensselaer Polytechnic Institute has been monitoring rainfall in the Adirondacks (RP1155). Seven monitoring sites have been established at three lakes. Samples of rain or snow are collected after each fall and analyzed for a number of chemical parameters in addition to pH and total acidity (buffer capacity). The results of this monitoring activity will be used by the Ecological Effects Program in its study of the causes of lake acidification in the Adirondacks. Preliminary measurements of precipitation indicate a typical pH range of 4.0–5.0 at all sites. Field observations show that for a given storm system, the pH of the rain differs little over hundreds of square miles. In contrast, successive storm systems can yield rains of markedly different pH.

All the EPRI-sponsored Adirondacks studies were reviewed at a meeting held in October 1978. In another acid precipitation project, begun this summer, Rockwell International Corp. is conducting a nine-month data collection program in the Northeast at nine stations of the SURE network (RP1376).

Plume chemistry studies

Two EPRI-funded projects have measured the rate of conversion of SO_2 to sulfate in power plant plumes in the East. During 1977, Battelle, Pacific Northwest Laboratories measured sulfur conversion rates of 0–3%/h in one oil-fired and two coal-fired power plants (RP860). The highest oxidation rates in this range were generally associated with high levels of ambient hydrocarbon concentration, solar insolation, temperature, and plume dispersion. No strong correlation, however, was observed between sulfate formation rate and ambient ozone levels. Kinetic modeling studies suggest that sulfate formation rates in plumes also depend on the rate at which nitrogen oxide in the plume is converted to nitrogen dioxide. Data analysis on the project will continue into 1979. A report describing the field program and modeling efforts will be published by EPRI in late 1978.

In a second project, Brookhaven National Laboratory is measuring sulfate formation rates in the plume of the Northport, Long Island, oil-burning plant of Long Island Lighting Co. (RP1000). SO_2-to-sulfate conversion rates of 0–2%/h have been calculated, with the highest rates in the range being associated with warm, sunny days. Measurements are also being made of direct sulfate emissions from the plant. The emitted sulfates occur both as sulfuric acid and as other particulate species. Sulfuric acid emissions appear to be directly proportional to the amount of excess oxygen in the furnace, whereas the other particulate forms seem to increase as the efficiency of the electrostatic precipitator decreases. Additional tests have been run to evaluate the effects of fuel additives on sulfate emissions and on conversion rates.

Solid waste projects

At Oak Ridge National Laboratory (ORNL), researchers have studied the chemistry and mineralogy of samples of ash from two coal-burning power plants—Tennessee Valley Authority's Kingston and Bull Run plants (RP1061). Studies of the solids reveal the occurrence of two predominant solid phases, each with characteristic trace metal affiliations. A mullite (aluminum-silicon oxides) phase is typically associated with the alkali elements, the alkaline earths, and the lanthanides. A spinel (iron oxide) phase commonly carries the transition metals. It appears, therefore, that certain specific phases and trace metal affiliations are characteristic of ash regardless of the type of coal or operating procedure used. This hypothesis is being tested in greater detail through a project at the University of Southern California (RP1371). A number of different ashes will be subjected to a series of successive extractions (ranging from extraction with distilled water through total dissolution with hydrofluoric-perchloric acids) as a means of identifying the chemical affiliation of a wide range of trace metals. The results of these two studies will provide information on the effect of combustion conditions on trace metal associations and on the availability of trace contaminants to natural leaching fluids.

Visibility measurement

Dames & Moore is conducting a preliminary evaluation in the Southwest of visibility-measuring devices and the relation between visibility impairment and the physics and chemistry of the atmosphere (RP1305). The field research will be carried out in northern Arizona and southern Utah. Visibility will be measured by cameras (black-and-white and color), telephotometers, and ground- and air-based nephelometers. Atmospheric particles will be collected on filters and analyzed for size distribution and for a number of chemical parameters, principally the presence of sulfates and nitrates. A similar program will be conducted early in 1979 at SURE stations in Duncan Falls, Ohio, and Scranton, Pennsylvania. SRI International plans to develop an automated telephotometer for visibility measurements. *Project Manager: Ralph Perhac*

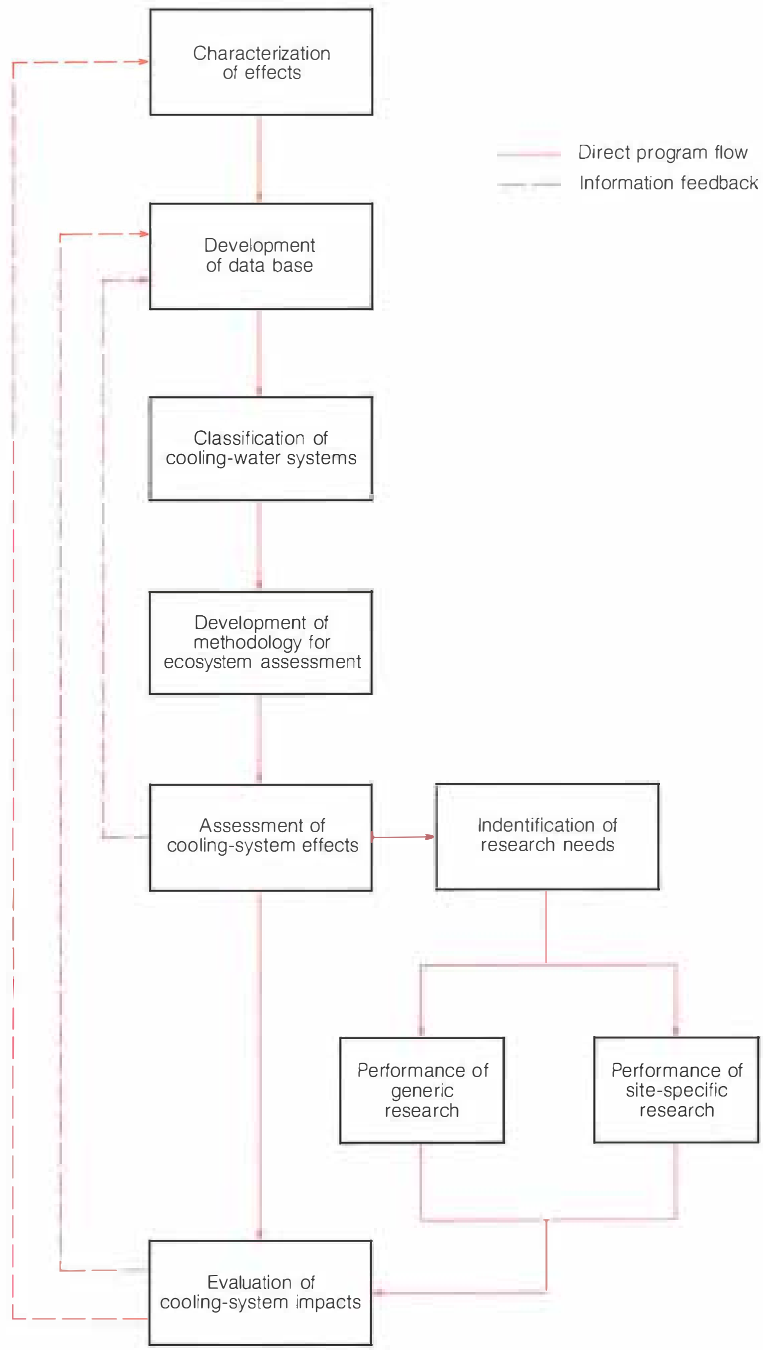
COOLING-SYSTEM EFFECTS

The basic objective of the cooling-system effects subprogram is to develop information and methods that permit reliable assessment of various cooling systems so that feasible alternatives can be fairly considered in project planning and regulatory review.

