Passive Reactor Designs

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Cover: Passive cooling concepts are central elements of a new generation of advanced nuclear power plants. Now on the drawing boards, these plants will also be smaller, simpler, and easier to operate than conventional units.

EDITORIAL

The Promise of Passive Plants

I have asked Jack DeVine, an employee on loan from GPU Nuclear, to write the editorial for this issue. Jack has been with EPRI's Advanced Light Water Reactor Program for the last three and a half years and has headed the effort for the last two years, bringing an important utility perspective to this leading edge of the nuclear power field. We are grateful to GPU for making his service here possible.

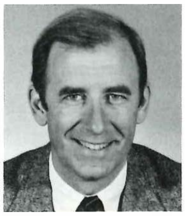
John J. Taylor, Vice President
Nuclear Power Division

Technical advances, plus a renewed determination to learn from past experience, are leading to a renaissance in nuclear power. One element of the technological advance is the concept of passive cooling—designing reactors to keep themselves in a safe state under loss-of-coolant conditions, without the need for rapid human intervention or automatic operation of complicated heavy equipment. Such simplified, built-in safety features can also allow reactors to be constructed economically in smaller units so as to provide utilities an option that might better match their growth needs today.

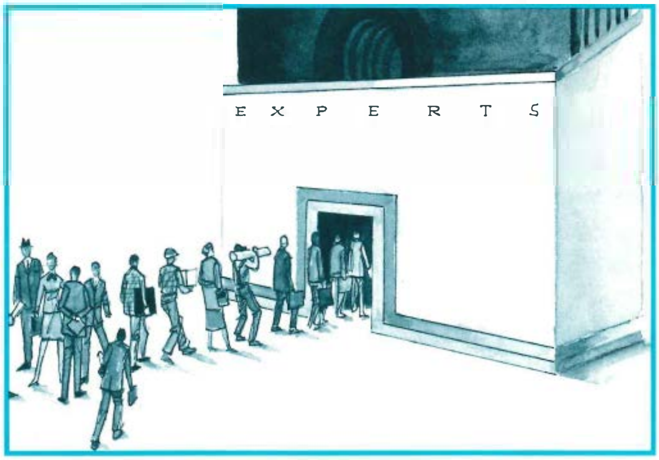
Passive cooling systems harness natural forces and are much simpler than the conventional active safety systems they replace, systems that utilize major pieces of equipment activated by complex automatic control systems and that demand a large supply of electric power. The emergency core cooling system of a passive light water reactor, for example, would use water propelled by gravity and compressed gas rather than by pumps and quick-start power generators. Eliminating such safety equipment can also help overcome economies of scale that have previously worked against small reactors.

As described in this month's cover story, three classes of small, passively stable reactors are now being developed in the United States. Furthest along in the development process is the advanced passive light water reactor, which should be ready for utility orders by the mid-1990s. Each of the other two designs has similar passive stability characteristics and offers potentially unique advantages. The liquid metal reactor can breed more fuel than it uses. The gas-cooled reactor can produce high-temperature process heat in addition to electric power.

Passively stable reactors can provide the foundation for building a new generation of nuclear power plants in the United States. Moreover, the degree of international cooperation—as well as competition—engendered by this development effort is testimony to their potential importance worldwide. Today's nuclear reactors have achieved a remarkable safety record. The next generation of passive reactors will maintain the utility industry's commitment to safety, while being significantly simpler and providing electric generating capacity in smaller unit sizes.



J.C. DeVine, Jr.
Senior Program Manager
Advanced Light Water Reactor Program



DEPARTMENTS

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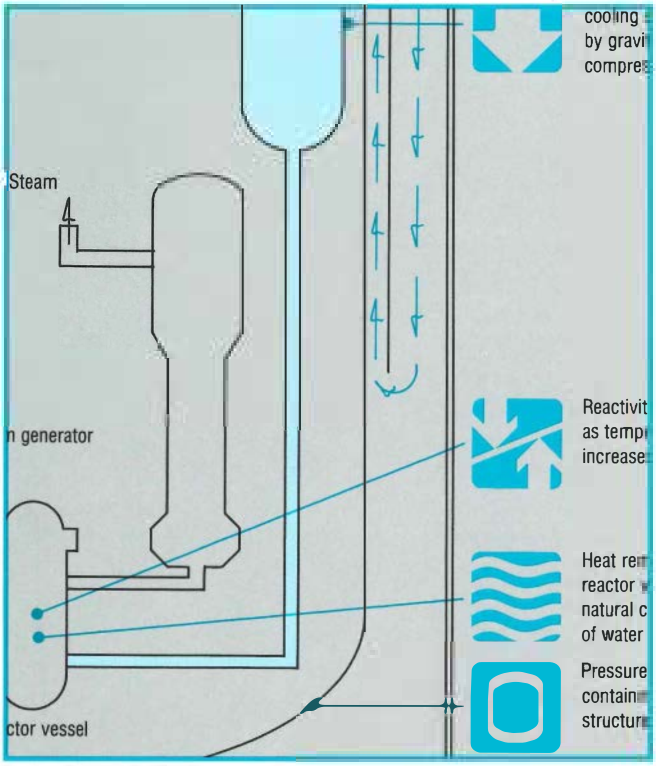
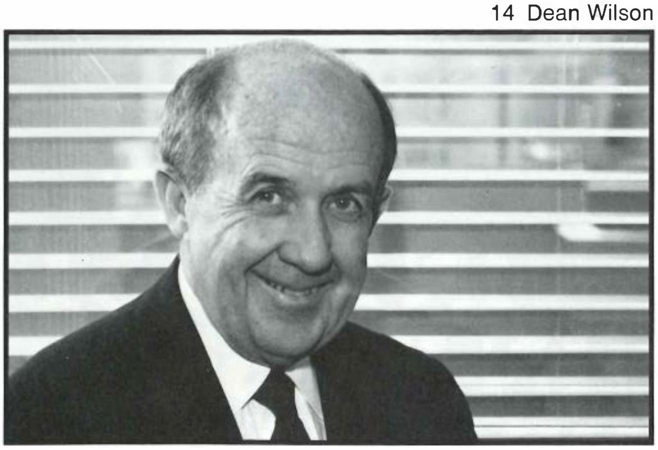
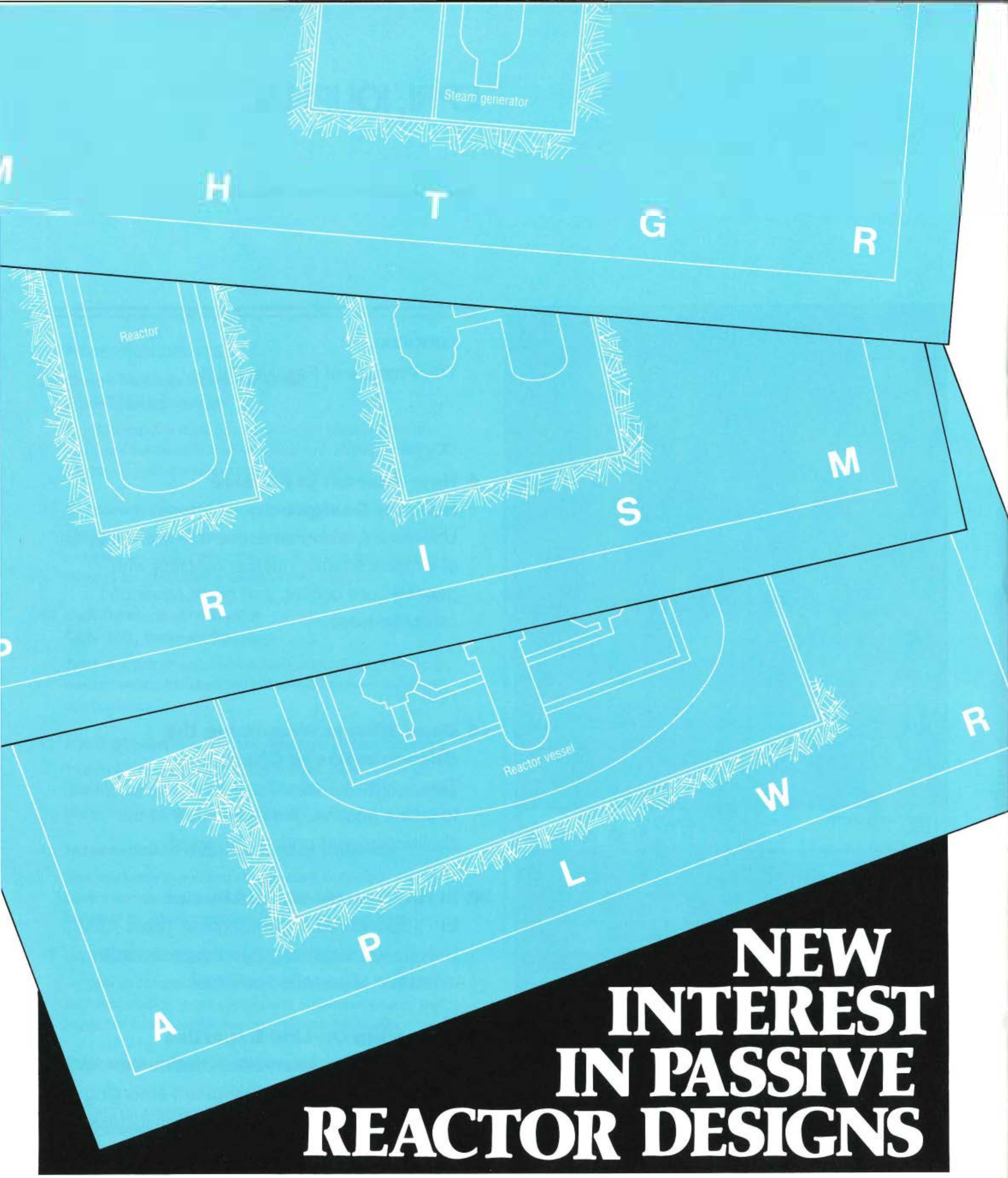