Part of the subprogram calls for characterization of cooling-system effects, which primarily involves data collection and environmental impact assessment in a broad perspective (Figure 3). Utility monitoring programs and assessments under sections 316(a) and 316(b) of the federal Clean Water Act generally fit into this category. Possible ecological impacts are suggested, but at this level of investigation they are not addressed in a quantitative, rigorous fashion.

An extensive data base is now available in the form of reports that were prepared as a result of environmental assessment programs conducted by individual utilities, industry groups, and other investigators. A project was initiated in 1976 to facilitate identification of relevant data and literature and to provide a means of accessing the information (RP877). The project is divided into two major portions. Under the AIF–INFORUM project, Atomic Industrial Forum, Inc., is responsible for obtaining, abstracting, and filing reports from the industry that are not available in the open literature. ORNL similarly compiles information published in journals, books, and government reports. The two groups work cooperatively and channel bibliographic information into compatible computerized systems. Both contractors maintain response and referral services and produce selected topical bibliographies. ORNL also produces critical

Figure 3 Framework of cooling-system effects subprogram.



reviews of selected topics in the cooling-system data base. Two workshops were held in 1978 to promote the use of these systems.

While the data base projects provide a readily accessible library of information and study reports, they do not provide comprehensive categorical listings of data on physical, chemical, and biological factors that would be pertinent for comparative studies or for extrapolation of results from one site to another. Since the basic systems for abstracting and classifying data have been developed, it is now imperative that a project be initiated to develop a classification of environmental descriptors associated with cooling systems and that the data base be expanded to include these factors. Such a project is planned for 1979.

Assessment of potential ecosystem effects requires that the collection and ordering of data be accomplished in a manner that ensures adequate description of the functional and structural characteristics of the system. It is necessary to establish a methodology for relating data on the various components of the ecosystem in a way that incorporates changes caused by cooling-system operation. The state of the art of ecosystem models is relatively primitive. However, models can determine the relative importance of ecosystem factors and compare system reactions to various stresses that might be imposed by alternative cooling systems.

Lawler, Matusky & Skelly Engineers (LMS) is conducting a project to develop a definitive methodology for assessing ecosystem effects of a single-plant cooling system in lakes, rivers, estuaries, and marine systems, concentrating on major species of fish and invertebrates (RP876). In a companion project, being conducted by Tetra Tech, Inc., a methodology will be developed to assess the impact of several power plants on a single body of water (RP878). Each of these projects will include test application of the methodology to representative plant sites. The LMS methodology is to be tested for the lower Hudson River plants, for Pilgrim Nuclear Power Station on Cape Cod Bay, and for the Missouri River near Nebraska City. Both LMS and Tetra Tech will apply their methodologies to Cayuga Lake in New York. The methodology development and testing by both contractors will be completed by late 1979.

The Illinois Natural History Survey has been developing an ecological model for a cooling reservoir, using both literature-derived relationships and information on Lake Sangchris in Illinois (RP573). The results of this study will be available in early 1979. However, the model will not fully integrate effects of plant operation or be readily adaptable to a wide range of cooling-reservoir conditions. A priority for 1979 is to extend the results of this effort to develop a more complete assessment methodology that can be applied in evaluation and planning for new cooling lakes.

Aquatic effects of cooling-system operation may be assessed in a variety of ways, ranging from intuitive judgments about the significance of organism mortality to complex ecosystem model simulations. Existing projects in this subprogram include broad reviews of potential or reported ecosystem impacts as well as support for improving techniques for measuring effects of plant operation.

LMS is also conducting a critical review of literature and data related to potential ecosystem impacts of phytoplankton and zooplankton entrainment (RP876). Another project, run by Battelle, Pacific Northwest Laboratories, involves a comprehensive review and assessment of the ecological aspects of cooling impoundments and power plant operations (RP880). This project will be completed this year and should provide valuable input to the development of a methodology for assessing cooling lakes. Effects of cooling-water chlorination have been considered in conjunction with the more basic problems of cooling-system effects.

The EPRI subprogram is largely directed toward generic problems, such as the development of acceptable assessment methods and data bases and the acquisition of generic data. But issues on cooling-system effects are to some degree site-specific. Utilities and other regionally oriented assessment groups can benefit if generic results are applied to a maximum degree. Site-specific data should be necessary only to confirm certain characteristics or to provide basic input for a methodological assessment.

A final evaluation of the acceptability of a given cooling-system design should be based (as far as possible) on the cumulative evidence and experience of the industry. It is necessary, therefore, to provide adequate maintenance of the data base and to further develop assessment methods. This feedback of information will strengthen the foundation of individual evaluations and help clarify genuine research needs. *Project Manager: John Reynolds*

EPRI Patents

This list includes EPRI inventions available for licensing as of September 1978. For further information, write EPRI's Manager of Patent Administration and Licensing or telephone (415) 855-2216.

ELECTRICAL SYSTEMS

AC Overhead Transmission

A Method for Forming Zinc Oxide-Containing Ceramics by Hot Pressing and Annealing
U.S. patent pending (KD0657-01-02)

A Setter for a Ceramic Body and Methods of Formation and Use
U.S. patent pending (KD0657-01-06)

A Voltage-Limiting Composition and Method of Fabricating the Same
U.S. patent pending (KD0657-01-04)

Chemically Activated Switch
U.S. patent pending (KD0281-02-09)

Circuit Interrupter Using a Minimum of Dielectric Liquid
U.S. patent pending (KD0478-01-02)

Circuit Interrupter Using a Dielectric Liquid with Energy Storage
U.S. patent pending (KD0478-01-03)

Combustible Gas-in-Oil Detector
U.S. Patent No. 4,058,373 (KD0748-01-01)

Current Interrupter Electrode Configuration
U.S. patent pending (KD0564-01-03)

Current Interrupter for Fault Current Limiter and Method
U.S. patent pending (KD0281-02-10)

Current-Limiting Circuit Arrangement
U.S. patent pending (KD0654-01-01)

Explosively Activated Fault Current Limiter
U.S. patent pending (KD0281-02-07)

Fault-Current-Limiting Resistor
U.S. patent pending (KD0281-02-01)

Filled Polymer Electrical Insulator
U.S. patent pending (ED1203-76-55)

Hermetic Quick Connection and Seal for Coupling Low-Pressure Systems
U.S. patent pending (KD0565-01-01)

High-Strength Alumina Ceramic Product and Method of Forming
U.S. patent pending (KD0424-01-01)

High-Voltage, High-Current Cable Terminal with Dual-Grading Capacitor Stack
U.S. patent pending (ED7814-76-52)

High-Voltage Overhead Electrical Transmission Cable Protected from Wet-Environment Corona Losses
U.S. patent pending (ED0068-76-47)

High-Voltage Plain-Break Circuit Interrupter
U.S. patent pending (KD0655-01-04)

High-Voltage Two-Stage-Triggered Vacuum Gap
U.S. patent pending (KD0754-01-01)

Improved Current Limiter Vacuum Envelope
U.S. patent pending (KD0564-01-08)

Improved Fault Current Limiter
U.S. patent pending (KD0654-76-36)

Method and Apparatus for Sensing the Clearance of Fault Current on an AC Transmission Line
U.S. patent pending (KD0281-02-02)

Method for the Nondestructive Testing of Voltage-Limiting Blocks
U.S. patent pending (KD0657-01-01)

Repulsion Coil Actuator for High-Speed, High-Power Circuits
U.S. Patent No. 4,086,645 (KD0564-01-09)

Structurally Improved Rod Array Vacuum Interrupter
U.S. patent pending (KD0754-01-03)

Temperature-Sensing Device
U.S. patent pending (KD0479-01-01)

Tiered, Convoluted, Shielded Insulators
U.S. patent pending (ED1203-75-16)

Vacuum Arc Current-Switching Device
U.S. patent pending (ED0476-76-28)

Vacuum-Arc-Switching Device With Internal Shielding
U.S. patent pending (KD0564-01-02)

Vacuum Envelope for Current Limiter
U.S. patent pending (KD0564-01-04)

Vacuum Interrupter Configuration
U.S. patent pending (ED0564-76-43)

Vacuum-type Circuit Interrupter
U.S. patent pending (KD0564-01-06)

Voltage Regulator Utilizing a Static VAR Generator
U.S. patent pending (KD0750-01-01)

Voltage Regulator Utilizing a VAR Generator With Half-Period Averaging and Saturating-type Firing Angle
U.S. patent pending (KD0750-01-02)

DC Transmission

Electronic Current Transducer for High-Voltage Transmission Lines
U.S. patent pending (KD0668-01-02)

Light-Activated Semiconductor Device Package Unit
U.S. patent pending (KD0669-01-01)

Method and Means for Trapping Particles in Enclosed High-Voltage Electric Bus Apparatus
U.S. Patent No. 4,029,892 (KD0213-01-06)

Multigate Light-Fired Thyristor and Method
U.S. patent pending (KD0669-01-07)

Package for Light-Triggered Thyristor
U.S. patent pending (KD0567-01-03)

Particle-Trapping Elbow Joint for Enclosed High-Voltage Electric Bus Apparatus
U.S. Patent No. 4,029,890 (KD0213-01-13)

Particle-Trapping Sheath Coupling for Enclosed Electric Bus Apparatus
U.S. Patent No. 4,029,891 (KD0213-01-08)

Particle-Trapping Sheath Coupling for Enclosed Electric Bus Apparatus
U.S. Patent No. 4,042,774 (KD0213-01-15)

Rapid Response Generating Voltmeters
U.S. Patent No. 4,054,835 (KD0213-01-16)

Self-Protection Against Breakover Turn-On Failure in Thyristors Through Selective Base Lifetime Control
U.S. patent pending (KD0669-01-02)

Stab Connector for Enclosed Electric Bus Apparatus
U.S. Patent No. 4,082,933 (KD0213-01-12)

Thyristor Device With Self-Protection Against Breakover Turn-On Failure
U.S. Patent No. 4,079,403 (KD0669-01-03)

Thyristor Device With Self-Protection Against Breakover Turn-On Failure
U.S. patent pending (KD0669-01-04)

Transformer Cascade for Powering Electronics on High Voltage Transmission Lines
U.S. Patent No. 4,087,701 (KD0668-01-01)

Distribution

Current-Limiting Fuse Construction and Method
U.S. patent pending (KD0428-01-03)

Current-Limiting Fuse With Resinous Arc-Quenching Filler
U.S. patent pending (KD0428-01-02)

Electrical Apparatus
U.S. patent pending (KD0930-01-05)

Overpressure Protection for Vaporization-Cooled Electrical Apparatus
U.S. patent pending (KD0930-01-12)

System for Detecting Foreign Particles and Voids in Plastic Material and Method
U.S. patent pending (KD0794-01-01)

System for Detecting Foreign Particles or Voids in Electrical Cable Insulation and Method
U.S. patent pending (KD0794-01-02)

Vaporization-Cooled and -Insulated Electrical Apparatus
U.S. patent pending (KD0930-01-14)

Vaporization-Cooled Electrical Apparatus
U.S. patent pending (KD0930-01-11)

Vaporization-Cooled Electrical Apparatus
U.S. patent pending (KD0930-01-15)

Vaporization-Cooled Electrical Apparatus
U.S. patent pending (KD0930-01-21)

Vaporization-Cooled Electrical Inductive Apparatus
U.S. patent pending (KD0930-01-17)

Rotating Electrical Machinery

A Stored-Field Superconducting Electrical Machine and Method
U.S. patent pending (ED0429-77-07)

An Auxiliary Field Winding for a Superconductive AC Electrical Machine and Method of Exciting Same
U.S. patent pending (KD0429-02-03)

Apparatus for Supporting a Stator Winding in a Superconducting Generator
U.S. patent pending (KD0429-02-04)

Extra-High Voltage Winding for Turbine Generator
U.S. patent pending (KD0429-01-05)

Flexible Coupling for Rotor Elements of a Superconducting Generator
U.S. patent pending (KD0429-01-04)

High-Voltage DC Transmission System and Method
U.S. patent pending (ED0429-76-56)

Improved Method and Apparatus for Operating Generator in Its Superconducting State
U.S. patent pending (KD0429-01-03)

Improved Superconducting Hybrid Magnetic Flux Pump
U.S. patent pending (ED0563-75-15)

Method and Apparatus for Cooling a Winding in the Rotor of an Electrical Machine
U.S. patent pending (KD0429-02-02)

Multiphasic Pump for Rotating Cryogenic Machinery
U.S. patent pending (KD0429-01-02)