4 Passive Reactors

14 Dean Wilson





NEW INTEREST IN PASSIVE REACTOR DESIGNS

Utilities are taking an active role in the development of advanced nuclear reactor designs that can better meet today's economic, operating, and regulatory demands. Besides being generally smaller in size, the new plants involve passive core cooling and other safety features that take advantage of simple physical principles to promote reactor stability.

More than a decade after the last U.S. utility placed an order for a nuclear power plant, intensive redesign effort is producing simpler, more forgiving reactors. These new designs respond to feedback from utilities—based on their operating experience—that although present reactors have been effective, they are too complex and too demanding.

This new design effort comes just in time to help meet the need for new generating capacity expected by many utilities during the next decade. It also coincides with increased concern that fossil power plants are contributing to acid rain and to possible climate change. Safety issues, however, remain the key to reacceptance of nuclear power by both the public and utilities, so the new designs also have improved safety features.

In a significant departure from traditional practice, electric utilities—rather than reactor vendors and architect/engineers—have taken a more active role in developing performance criteria for the new generation of nuclear power plants. In addition to requiring improved safety, utilities have demanded that the new plants be simpler, more rugged, easier to operate, standardized, predictably licensable, less costly, and quicker to build—with substantially higher availability and longer life expectancy. The utilities would also like the option of smaller units.

This formidable shopping list has stimulated a major development effort requiring unprecedented cooperation among the various parties involved: utilities, manufacturers, architect/engineers, government agencies, and a growing number of international participants. The result has been not only a fundamental rethinking of reactor design, but also an increasingly spirited competition among the three main technological alternatives. Reflecting the priorities of its member utilities, EPRI has assumed the lead role in the development of one alternative, the advanced passive light water reactor (APLWR), and is conducting smaller projects related generically to the other two—a liquid metal reactor and a gas-cooled reactor.

Advanced designs

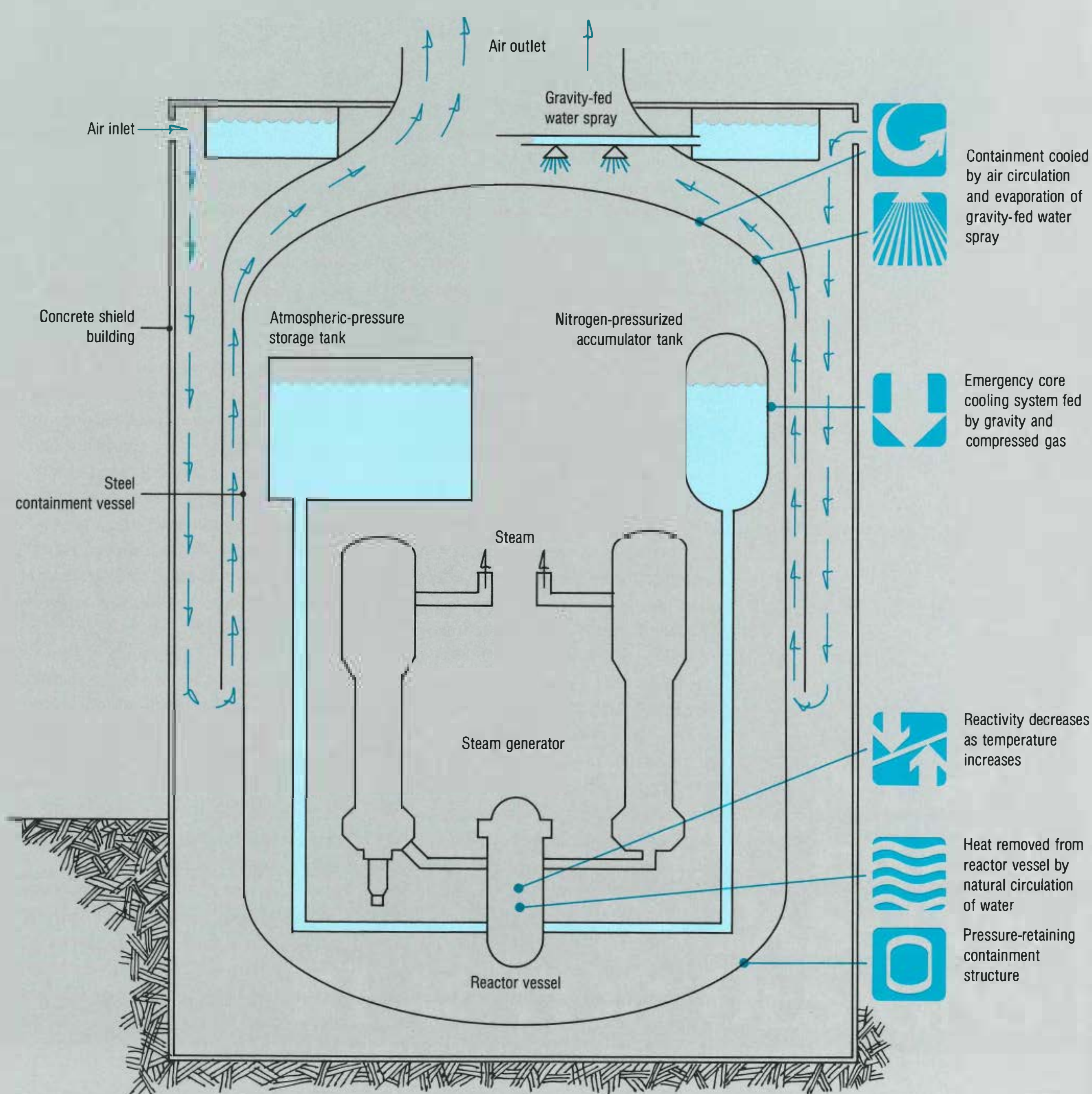
For most of the quarter century since nuclear power became commercially available, reactor design has focused on achieving greater efficiency through economies of scale. Plant size rose to 1300 MWe, and light water reactors based on American designs came to dominate nuclear power worldwide. In countries like France and Japan, which standardized plant design and maintained regulatory stability, the economic advantages of nuclear power are still evident. The cost of generating electricity from coal is 80% higher than from nuclear power in France and about 40% higher in Japan.

Much of the economic problem with nuclear power in the United States has resulted from conspicuous delays and cost overruns at some recently completed nuclear plants. Construction schedules of these plants have ranged from 6 to 18 years and costs from \$1050 to \$4475 per kWe. In addition, the cost of operation and maintenance at American plants averages roughly twice that in other countries.

The traditional approach in light water reactor design has included a variety of active emergency cooling systems to sustain core cooling if there is an accidental loss of normal cooling. These emergency core cooling systems include large pumps and diesel generators designed to keep the reactor core covered with coolant water, even if a plant should be cut off from outside sources of power. In addition, each reactor is enclosed in a steel or concrete containment building capable of retaining the pressurized steam and gases that could be released from the reactor during a serious accident.

ADVANCED PASSIVE LIGHT WATER REACTOR

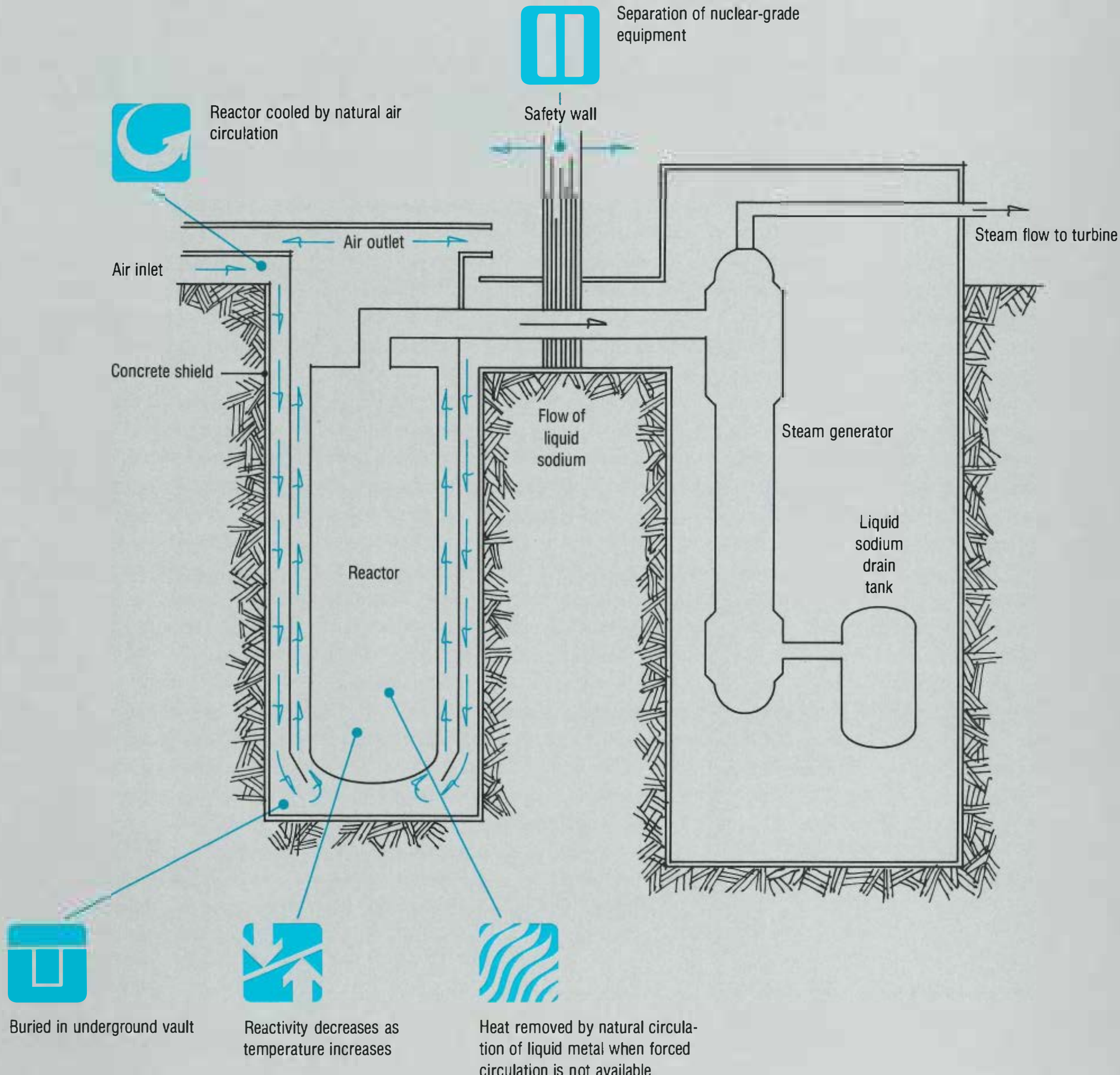
The APLWR, configured similarly to conventional light water reactors, has passive emergency core cooling, decay heat removal, and containment cooling systems. In the PWR version, shown here, the core is cooled in an emergency by massive water storage tanks located above the core; water flowing from these tanks by the force of gravity or compressed nitrogen has the capability to cool the core for at least three days after a loss-of-coolant accident. Excess heat is removed by natural circulation of this water, so electrically driven pumps and other active systems are not needed. The containment is cooled by natural circulation of air and evaporation of water around the steel containment structure. Like all modern U.S. designs, the APLWR has a negative temperature coefficient—that is, the core's nuclear reactivity naturally decreases as its temperature increases.



A P L W R

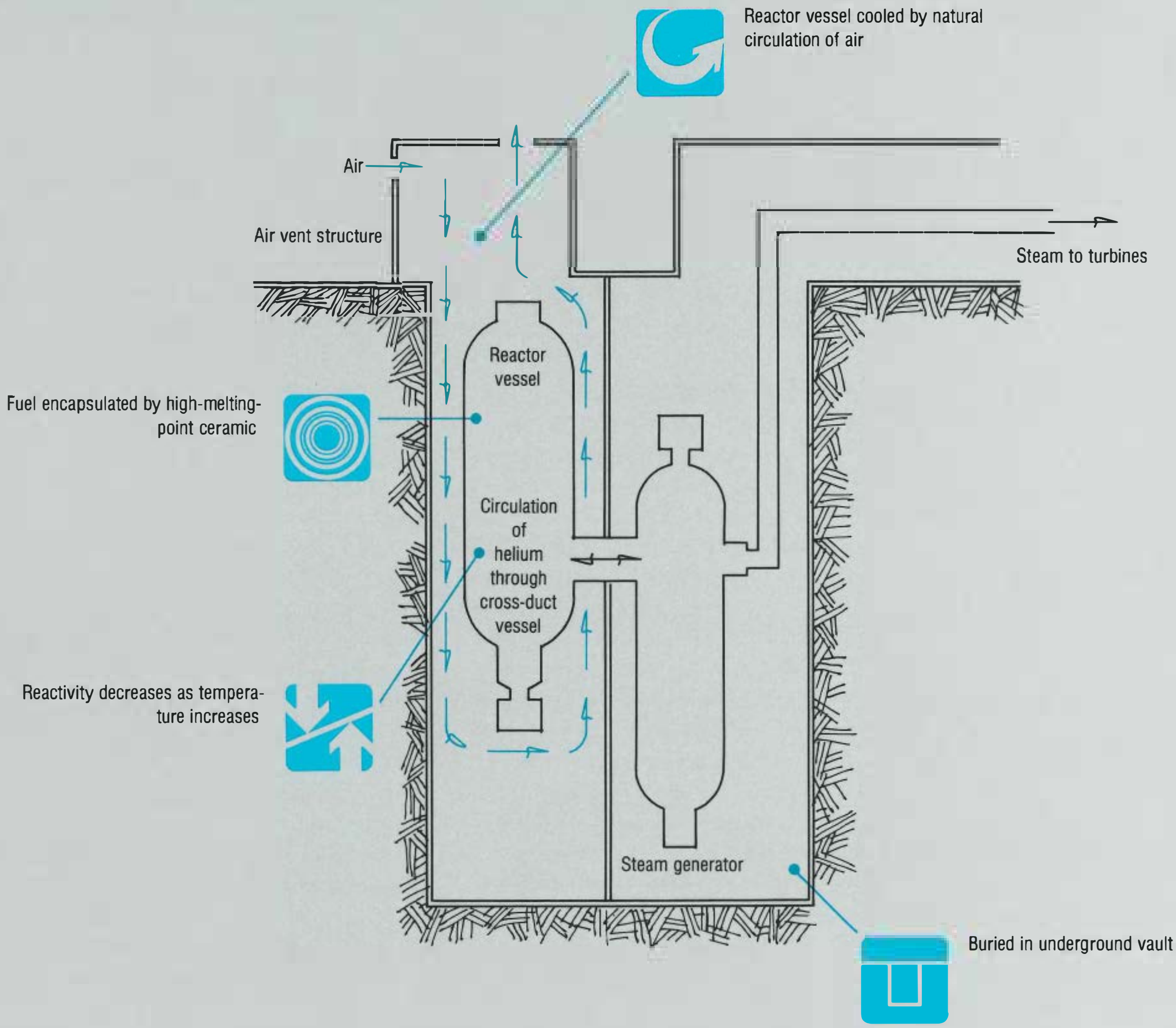
L I Q U I D M E T A L R E A C T O R

The LMR uses liquid sodium rather than water for core cooling. The reactor itself is situated in an underground concrete silo and cooled by natural air circulation when the normal heat removal paths are not available. At about 155 MWe, the LMR units are relatively small—about a quarter the capacity of the APLWR—and are designed as modules that can be shop-fabricated and shipped to the site intact. The modules are ganged in groups of three to supply one 465-MWe turbine generator, and up to three turbine generators can be ganged electrically and operated from one control center.