Sliding Support for a Superconducting Generator Rotor
U.S. Patent No. 4,092,555 (KD0429-01-01)

Spiral Pancake Winding for Two-Pole Electrical Machine, Specifically, Turbine Generator
U.S. patent pending (KD0429-01-06)

Superconducting Generator and Method
U.S. patent pending (KD0429-01-09)

Superconducting-Generator Thermal-Radiation Shield Having Substantially Uniform Temperature
U.S. patent pending (KD0429-02-01)

Underground Transmission

Backfilling Material and Method of Preparation Thereof
U.S. patent pending (KD7841-01-01)

Cutter for Corrugated Pipe for Flexible Gas-Insulated Transmission Line
U.S. Patent No. 4,078,304 (KD7837-01-01)

Cutter for Helically Corrugated Tube for Flexible Gas-Insulated Cable
U.S. Patent No. 4,063,355 (KD7837-01-03)

Evaporation-Cooled Transmission Line System
U.S. Patent No. 4,091,230 (ED7834-75-12)

Extruded Sheath Section for Compressed-Gas-Insulated Transmission Lines
U.S. patent pending (KD7840-01-02)

Improved Transmission Line Breakdown Voltage
U.S. patent pending (ED7835-75-08)

Insulation Spacer for Flexible Gas-Insulated Transmission Line
U.S. patent pending (KD7837-01-04)

Means for Protecting Underground Equipment From Thermal Runaway
U.S. patent pending (ED7841-76-33)

Method of Fabricating Compressed Insulated Cable
U.S. Patent No. 4,053,338 (KD7840-01-04)

Multiple Part Insulator for Flexible Gas-Insulated Transmission Line Cable
U.S. patent pending (KD7837-01-06)

Multiple Part Insulator for Flexible Gas-Insulated Transmission Line Cable
U.S. patent pending (KD7837-01-09)

Offset Constant Thickness Web for Insulator Support Disk
U.S. patent pending (KD7837-01-07)

Self-Contained Flexible Bus Reel Assembly
U.S. patent pending (KD7837-01-08)

Sodium-Filled Flexible Transmission Cable
U.S. Patent No. 4,056,679 (KD7837-01-02)

Termination for Stranded Cable
U.S. patent pending (KD7837-01-05)

Welded Joint in Segmented Sheath for Compressed-Gas-Insulated Transmission Lines
U.S. patent pending (KD7840-01-03)

Multiprograms

Arc Spinner Interrupter With Chromium Arcing Contact
U.S. patent pending (KD0661-01-07)

Arc Spinner Interrupter With Contact Follower
U.S. patent pending (KD0661-01-06)

Hybrid Power Circuit Breaker
U.S. patent pending (KD0661-01-01)

Moving Contact for Localized Gas-Flow Arc Spinner-type Interrupter
U.S. patent pending (KD0661-01-05)

Thin Arc Runner for Arc Spinner Interrupter
U.S. patent pending (KD0661-01-03)

FOSSIL FUEL AND ADVANCED SYSTEMS

Air Quality Control

Apparatus and Method for Ionizing Gases, Electrostatically Charging Particles, and Electrostatically Charging Particles or Ionizing Gases for Removing Contaminants From Gas Streams
U.S. patent pending (KD0386-01-01)

Assembly for and Method of Sampling Particle-Laden Fluids and a Cascade Impactor Used Therewith
U.S. patent pending (KD0414-01-01)

Convective Heat Transfer Steam Boiler for Fuels of Low Energy and Ash Content
U.S. patent pending (ED0265-75-07)

Focusing Electrodes for High-Intensity Ionizer Stage of Electrostatic Precipitator
U.S. patent pending (KD0386-01-03)

Oil Burner for NO_x Emission Control
U.S. Patent No. 4,023,921 (ED0899-75-06)

Resistive Anode for Electrostatic Precipitation
U.S. patent pending (KD0386-01-02)

Urea Reduction of NO_x in Combustion Effluents
U.S. patent pending (KD0461-01-01)

Urea Reduction of NO_x in Fuel-Rich Combustion Effluents
U.S. patent pending (KD0461-01-02)

Vaned Anode for High-Intensity Ionizer Stage of Electrostatic Precipitator
U.S. patent pending (KD0386-01-04)

Clean Gaseous Fuels

GEGAS-D Coal Gasifier Grate Design for Clinker Crusher
U.S. patent pending (KD0357-01-08)

Membrane Package for Immobilized Liquid Membrane
U.S. patent pending (KD0357-01-09)

Clean Liquid and Solid Fuels

A Process for the Isolation of Chemicals From Processed Coals
U.S. patent pending (KD0410-01-02)

Hydroprocessing Coal Liquids
U.S. patent pending (KD0361-02-03)

Hydroprocessing of Solvent-Refined Coal
U.S. patent pending (KD0361-02-04)

Method for Hydroprocessing Solvent-Refined Coal
U.S. patent pending (KD0361-01-01)

Method of Improving Compatibility of Coal Liquids With Petroleum Base Fuels
U.S. patent pending (KD0361-01-02)

Phenolic Recycle Solvent in Two-Stage Coal Liquefaction Process
U.S. patent pending (KD0410-01-03)

Prevention of Solids Formation in SRC Reactors
U.S. patent pending (KD1234-76-04)

Process for Coal Liquefaction
U.S. patent pending (KD0410-01-08)

Reactor for Solvent-Refined Coal and Method
U.S. Patent No. 4,021,328 (ED0779-74-03)

Reactor for Solvent-Refined Coal and Method
U.S. patent pending (KD1234-74-04)

Synthetic Liquid Fuels
U.S. patent pending (KD0832-76-17)

Treatment of Coal for the Production of Clean Solid Fuel and/or Liquid Turbine Fuel
U.S. patent pending (KD0410-01-01)

Two-Stage Coal Liquefaction
U.S. patent pending (KD0410-01-07)

Energy Storage

A Composite Sulfur Electrode Container and Method of Manufacture
U.S. patent pending (KD0128-04-10)

A Sodium-Sulfur Cell Component Protected by a High Chromium Alloy and Method for Forming
U.S. patent pending (KD0128-04-07)

Construction for Solid Electrolyte in Sodium-Sulfur Battery
U.S. Patent No. 4,049,885 (KD0128-02-02)

Contact Between Metal Can and Carbon-Graphite Fibers in Sodium-Sulfur Cells
U.S. Patent No. 4,053,689 (KD0128-03-01)

Efficient Sodium-Sulfur Battery
U.S. Patent No. 4,070,527 (KD0128-03-04)

Improved Multi-Ring Inertial Energy Storage Wheel Having Tapered Ring-Mounting Members
U.S. patent pending (KD0269-01-03)

Improved Ring Assembly for Inertial Energy Storage Rotor
U.S. patent pending (KD0269-01-02)