MODULAR HIGH-TEMPERATURE GAS-COOLED REACTOR

The MHTGR is another underground modular design, conceptualized as 134.5-MWe units that are ganged in pairs to supply each turbine generator, which in turn can be ganged in pairs. The fuel is made of small grains of nuclear fuel, each coated with multiple layers of heat-resistant ceramic material. These fuel grains are put in a low-power-density core, which makes it slower to overheat during a power surge and limits the possibility of fuel failure. The helium gas coolant, circulated through the system by an electrical blower, is heated to a high temperature, allowing for highly efficient operation. However, even if this forced-circulation system should fail, the reactor vessel would be sufficiently cooled by natural air circulation and direct heat loss to the surrounding earth.



Both the strengths and the weaknesses of this approach were revealed by the accident at Three Mile Island in 1979. Although the public was indeed protected from release of radiation by the sealed containment building, a combination of mechanical malfunction and operator error led to severe damage in the reactor core. The utility industry responded by instituting cooperative organizations to apply the lessons learned from this accident and other operational experience to the current generation of reactors, and to initiate the development of substantially improved reactors for the future.

The program to develop advanced light water reactors is under the joint sponsorship of EPRI and the U.S. Department of Energy (DOE), with additional funding from reactor suppliers and foreign utilities. It has had two components. The first was to develop plans for a standardized, "evolutionary" type of reactor that would incorporate the nuclear operating experience utilities have gained over the last 25 years into a single, integrated set of design requirements. These criteria stress simplicity, safety, and increased operating margins.

This initial design effort is now nearly complete. Detailed design, construction, and performance criteria for an evolutionary 1300-MWe reactor have been incorporated into a 13-chapter requirements document, which will be submitted to the Nuclear Regulatory Commission (NRC) later this year for certification. Although this type of reactor will have the same degree of active emergency equipment as current light water reactors, it is designed to provide a tenfold reduction in the probability of having a severe accident and to allow operators a longer response time during emergencies. The NRC certification process is scheduled for completion in 1990.

The second part of the utility industry's initiative was to develop less detailed, conceptual designs for a more advanced light water reactor—the APLWR—which would be considerably smaller and incorporate passive cooling features. At 600 MWe, this reactor would enable utilities to add capacity in increments that more closely match today's slower load growth. To offset cost penalties associated with economies of scale, the relatively small APLWR offers greater opportunities for simplification, modular construction, and shop fabrication of major components. With the conceptual designs now nearly complete, EPRI is launching a follow-up effort to produce detailed requirements for the APLWR, which should lead to NRC certification by 1996.

Passive features

Passive safety devices are familiar features in much of the machinery encountered in everyday life. They are distinguished by the use of natural forces to prevent serious damage to equipment, without human intervention or external power. An electric fuse, for example, passively cuts off power when current levels become high enough to melt a filament inside. Similarly, thermal contraction in an automatic valve prevents the flow of gas when the pilot light goes off in some ovens.

Existing light water reactors have significant passive safety features, which help account for the early popularity of this reactor type. The formation of steam bubbles in the coolant water, for example, tends to decrease the core's reactivity. Similarly, control rods are designed to lower reactivity throughout their whole insertion length. The absence of these two passive safety features contributed to the severity of the Chernobyl accident, in which both the formation of steam bubbles and the initial insertion of control rods exacerbated a runaway nuclear reaction.

The conceptual designs for the APLWR expand the use of passive features from reactor control to emergency core cooling functions. The passive cooling features vary somewhat between the two main APLWR versions being designed with EPRI and DOE funding, a boiling water reactor and a pressurized water reactor. In both versions, the passive safety systems are designed to prevent damage to the core after a loss-of-coolant accident (LOCA) by flooding it with enough water to last for at least three days, even if no further action is taken by operators. This compares with a required response time of about 20 minutes to prevent exposing the core under the worst circumstances in today's reactors.

The PWR version is being developed by Westinghouse Electric, Avondale Shipyards, Bechtel, and Burns and Roe. Called the AP600, this 600-MWe reactor features a passive emergency core cooling system in which water is stored in large tanks above the core. During a LOCA, water from two of these tanks is injected into the core while the reactor is still pressurized; the water is driven by the energy of pressurized nitrogen in the tanks. If the reactor becomes depressurized, even more water can flow downward into the core, pulled by the force of gravity alone, from a massive tank inside the containment structure at atmospheric pressure. The flow of this water is controlled by air-operated valves that open automatically if they lose either pressure or their control signal. Neither form of emergency core cooling requires pumps or emergency electric power.

Once a reactor is shut down, heat resulting from the decay of radioactive materials in the core must still be removed. Ordinarily this would be facilitated by the steam generators, which use heat from the core coolant water to raise steam for a turbine. If the steam generators were not operable, however, another passive safety system in the AP600 would use natural circulation of water to transfer thermal energy from the core to the huge storage tank located just above the reactor. Similarly, heat removal from the containment shell itself to the outside environment is facilitated by a gravity-fed water spray and by natural circulation of air, which is directed by large baffles, without the use of large fans and coolers as in today's plants.

The presence of these passive safety systems opens several opportunities for simplifying overall plant design. The number of large pumps, for example, can be reduced by half in the AP600, compared with a plant of similar size using active safety systems. Similarly, the volume of buildings designed to nuclear-grade seismic standards, the number of valves, and the amount of piping are all lowered by 60%. Westinghouse is working with Avondale Shipyards to simplify construction by building the reactor in large modules that could be transported by barge or rail for rapid on-site assembly. Similar levels of simplification and modular construction benefits can be achieved with the other types of passive designs discussed below.

The BWR version of the APLWR, also sized at 600 MWe, is being designed by General Electric, Bechtel, and the Massachusetts Institute of Technology. Called the SBWR, this reactor operates at full power with natural circulation of cooling water, which is driven by thermal gradients rather than pumps, valves, and associated controls. The elimination of this equipment promises not only to lower cost but also to enhance plant reliability.

The passive safety features of the SBWR are centered on a massive pool of water that encircles the reactor above the level of the core. In the event of a LOCA, steam from the reactor is vented into this so-called suppression pool to depressurize the reactor coolant system. Once depressurization is accomplished, water from the pool can flow into the reactor vessel by gravity. After shutdown, decay heat from the reactor can be transferred to the suppression pool by natural circulation through a special condenser, should normal heat transfer through steam turbine lines become unavailable.

To cool the concrete containment structure after an accident, a waterwall is placed between the suppression pool and the inner containment surface. Water in this wall is continuously replaced by gravity feed from a refill pool above it. Through the natural circulation of this clean water and its evaporation to the atmosphere, heat is passively removed from the suppression pool and, in turn, from the reactor core.

Earlier this year, Combustion Engineering, the UK Atomic Energy Agency, and Rolls Royce announced their sponsorship of a 140-MWe advanced passive light water reactor called SIR (for safe integral reactor). SIR has a unique design that incorporates both the steam generators and the pressurizer as components inside the reactor pressure vessel. There are 12 steam generators, only 11 of which are needed to achieve full power; these are modular in design to facilitate removal for maintenance or replacement. The main coolant pumps are mounted on the side of the pressure vessel, thus eliminating the traditional main coolant piping associated with PWRs. Like the SBWR and the AP600, SIR has passive emergency core cooling and decay heat removal systems.