Inertial Energy Storage Rotor With Tension-Balanced Catenary Spokes
U.S. patent pending (KD0269-01-05)

Metal Halogen Cell Operation With Storage of Halogen Via Organic Complexation External to the Electrochemical Cell
U.S. patent pending (KD0635-01-01)

Method and Apparatus for Measuring the Interior Dimensions of a Hollow Body
U.S. patent pending (KD0737-01-01)

Method for Producing Sodium-Beta-Alumina Solid Electrolytes
U.S. Patent No. 3,959,022 (KD252-01-01)

Modular Electrical Energy Storage Device
U.S. Patent No. 4,012,562 (KD0116-02-01)

Multiple-Ring Inertial Storage Wheel With Improved Inter-Ring Connector
U.S. Patent No. 4,058,024 (KD0269-01-01)

NaS Cell Reactant Container With Metal Aluminide Coating
U.S. Patent No. 4,048,390 (KD128-03-09)

Naturally Commutated Voltage-Fed Converter for Linking a DC Source to an AC System
U.S. patent pending (KD0390-01-01)

Positive Electrode for Electrical Energy Storage Device
U.S. Patent No. 3,925,098 (KD-116-02-03)

Recovery of Lead From Batteries
U.S. Patent No. 4,058,396 (ED0419-75-11)

Rotor Ring for Inertial Energy Storage Rotor
U.S. patent pending (KD0269-01-04)

Sodium-Sulfur Battery
U.S. patent pending (KD0128-03-12)

Sodium-Sulfur Cell Casings
U.S. patent pending (KD0128-03-08)

Sodium-Sulfur Cell Construction and Method
U.S. patent pending (KD0128-04-04)

Sulfur Electrode Container and Methods of Manufacture
U.S. patent pending (KD0128-04-08)

Sulfur Electrode Container Construction and Method of Manufacture
U.S. patent pending (KD0128-04-03)

Fluidized Combustion and Coal Cleaning

Apparatus and Method for Combusting Carbonaceous Fuels Employing in Tandem a Fast-Bed Boiler and a Slow Boiler
U.S. patent pending (ED1028-76-02)

Gas Distributor for Fluidizing Beds
U.S. patent pending (KD0525-01-01)

Fuel Cells and Chemical Energy Conversion Technology

Electrolytic Cell Having a Novel Electrode Including Platinum on a Carbon Support Actuated With a Phosphorus-Oxygen–Containing Compound
U.S. patent pending (KD0583-01-01)

Highly Dispersed, Supported Group VIII Metal-Phosphorus Compounds and Highly Dispersed, Supported Group VIII Metal-Arsenic Compounds and a Process for Making Said Compounds
U.S. patent pending (KD0583-01-02)

The Preparation of Highly Dispersed, Supported Group VIII Metal Catalysts and the Redispersion of Sintered or Agglomerated, Supported Group VIII Metal Catalysts by the Addition of Phosphorus
U.S. patent pending (KD0583-01-03)

Fusion

Brush Actuation Mechanism
U.S. patent pending (KD0469-03-01)

Releasable High-Pressure Seal and Method of Forming Same
U.S. Patent No. 4,113,242 (KD0473-01-01)

Power Generation

Blade Attachment Structure for Gas Turbine Rotor
U.S. patent pending (KD0421-01-02)

Bucket Tip Construction for Open-Circuit Liquid-Cooled Turbines
U.S. patent pending (KD0234-03-05)

Ceramic Rotor Blade Having Root With Double Curvature
U.S. patent pending (KD0421-01-01)

Dimpled Cooling Passages for Water Cooling a Gas Turbine Bucket
U.S. patent pending (KD0234-03-08)

Improved Cooling System for a Gas Turbine, Using V-Shaped Notched Weirs
U.S. patent pending (KD0234-02-02)

Liquid-Cooled Gas Turbine Buckets
U.S. patent pending (KD0234-01-09)

Liquid-Cooled Transition Member and Method of Manufacture of the Transition Member
U.S. patent pending (KD0234-02-01)

Liquid-Cooled Turbine Rotor
U.S. patent pending (KD0234-01-12)

Multiple-Piece Ceramic Turbine Blades
U.S. patent pending (KD0421-01-06)

Pin-Finned Cooling Passages for Water Cooling a Gas Turbine Bucket
U.S. patent pending (KD0234-03-06)

Rotor Disk Coupling Means
U.S. patent pending (KD0234-01-05)

Turbine Rotor Tip Water Collector
U.S. patent pending (KD0234-01-15)

Turbine Rotor With Ceramic Blades
U.S. Patent No. 4,093,399 (KD0421-01-05)

Turbine Rotor With Pin-Mounted Ceramic Turbine Blades
U.S. Patent No. 4,084,922 (KD0421-01-04)

Multiprograms

Apparatus for Defrosting Low-Temperature Heat Exchanger
U.S. patent pending (KD0544-01-04)

Fuel-Fired Supplementary Heater for Heat Pump
U.S. patent pending (KD0544-01-05)

Heating and Cooling System and Method
U.S. patent pending (KD0544-01-06)

Heat Pump System and Improved Heat Transfer
U.S. Patent No. 4,042,012 (ED0544-76-41)

Loss-Heat-Suppression Apparatus and Method for Heat Pump
U.S. patent pending (KD0544-01-01)

Two-Speed Drive Apparatus
U.S. patent pending (KD0544-01-03)

Variable-Speed Drive Unit for Compressor of Heat Pump
U.S. Patent No. 4,094,165 (KD0544-01-02)

NUCLEAR POWER

Developing Application and Technology

Apparatus for Sealing a Rotatable Plug in a Nuclear Reactor
U.S. patent pending (ED0620-76-51)

Method and Apparatus for Controlling the Neutron Flux in Nuclear Reactors
U.S. patent pending (ED0620-76-15)

Method and Apparatus for Reducing the Power Level in a Nuclear Reactor During Temperature Transient
U.S. patent pending (ED0620-76-39)

Fuels, Waste, and Environment

Apparatus and Method for Detecting Power Distribution in a Nuclear Reactor Fuel Element
U.S. patent pending (ED0130-75-17)

Mixed-Oxide Fuel Pellet for Fuel Rod of Nuclear Reactor Core
U.S. patent pending (ED0396-75-21)

Reliability, Availability, and Economy

Method of Detecting and Monitoring a Leak Crack Caused by a Through-Wall Crack in a High-Pressure Fluid System
U.S. patent pending (ED1246-76-13)

Water Reactor System Technology

A Linear Transducer Array and Method for Both Pulse-Echo and Holographic Imaging
U.S. patent pending (KD0606-01-01)

A Method of Improving the Efficiency of Generating Elastic Waves, Using Electromagnetic Transducers
U.S. patent pending (KD0698-01-02)

An Electromagnetic Transducer
U.S. patent pending (KD0698-01-01)

Biaxial Capacitance Strain Transducer
U.S. Patent No. 4,030,347 (KD0218-01-01)

Method and Apparatus for Energizing an Array of Acoustic Transducers to Eliminate Grating Lobes
U.S. patent pending (KD0606-01-02)

Method and Apparatus for Nondestructively Testing Electrically Conductive Components With Eddy Currents
U.S. patent pending (KD0403-01-02)

Method and Apparatus for Rotating Cartesian Coordinate Signals
U.S. patent pending (KD0403-02-01)

Method and Apparatus for Ultrasonically Measuring Concentrations of Stress
U.S. patent pending (KD0504-01-01)

Optical Fiber Temperature-Sensing System
U.S. patent pending (KD0970-01-02)

Quick-Opening Pressure-Release Device and Method
U.S. patent pending (KD0687-01-01)

Response-Time Verification of In Situ Hydraulic Pressure Sensors in a Nuclear Reactor
U.S. patent pending (KD0503-01-01)

Turbine Generator Ground-Current-Arcing Detection Apparatus and Method
U.S. patent pending (KD0970-01-01)

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ELECTRICAL SYSTEMS

Longitudinal Unbalanced Loads on Transmission Line Structures

EL-643 Final Report (RP561)

GAI Consultants, Inc., developed analytic procedures for calculating static and dynamic longitudinal loads on transmission line structures. Loadings because of broken wire and differential ice disturbances were considered. A computer program solved the nonlinear equilibrium equations and calculated the residual static longitudinal loads and displacements caused by these disturbances. This report contains easy-to-use design guides for the rapid determination of static and dynamic loads. *EPRI Project Manager: Richard Kennon*

Improvement and Performance Evaluation of an Advanced Hybrid Simulator for Power System Dynamics

EL-724 Final Report (RP908)

An analog model of a power system, which was scaled to operate 20 times faster than real time, was programmed for a special-purpose hybrid computer by the University of Missouri at Columbia. The hybrid computer was controlled by a digital computer. The model was used in research on long-term power system dynamic behavior under contingency conditions. The purpose of this project was to further investigate the capabilities of the hybrid computer to meet utility technical performance criteria, while satisfying cost objectives. *EPRI Project Manager: Timothy Yau*

Frequency Domain Analysis of Low-Frequency Oscillations

EL-726 Interim Report, Parts 2 and 3 (RP744-1)

This report by Westinghouse Electric Corp. describes mathematical models and computing methods for determining the natural frequencies and damping of generator rotor oscillations in large electric power systems. These models and methods provide the basis for estimating those eigenvalues most closely related to rotor motion. The principal computation problem is the calculation of incremental voltage oscillations in a linear system model subjected to an external forcing function. This linear system model is derived from networks and generator representations used in conventional time-domain stability calculations. The report explains methods of using the model to calculate voltages and using these voltages in an iterative process to estimate eigenvalues. *EPRI Project Manager: Richard Steiner*

Three-Phase UHV AC Transmission Research

EL-823 Final Report (RP68-2)

General Electric Co. constructed and operated a three-phase ac test line at EPRI's Project UHV with line voltages up to 1500 kV. The feasibility of UHV transmission was demonstrated, and problems affecting cost and performance were identified. The research provided design data on the corona performance of conductor and line configurations and on the dielectric strength of the external insulation of UHV transmission systems. *EPRI Project Manager: Frank Young*

Controlled Impedance Short-Circuit Limiter

EL-857 Final Report (RP654)

Fault currents in power systems are approaching the rating limits of installed equipment, particularly circuit breakers. Various ways to limit fault currents have been proposed, but Westinghouse Electric Corp. investigated the controlled impedance short-circuit limiter (CISCL). The CISCL places a series-tuned, inductor-capacitor circuit in each line that virtually has zero impedance during normal operation but rapidly switches to a parallel-tuned, high-resistive impedance at the start of a fault, thus limiting the current before the first high-current peak. *EPRI Project Managers: Arnold Johnson and Vasu Tahiliani*

ENERGY ANALYSIS AND ENVIRONMENT

The Potential of Helium As a Guide to Uranium Ore

EA-813 Final Report (RP807-1)

Martin Marietta Corp. and Earth Sciences, Inc., studied the effectiveness of helium surveying as a tool for uranium exploration. They generated basic data on the little-known distribution of helium in soils, tested various techniques for conducting surveys in the field, developed guidelines for helium surveys and interpretation, and stimulated interest, if it was warranted, in the further testing and application of promising approaches. *EPRI Project Manager: Jeremy Platt*

Cooling-System Effects on Water Quality and Aquatic Biota

EA-872 Special Report (RP877-1)

A bibliography of about 1200 reports contributed by U.S. electric utilities was compiled by Atomic Industrial Forum, Inc. The reports, which cover cooling-system thermal and chemical effects, entrainment, and impingement, were abstracted and keyworded in a computer data base available for industry use. *EPRI Project Manager: Robert Goldstein*

FOSSIL FUEL AND ADVANCED SYSTEMS

Some Safety Considerations for Conceptual Tokamak Fusion Power Reactors

ER-546 Final Report (RP236-1)

The major objective of this study by the University of California at Los Angeles was to identify potential safety questions for magnetically confined fusion power reactors. The results are largely based on one design, a conceptual tokamak reactor operating on the deuterium-tritium fuel cycle.

The principal hazards were identified as tritium, induced activity in the first wall and in corrosion and structural materials, and the presence of relatively large quantities of nonradioactive toxic materials. *EPRI Project Manager: Noel Amherd*

Some Safety Considerations in Laser-Controlled Thermonuclear Reactors

ER-547 Final Report (RP236-1)

The University of California at Los Angeles examined potential safety questions for laser-controlled thermonuclear reactors. From conceptual designs, it does not appear these reactors present hazards that are very different from those of magnetically confined fusion reactors. Some hazards are comparatively reduced, such as small lithium inventories and the absence of cryogenic devices, while other hazards are concept-specific, such as the explosion of pressure vessels and the inherent laser hazards. Major aspects considered in this report are general safety considerations, tritium inventories, system behavior during loss-of-flow accidents, and safety considerations of laser-related penetrations. *EPRI Project Manager: Noel Amherd*

Some Safety Studies for Conceptual Fusion-Fission Hybrid Reactors

ER-548 Final Report (RP236-2)

Potential safety questions for conceptual fusion-fission hybrid reactors were investigated by the University of California at Los Angeles. The study and subsequent analysis were largely based on one design, a conceptual mirror fusion-fission reactor operating on the deuterium-tritium plasma fusion fuel cycle and the uranium-plutonium fission fuel cycle. *EPRI Project Manager: Noel Amherd*