For the next generation of reactors to be viable candidates for utility investment, not only must they meet all safety criteria, but they must be able to compete economically with coal-fired plants and must have predictable construction schedules and costs, according to Sherwood Smith, president and chairman of Carolina Power & Light. "In the advanced light water designs [both evolutionary and passive], we believe we do have the model of such an investment for utilities to consider as an option in the future."

Liquid metal reactor

In addition to the APLWR, two other small, passively stable reactor types are currently being developed. Because of their different fuel structures and coolants, the designs each have a potential advantage in providing passive stability.

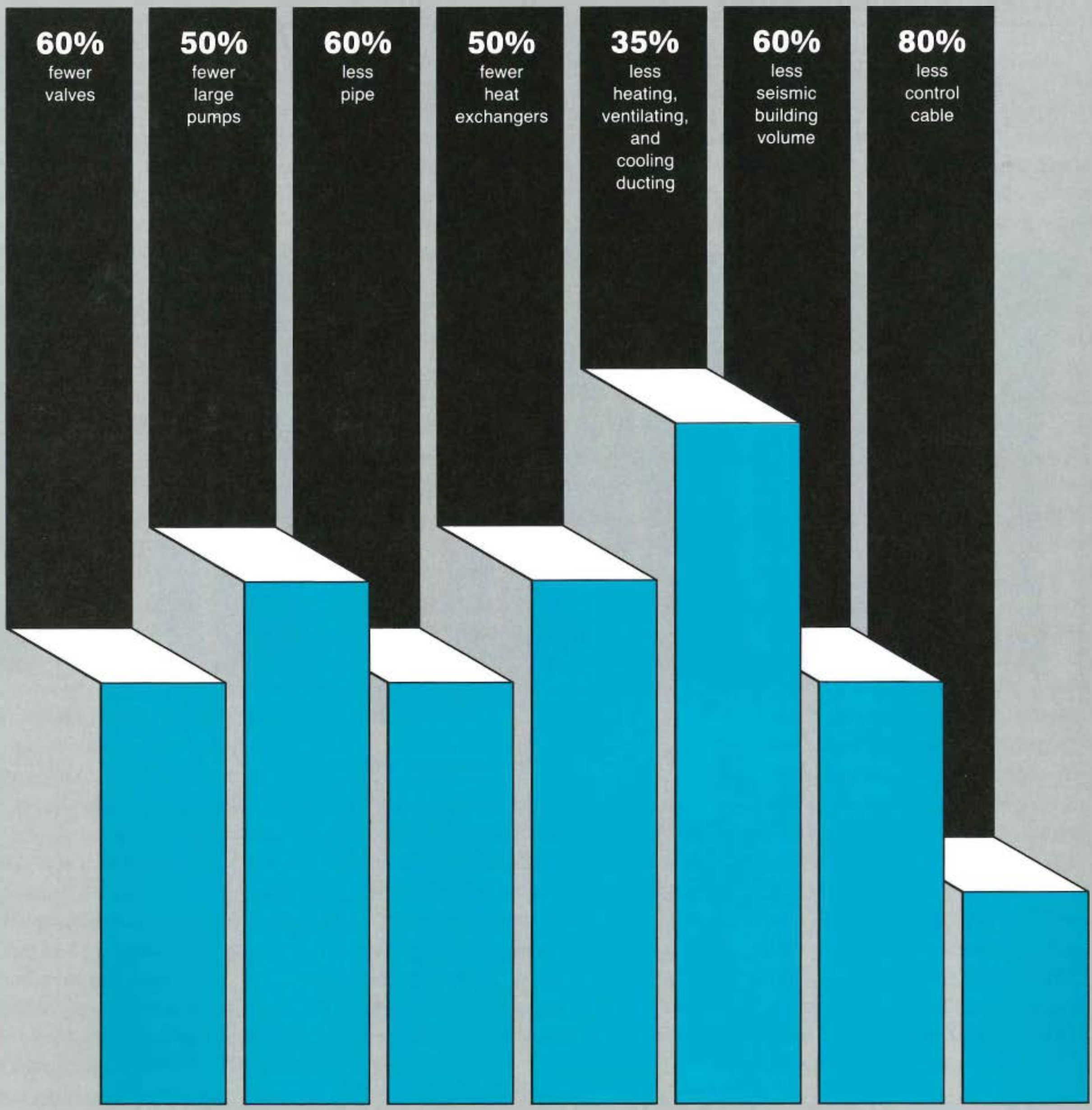
One of these alternatives uses molten sodium as a coolant. Such a liquid metal reactor (LMR) does not require pressurization. The LMR design has both passive reactor control and passive core cooling. During recent tests at an experimental 20-MWe LMR, the reactor passively shut itself down and did not overheat even when all active systems for controlling the nuclear reaction and cooling the core were turned off. These results suggest that surrounding the reactor core with a large enough pool of highly conductive liquid metal could provide an unlimited response time in case of an accident.

The development of a modular, passively stable LMR for utility application is being carried out under DOE sponsorship by a design team led by General Electric. Called PRISM (for power reactor inherently safe module), this 465-MWe nuclear plant consists of three 155-MWe reactor modules connected to a common steam turbine. Each reactor module is small enough to be fabricated in a factory and shipped by rail or large truck.

In the judgment of its designers, PRISM is so passively stable that a standard containment is not needed. To ensure that liquid sodium is always available to cool the reactor core, the reactor vessel is placed in an outer "guard vessel." The purpose of this vessel is to catch any leaking sodium, not to withstand a severe accident. The gap between the two vessels is about 5 inches wide and is filled with argon to prevent reaction of sodium with air. Both vessels are placed in a concrete silo underground, with air allowed to circulate freely between the silo wall and guard vessel to remove residual heat passively to the outside environment.

Passive Plants Are Simpler Plants

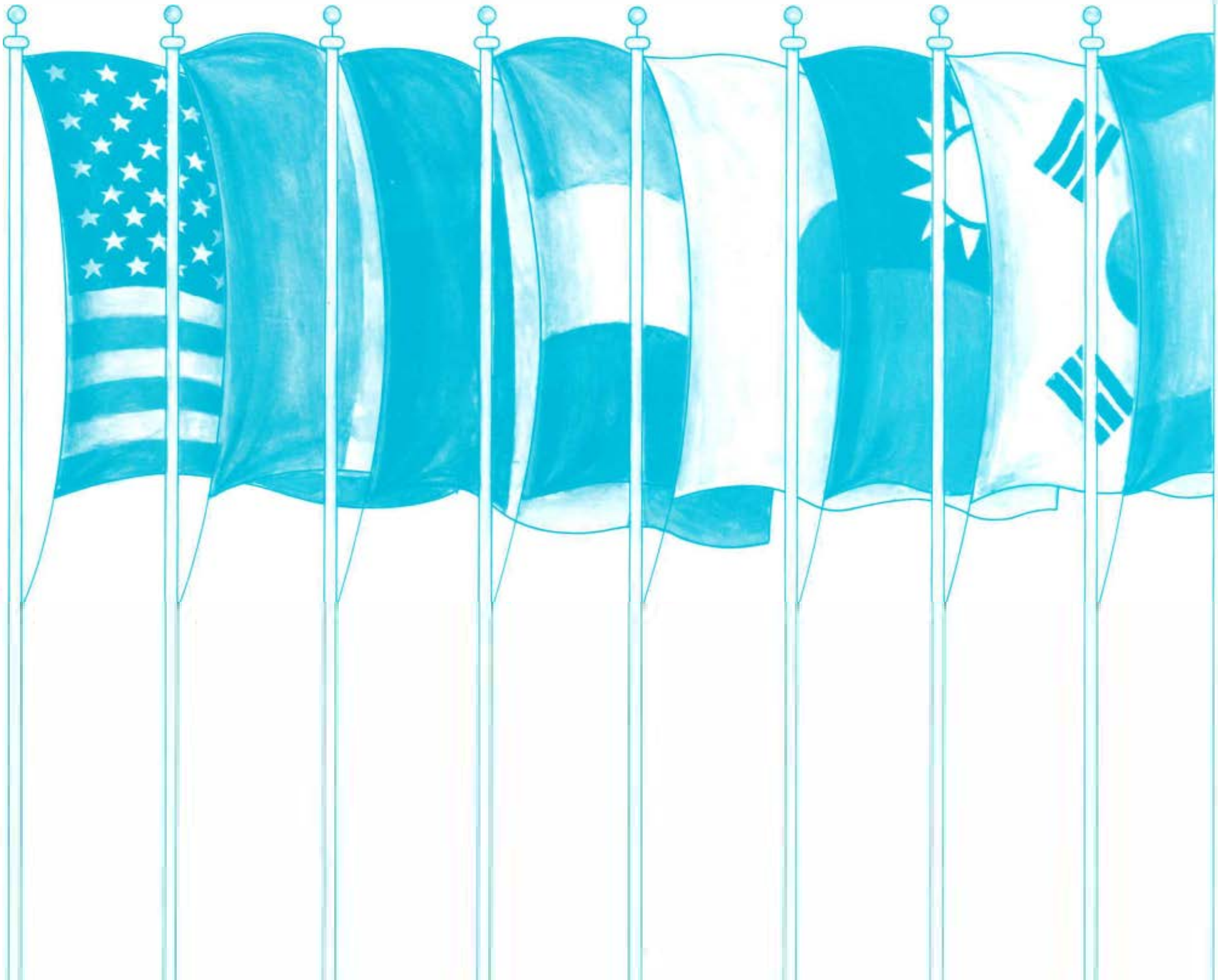
In addition to providing reactor stability and increased response time for plant operators, passive safety features allow the new nuclear plant designs to be much simpler than conventional units. Specifications for the AP600, an advanced passive light water reactor being designed by Westinghouse, call for no safety-grade diesel generators and provide tremendous reductions in valves, pumps, and other active safety-related equipment.