Physiological Effects of Redirected Solar Radiation

ER-651 Topical Report (RP955-1)

Black and Veatch Consulting Engineers examined potential hazards of redirected solar radiation from heliostats used in a solar-thermal power facility. Using high-intensity optical sources to simulate the solar spectrum, hazards to skin and eyes were defined by wavelength in an attempt to establish burn thresholds and thus to determine limits of exposure and restricted occupancy areas at the facility. *EPRI Project Manager: John Bigger*

AC/DC Power Converter for Batteries and Fuel Cells

EM-662 Annual Report (RP841-1)

In the design of an advanced power converter for use in battery energy storage and fuel cell generation systems, United Technologies Corp. expanded an existing FCG-1 fuel cell power-conditioning inverter into a high-efficiency inverter-rectifier system. UTC used improved commutation circuits and advanced semiconductor devices that were capable of operating over wide dc voltage ranges. *EPRI Project Manager: Ralph Ferraro*

Low-Cost Performance-Monitoring System for Solar Water Heaters

ER-795 Key Phase Report (RP554-1)

A need to monitor on-site performance of solar domestic water heaters has been identified throughout the solar industry. This report by Daystar Corp. describes a low-cost method for accomplishing this objective. The system uses a moderate amount of basic instrumentation for data acquisition and a manual data reduction technique. Comparative testing of the method by using two separate configurations of commonly available instruments is reported. *EPRI Project Manager: Gary Purcell*

Mixing and Kinetic Processes in Pulverized-Coal Combustors

FP-806-SY Final Report (RP364-1)

An atmospheric coal combustion furnace was designed and constructed by Brigham Young University to study the effects of turbulent mixing and the kinetic processes occurring in pulverized-coal furnaces. The reactor was constructed in sections, one of which contained several sampling probes that permitted simultaneous gas and particulate sampling. The probes were positioned in the reactor to sample both radially and axially. *EPRI Project Manager: John Dimmer*

Submicron-Particle-Size Measurement With a Screen Diffusion Battery

FP-840 Final Report (RP723)

Air Pollution Technology, Inc., conducted a study of particle collection on wire mesh screens used in the screen diffusion battery. Diffusion is the major collection mechanism for particles in the 0.005–0.5 μm size range.

The study reports experiments performed on arrays of parallel wires. The results verify the theory of particle collection on single cylinders. The single-wire diffusional collection efficiencies of 120-, 250-, and 325-mesh screens fit one design equation but are somewhat greater than efficiency predictions based on theory. *EPRI Project Manager: Robert Carr*

Comparison of Solar Absorption and Vapor Compression Residential Cooling Systems

ER-843 Interim Report (RP923-1)

Texas Electric Service Co. and the University of Texas at Arlington performed tests to compare solar-powered absorption cooling and solar-assisted, electric-powered heat pump cooling for a single-family residence. Solar hot water heating and space heating with electric resistance and heat pump heating as back-ups are included. The house was constructed as a solar energy research facility on the campus of the University of Texas at Arlington. *EPRI Project Manager: Gary Purcell*

Cascade Impactor Sampling System for 0.02–20-μm-Diameter Particles

FP-844 Final Report, Vol. 1 (RP414-1)

An improved cascade impactor sampling train was constructed by the University of Washington (UW) to size particles emitted from electricity-generating stations. The new sampling-train components were designed to accompany the UW Mark 3-4 source test cascade impactor. The capability of this instrumentation to perform in-stack particulate sizing in the 0.02–20-μm diameter range has been demonstrated. Source tests were conducted at the coal-fired power boiler at the J. E. Corette Power Plant, Billings, Montana; the Nucla Power Plant, Nucla, Colorado; and the University of Washington Power Plant, Seattle, Washington. *EPRI Project Manager: Robert Carr*

Low-Btu Gas Combustion Research

FP-848 Final Report (RP210-0-6)

The Institute of Gas Technology conducted a study to characterize problems associated with retrofitting existing utility boilers with low- and medium-Btu gases manufactured from commercially available coal conversion processes. All the experimental results were gathered from a pilot-scale furnace fired with a movable vane boiler burner at a heat input of 0.66 MW (2,250,000 Btu/h). The low- and medium-Btu gases tested ranged in heating value from 3.7 to 11.2 MJ/m^3 (100–300 Btu/ft^3). They were synthetically produced with a natural gas reformer system. Data were collected to permit a comparison between natural gas and low-Btu gases in the areas of flame stability, flame length, flame emissivity, furnace efficiency, and NO_x emissions. *EPRI Project Manager: Donald Teixeira*

Combustion Turbine Repowering of Reheat Steam Power Plants

FP-862 Final Report (RP528-1)

This report by Westinghouse Electric Corp. presents the technical and economic factors related to the repowering of fossil-fired reheat steam power plants. Three configurations are given in which combustion turbines are integrated with the steam cycle, while retaining the existing boilers. Two of the three systems use combustion turbine exhaust gas for combustion of fuel in the main boiler. *EPRI Project Manager: Donald Teixeira*

Heber Geothermal Demonstration Power Plant

ER-863 Interim Report (RP580-2)

The objective of the Heber project is to design, construct, and operate a power plant that will produce a net power output of 45 MW (e), deriving energy from the low-salinity, moderate-temperature (182°C, 360°F) brine heat source available from the Heber geothermal reservoir. A binary-cycle conversion system uses a light aliphatic hydrocarbon mixture to derive heat from the brine supply through heat exchangers and drive the turbine-generator to produce power. Chevron Resources Co. develops the geothermal resource for sale to San Diego Gas & Electric Co. Power output will be distributed to California's Imperial Valley by the Imperial Valley Irrigation District.

The report reviews earlier baseline geothermal studies performed by Holt/Procon for EPRI and the current design optimization performed by Fluor Engineers and Constructors, Inc., and The Ben Holt Company. *EPRI Project Manager: Vasel Roberts*

Vibration Analysis of Rotating Auxiliary Machinery

FP-864 Final Report (RP984-1)

This research effort concentrated on methods of analyzing and predicting excessive vibrations of forced-draft, induced-draft, and booster fans in large power plants. Such vibrations are one of the most common problems for power utilities and cause costly plant shutdowns. A digital computer program was developed to perform dynamic response analyses of total vibratory systems. Results demonstrate that this total-system approach provides a better means for analyzing the multiparameter, fan-foundation-soil interaction problem and for predicting potentially excessive vibrations. *EPRI Project Managers: John Dimmer and Donald Anson*

A Methodology for Solar-Thermal Power Plant Evaluation

ER-869 Interim Report (RP648-1)

Westinghouse Electric Corp. developed an evaluation methodology for solar-thermal power plants. It includes processes for evaluating the impact of solar-thermal plants on utility reliability and margin requirements and economics, plus the impact of solar plant penetration. *EPRI Project Manager: John Bigger*