The NRC is expected to require the construction and testing of a single-module PRISM demonstration plant before certifying the current design. Experimental reactors at DOE laboratories have already been used to test the passive cooling capability of the LMR concept, and conceptual designs for PRISM are scheduled for completion by 1991. Although not directly involved in the PRISM design effort, EPRI, under the guidance of a utility committee, is carry-

International Activity

Interest in passive concepts has sparked renewed international participation in advanced reactor design. Organizations from the United States, Italy, France, the Netherlands, and Japan are funding the development of passive concepts, and negotiations for cooperative research are also under way with Taiwan, Korea, and Spain.



ing out operationally oriented reviews of PRISM and its unique fuel cycle. EPRI is also cooperating with Britain and Japan on generic technical developments applicable to LMRs.

Gas-cooled reactor

The third type of new small, passive reactor design is the modular high-temperature gas-cooled reactor (MHTGR). Its core features a low power density, coupled with a large heat sink. To form the core, small grains of nuclear fuel particles are coated with multiple layers of heat-resistant ceramics and then bonded to form fuel rods that are sealed into graphite blocks. The result is a reactor that can operate at high temperatures but still remains well below the failure point of the fuel particles.

Recent tests indicate that even with complete depressurization of coolant, a gas-cooled reactor using this type of fuel would not overheat enough to make the fuel fail—providing an essentially unlimited response time for operators to take action after a complete loss of cooling. Helium gas is used to transfer heat from the reactor core to the steam turbine at 1268°F—considerably higher than the temperature of coolants leaving the core of an APLWR or an LMR. This elevated temperature would enable an MHTGR power plant to operate more efficiently and hence reject about 25–30% less waste heat than the other two designs. Wet cooling towers could therefore be proportionally smaller. In addition, the higher-temperature steam produced by the MHTGR would be suitable for a variety of industrial processes, ranging from coal gasification, chemical manufacturing, and petroleum refining to desalination of sea water.

An MHTGR conceptual design has already been completed by a team led by GA Technologies, with funding from DOE and assistance from an ad hoc utility group, the Gas-Cooled Reactor Associates. EPRI has provided technical support. The design is now undergoing NRC review, and GA Technologies recently completed an agreement with Siemens of West Germany and Bechtel to commercialize the reactor.

The power plant envisioned by GA Technologies would consist of four MHTGR modules providing thermal energy to two steam turbines for a combined generating capacity of 538 MWe. Each reactor vessel and steam generator would be enclosed in an underground silo. A passive cooling system is provided for each of these enclosures, but even if it should fail, direct heat loss to the surrounding earth would keep fuel temperatures well below the melting point. As in the case of PRISM, the passive safety features of the MHTGR have led designers to believe that conventional containment is not necessary.

Although there is some operating experience with gas-cooled reactors here and abroad, the MHTGR design is innovative enough that a one-module prototype demonstration is planned. DOE recently announced that it will build a modified MHTGR to produce tritium for nuclear weapons. This plant, unlike the proposed civilian design, features a conventional containment structure. It is expected that experience with this modified military reactor will contribute significantly to the development of a commercial civilian version of the MHTGR.

The nuclear future

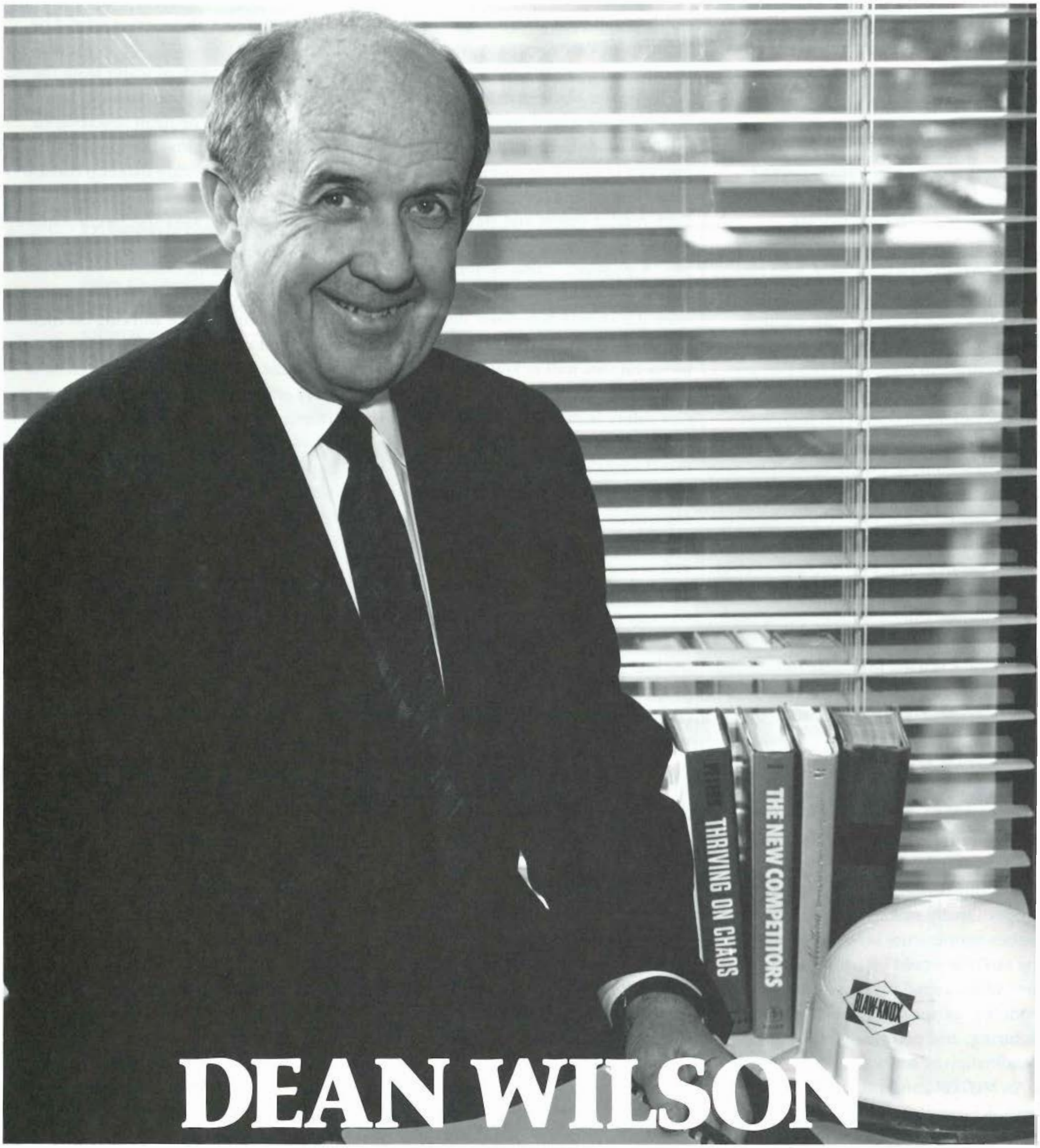
The advent of a new generation of smaller, passively stable reactors will contribute to the renewed expansion of nuclear power in the United States—but America no longer dominates global nuclear development. In addition to the innovative U.S. designs just discussed, other reactor concepts are being developed abroad that may help shape the nuclear future.

Asea Brown Boveri of Sweden, for example, has proposed building a light water reactor in which the reactor vessel is immersed in a large pool of borated water. Called PIUS (for process inherent, ultimate safety), this reactor would be shut down passively in the event of a LOCA by the inrush of water from the surrounding pool. The boron in this water is a strong neutron absorber, so the influx would slow the nuclear reaction as well as provide makeup coolant. As in the case of the LMR and the MHTGR, utilities are expected to require prototype demonstration before placing commercial orders.

In addition to this effort, several industrial countries are working on their own versions of the three reactor designs just discussed. Although most of these efforts are essentially competitive (in expectation of a growing export market for nuclear power plants), an unprecedented amount of cooperation is also taking place. EPRI's program to develop the APLWR, in particular, has strong international participation, involving six utility organizations in Asia and Europe.

The resurgence of interest in nuclear power around the world is an important factor in promoting the current reactor design effort, concludes Karl Stahlkopf, director of the Materials and Systems Development Department in the Nuclear Power Division. "EPRI's view is that the new reactors will be complementary to each other. The APLWR will reach commercial availability first and help pave the way for nuclear power over the next several decades. The LMR will offer opportunities to breed nuclear fuel so that it can last into the indefinite future. And the MHTGR will open new opportunities for using nuclear power as a source of industrial heat, in addition to generating electricity. Together, I believe, these new reactors can help restore confidence in nuclear power and thus fulfill its original promise, tempered by experience." ■

This article was written by Jack Catron, science writer. Technical background information was provided by Karl Stahlkopf and Jack DeVine, Nuclear Power Division.



DEAN WILSON

Welcoming the Opportunities of Change

Having experienced firsthand the changes in heavy manufacturing over the past 20 years, this steel executive understands the challenges facing the utility industry and EPRI. As a member of the Advisory Council, he shares both his knowledge and his optimism.

Dean Wilson, president of Blaw Knox today, remembers his boyhood clearly. "If you lived on a farm in central Utah, you worked—hard. You started out thinning beets, putting up hay, and helping the threshers with the grain. Then, before and after the work day, you had chores: taking care of the cows, the hogs, the chickens." An only child, Wilson wished for brothers and sisters to share the load—"and so did my dad!"

The experience was indelible, and the work ethic remains one of his strong values—"the idea that you must work to get the things that are needed. I've done that all my life. My kids say I'm a workaholic. I probably am, but I enjoy my work; I absolutely enjoy it."

Wilson's point of view makes all the difference. "I don't think I've ever held a position that wasn't exciting in some way. There was a challenge. I enjoy being challenged. If you can look on the things that are thrust upon you in life that way, I think you're much happier."

Choosing technology

Wilson speaks from the perspective of 34 years in heavy industry (25 of them with U.S. Steel, now known as USX), including 8 years as a member of EPRI's Advisory Council. He has fully experienced the changes that have swept over the traditional manufacturing industries of the United States during that time—product specialization, competition from both regional and foreign firms, new relationships among the costs of capital, materials, labor, and energy.

Wilson's move from the farm came with a World War II defense plant that later would become the Geneva Works of U.S. Steel, near Provo and only about 25 miles north of his home town of Payson. "The plant was under construction during most of the war, and it supplemented a lot of farmers' incomes. My father was one of them. In 1946 he sold the farm and went to work there full-time."

One year later Wilson finished high school and headed for Brigham Young University on a scholarship, deciding that he liked the physical sciences well enough to major in chemistry. After graduating and marrying a BYU classmate in 1951 and adding an MS in 1952, he went to work with Kennecott Copper at its newly established research laboratory in Salt Lake City.

Wilson's career path straightened, narrowed, and was paved, so to speak, by four more years of graduate work—this time at the University of Utah—and a 1958 PhD in fuels engineering. He joined U.S. Steel in 1957 and moved from research into work with a progressively greater emphasis on resource use.

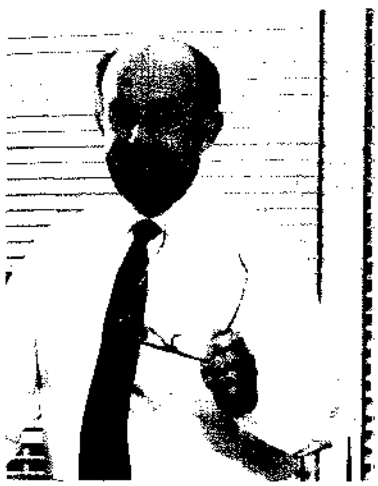
"The chemicals distilled from coal during the production of coke gradually took on a market life of their own," Wilson explains. "Coke oven gas, for example, is especially rich in elemental hydrogen—more than 50%—so we separated out the hydrogen and combined it with nitrogen (from the air) to make anhydrous ammonia for fertilizer. And the pitch from coal tar is still a preferred binding material for all the large electrodes used in electric furnaces."

Coal chemicals thus became a profit center in the steel business, and Wilson contributed to the bottom line at the Geneva Works by conserving resources and energy, gaining both efficiency and revenue growth.

During the years between 1957 and 1969, Provo was also a place of personal fulfillment. It was family time, with five sons joining the Wilsons. "We spent a lot of time together in the intermountain forests and deserts," Dean recalls. "Camping, hunting, and fishing were family activities. Scouting, too. And the boys all played baseball, so I had my stint as president of the Little League for something like nine years."

The memory stirs observations that are familiar to other parents. "As I see the boys raising their own families today, the thing that strikes me is the tremendous time it takes. I don't think I was conscious of it with them; time was just something that happened as you fed them, clothed them, and so on."

When the youngest boy was five or six, the Wilson family became complete: they added a newborn daughter, now 19 and with a freshman year at BYU already behind her. "It was a tremendous thing for all of us," Wilson says, "a little girl in there



"We became very cost-conscious because the energy portion of manufacturing cost had ballooned; it had become a big, big number."

with all those boys growing up around her."

He found positive ways to motivate them toward the value and the world of work. They had odd jobs, as kids always do, even earlier than junior high school days, and Wilson remembers making a deal with each of them. "'For things you really like,' I said, 'a fancy shirt or something, I'll pay half and you pay half. Then you decide how badly you really want it.' It's amazing," he concludes, "how they set their priorities when they have a real stake in what they do."

Chosen for change

After a dozen years of professional seasoning in Provo, Wilson moved to Pennsylvania as general superintendent of U.S. Steel's Clairton Works, several miles southeast of Pittsburgh. Not just a steel plant, Clairton at that time was the largest coke plant complex in the world. Strategically sited on the Monongahela River, it received coal from Pennsylvania and West Virginia mines and shipped coke to several other U.S. Steel plants. Wilson defines his responsibility in one sentence. "We were coking about 33,000 tons of coal a day in the early 1970s."

For some 10 years, Wilson worked successively in plant management (at Clairton and the nearby Homestead Works) and as a U.S. Steel vice president, first for engineering and then, as general manager also, for planning, engineering, and construction of all U.S.S. facilities. But during that time major changes in the steel and other heavy manufacturing industries in the United States got well under way.

Thinking back even further, Wilson shakes his head ruefully. "If someone had asked me early in my career which two industries were solid and stable and would not change much, I'd have said steel and utilities. Wrong on both counts.