Geologic Assessment of Compressed-Air Storage Sites in Kansas

EM-877 Final Report (RP102-1)

Black & Veatch Consulting Engineers made a geologic assessment for use in siting compressed-air energy storage plants in Kansas. There were four tasks: to review generation and transmission requirements of the Kansas utility system; to establish a site selection procedure; to select candidate sites; and to develop a site development schedule. *EPRI Project Manager: Thomas Schneider*

NUCLEAR POWER

A Study of Preoperational Practices in Nuclear Power Plants

NP-333 Final Report (TPS76-643)

NUS Corp. investigated the effect of preoperational factors in reactor construction on subsequent radiation buildup and reactor availability. Within the framework of the work performed, there was no indication of a correlation between plant radiation buildup and preoperational factors. *EPRI Project Manager: Robert Shaw*

Gamma Scan Measurements at Edwin I. Hatch Nuclear Plant, Unit 1, Following Cycle 1

NP-511 Final Report (RP130-3)

General Electric Co. conducted a measurement program to obtain relative La-140 gamma-ray intensities from irradiated fuel bundles and rods at the Hatch-1 reactor during the refueling and maintenance outage at the end of the first fuel cycle. Of 106 bundles measured, 75 composed a complete octant of the core, and 35 were adjacent to partially inserted control blades. The data are reported as relative La-140 intensities for discrete locations along the fuel axis. The data are further formatted into various displays to accentuate particular features of the core, such as controlled bundle shapes, core radial shapes, and bundle power asymmetries. *EPRI Project Manager: Robert Whitesel*

Core Design and Operating Data for Cycles 1 and 2 of Peach Bottom-2

NP-563 Topical Report (RP1021-1)

This report by General Electric Co. contains the design and operating data needed to define the fuel characteristics, vessel internal components, nuclear steam supply system components, and reactor operation characteristics for cycles 1 and 2 of the Peach Bottom-2 reactor. The purpose is to provide reference-quality data for use in the qualification of reactor core analysis methods and to provide the basis for assessment of the irradiation environment during cycles 1 and 2. *EPRI Project Manager: Robert Whitesel*

An Analytic Model for Bottom Reflooding Heat Transfer in LWRs

NP-756 Key Phase Report (RP248-1)

The University of California at Berkeley developed the UCFLOOD code, which is based on mechanistic models for analysis of bottom reflooding of a single-flow channel and its associated fuel rod or a tubular test section with internal flow. *EPRI Project Manager: K. H. Sun*

In Situ Response-Time Testing of Platinum Resistance Thermometers

NP-834 Final Report, Vols. 1 and 2 (RP503-3)

The University of Tennessee studied the time response of in situ resistance temperature detectors in nuclear reactors. The report covers the theoretical bases, laboratory experimentation, and in-plant testing of three prospective methods. Sensors in the project were representative of those used in safety-related applications in the field. *EPRI Project Manager: David Cain*

Consolidating Power Plant Data Systems

NP-836 Final Report (TPS77-722)

Power plants submit data on plant performance and component performance to a number of organizations. Consolidation of these data in one organization would reduce the burden of reporting and would improve the quality and availability of the data. S. M. Stoller Corp. studied the experience of two utilities and six nonutility companies with the collection and use of equipment performance data in large complex systems and assessed the feasibility of consolidating power plant data bases. *EPRI Project Manager: William Lavallee*

A Preliminary Study of Annulus ECC Flow Oscillations

NP-839 Interim Report (RP347-1)

Creare Inc. fabricated an exploratory test facility to permit observation of potential annulus-flow instability mechanisms that could arise in scale-model reactor tests. The report describes observations of flow behavior in a two-loop model. *EPRI Project Manager: Charles Sullivan*

Refueling Outage Trends in LWRs

NP-842 Interim Report (RP705-1)

Operating experience in LWRs has shown that the impact of refueling outages on loss of availability is much higher than anticipated. Science Applications, Inc., examined the principal causes of the extensions of refueling outages and the effect of these outages on plant productivity, and it suggests an alternative refueling cycle to reduce the outage impact. Both the refueling outages and other major outages are displayed in the report as a function of plant age, which aids in the identification of trends as a plant matures. In addition, 27 refuelings are investigated in depth to determine the contributors to refueling outage extensions. An evaluation indicates that utilities can improve plant availability by up to 6% per year by increasing the time between refuelings from 12 months to 18 months. *EPRI Project Manager: William Lavallee*

Methods for Determining the Cost of Fuel Failures in Nuclear Power Plants

NP-854 Final Report (TPS77-744)

Scandpower Inc. studied the cost of fuel failures in commercial nuclear power plants. Fifteen specific cost elements were identified and related to 44 input parameters. Using the cost relationships developed, about 300 cases were analyzed, taking into account a wide range of fuel performance and parameter variations for large LWRs. *EPRI Project Manager: Adrian Roberts*

Zircaloy-Cladding Deformation and Fracture Analysis

NP-856 Interim Report (RP700 and RP971)

Stanford University and Failure Analysis Associates conducted a performance improvement study of Zircaloy fuel rods, which was directed primarily at the development of a mathematical model of performance. The focus was on mechanical loading, crack formation, and crack propagation. *EPRI Project Manager: Terry Oldberg*

BWR Decay Heat Removal: System Appraisal

NP-861 Interim Report (RP767-7)

Science Applications, Inc., reviewed and independently assessed the decay heat removal system unavailability for a BWR. Although the Rasmussen reactor safety study estimated the system unavailability as 1.6×10^{-6} per year, this report concludes that the system unavailability is 1.4×10^{-8} per year. Fault tree methodology and operating experience were used in the calculations. *EPRI Project Manager: Gerald Lellouche*

Study of Nonlinear Effects on One-Dimensional Earthquake Response

NP-865 Final Report (RP615-1 and RP615-2)

In this report by Dames & Moore and Science Applications, Inc., results of one-dimensional earthquake response computations using the nonlinear explicit finite-difference computer code STEALTH are compared with those obtained from the equivalent linear computer code SHAKE. Two soil profiles subjected to several input motions were studied. The nonlinear soil models used were improved derivations of existing models. Certain features of the models were qualitatively verified with the results from dynamic soil property tests. *EPRI Project Manager: Conway Chan*

PLANNING STAFF

Technical Assessment Guide

PS-866-SR Special Report

This guide was compiled for the use of EPRI staff and contractors to provide a common basis for evaluation of technology alternatives. Data and methods are presented in the report. The sections on data contain fuel price projections, transmission system costs, and information on cost and performance of generating plants that use a wide range of technologies. The sections on methods deal with basic financial assumptions and describe the techniques commonly used by utilities in assessing the relative economic worth of alternative technologies, plants, or system configurations. *Manager, Technical Assessment: Harry Colborn*

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