"As I look back on it now," he muses, "it was simply an evolutionary process, and there were a lot of circumstances involved, a lot of external causes. Changes occur all the time in almost all industries. But the striking thing we're seeing since the seventies is the rate of change. It's speeding up all the time."

Wilson and other industrialists shared what he now says may have been a naivete, "but as late as 1970 I felt things were very stable and what was there, in our industry, would last for many, many years." As he reviews the changes that followed instead, he thinks first of the economic environment and then of the industrial responses.

"The United States became part of a global economy," he says flatly. "The steel industry certainly did." The United States had exported steel since World War II, among other things rebuilding the steel industries of Germany and Japan, but the major steel market was domestic; domestic business cycles were the index of economic health, and for many years all signs pointed upward.

Even so, globalization of the steel industry wasn't a thing unto itself. Rather, in Wilson's words, "the steel industry became part of a global economy. What happened in any other country and what happened in any other steel-consuming or -producing company—those events affected what happened in the United States.

"Ease of transportation added to this," he goes on. "It became feasible to ship industrial goods across the oceans in almost any direction. You could ship raw materials, you could ship products, and still compete in a global economy. U.S. imports of steel products started to increase in the late 1960s and then grew at a tremendous rate."

The oil embargo of the early 1970s was a decisive blow. "First the shortage, then the rise in price really changed the way you thought about your company's operations," says Wilson. As a pure challenge, he found it appealing—"an exciting time, because from what had been a very stable situation, you now had to look at many more options, become extremely flexible. We became very cost-conscious because the energy portion of manufacturing cost had ballooned; it had become a big, big number."

Examples roll easily from Wilson's experience. "To make an industrial process more fuel-efficient cost capital dollars. There were industrial plants where none of the waste heat was being recovered. But the picture changed when the price of fuel went up in the seventies. All of a sudden we put in heat exchangers and recovery systems that recycled heat back into the process because it was financially attractive to do so. We installed multiple-fuel furnaces, so as to burn any fuel, depending on the cost."

Formerly motivated by the opportunity for revenue growth, resource and energy conservation were now motivated by the need for cost containment. "I think it was a good thing," Wilson acknowledges, "because as a society we'd been very wasteful. The conservation ethic was introduced, and now it's become the basis for the thinking of everyone who uses fuel. It's been established in the general populace, too, I believe, and will probably continue on its own."

Chosen to advise

It wasn't until 1980 that Wilson again truly focused on chemicals, becoming vice president for research, engineering, and planning for two U.S. Steel subsidiary chemical companies. That was also when he joined EPRI's Advisory Council, possibly, he thinks, with some impetus provided by Kay Randall, a onetime BYU acquaintance who had come to the Advisory Council via a career in banking.

The advisory connection has been a useful one, with Wilson contributing the perspective of a heavy manufacturing executive. The Council is a sounding board for Institute management, a way to learn how various professional, economic, demographic, and organizational constituencies of U.S. society see the institutions of electric power. It serves reciprocally as a reality check on EPRI's planned research directions. Education, conservation, science, utility regulation, law, commerce, medicine, and others are frequent backgrounds of Advisory Council members, "but there hasn't been a large representation from manufacturing," says Wilson, "although industry represents the major customer segment for many electric utilities—and close to 40% of our overall electricity use."

But the context is larger than electricity use alone, he says. Wilson volunteers that EPRI and its utility members are inescapably part of the energy industry and thus of the global economy. "EPRI is in energy research, not electricity research," is the way he puts it. "Utilities are transforming energy from one form to another. Their managers are caught up in the same forces as all industrial managers—having to adapt to change and make adjustments, some of them very quickly. And it's difficult," Wilson acknowledges, "because, historically, utilities have made very large investments that have lasted a long time."

But the picture isn't as bleak as it might seem, according to Wilson. "The main structure of a plant—or an industry, for that matter—may be built to last 40 years, but internal changes go on all the time." For utilities, he points to new power plant control systems, new switchgear, new distribution controls. "Industry doesn't just plod along," he argues.

As for entirely new industrial facilities, Wilson recognizes that today's patterns and growth rates of energy use have invalidated the popular thinking that bigger is better, without limit. "We certainly went away from that in the steel industry. I think the utility industry is going away from it, too. But changes in peripheral systems and components allow us to keep up with the growth of new technology. That's why industry is exciting. The thing that makes it a challenge is how we can incorporate advances into our businesses."

Do electric utilities uniformly see and welcome the opportunities that Wilson believes are to be found in so much of to-

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day's change? His answer is mixed. First, he speaks of the breadth and quality of information at hand. "The notable thing about my experience on the Council is that there is so much advice available to EPRI management, from the board, the industry advisory structure, and so on. EPRI probably gets more than it sometimes wants. But, at least, with advice from so many directions, a one-sided research approach isn't likely."

Promptly following up this good-natured characterization, Wilson adds his conviction that both EPRI and its members are indeed getting the message of quickening change and its implications for them. "I also realize that change at first is forced on managements by external events—fuel prices, regulatory views, and the like. Utility managers, like managers in many entrenched industries, have had to get used to change, and then it's easier. Becoming accustomed to change is an educational process," Wilson concludes.

Choosing to change

During his EPRI advisory tenure, Wilson has continued to undertake and experience change himself. In 1982, the quickening pace of steel industry change prompted Wilson himself to move, from Big Steel in Pittsburgh to Lone Star Steel in Dallas. "I was ready for a new puzzle, and this was an interesting opportunity—focusing on the end uses of steel products more than on their manufacture." Lone Star was principally a supplier of casing and tubing for oil well drilling, at the time a vigorous and profitable business. But petroleum exploration is driven by the price of crude oil, and Wilson is quick to remember the numbers that mattered—"say, $35 a barrel in 1982, dropping to $20 in 1984. Right now, I think, it's between $16 and $18."

Wilson's work as Lone Star's executive vice president became that of reorganization and retrenchment, reducing unit costs by as much as 40% and building the company's competence toward a new identity as Lone Star Technologies. With the new identity came new directions entirely outside manufacturing, so Wilson returned to Pittsburgh in 1988, where he is now president and CEO of Blaw Knox.

There's no end of fascination in his new work, Blaw Knox having just returned to private ownership and therefore presenting many challenges in the positioning and structuring of its operations—six subsidiaries that produce steel and iron rolls for rolling mills, industrial machinery, coffee roasters and cereal machinery, air conditioners and electric motors, alloy forgings for the steel and petrochemical industries, and material handling and transportation equipment.

Mill rolls and industrial machinery are familiar enough to Wilson; they go to traditional markets that he calls support industry for steel producers. But among the other products, light rail transit cars and airport equipment, in particular, are a new challenge. "I'd like to expand that part of our business and diversify our lines so as to depend less on the steel industry."

Such hedging is increasingly the smart executive move in an uncertain and changing industrial business environment. Wilson's personal sentiments are evident only in his understandably warm feeling for the industry and company that he virtually grew up with between 1958 and 1980. His choices today are the pragmatic ones of doing what is needed in the circumstance. He has trained himself to respond in that manner.

Utility CEOs have been faced with equally hard choices, Wilson observes. He cites nuclear energy, the fuel crisis, and, more recently, cogeneration as examples of external forces that elicit strong expressions but require a leader to look beyond traditional value judgments. "Cogeneration was started (at least, in recent years) for one reason, to get more energy into the system when there was a shortage. Now people are approaching it on the basis that there may be a business opportunity for groups outside the utility industry itself. That's a tremendously changed circumstance, and I don't think the possibility was seriously considered when the cogeneration regulations were drafted."

The potential impacts of cogeneration on electricity quality and reliability appear to compromise the traditional utility capability—and commitment—to provide power at all times. "But there's at least a question," Wilson says, "whether that is something customers uniformly want and are willing to pay for today. It's going to be debated for some time, I think—like telephone deregulation. That breakup has been more complicated than anyone thought. Is the service better? I don't know. In some respects it is, and in some respects not. These are evolutionary things, still very much under development."

Choosing new technology

Dean Wilson clearly believes that EPRI's role is a beneficial one, regardless of the changing shape of the utility industry. "EPRI has established itself as a first-class technical institute," he says, "its projects thoroughly examined, its results reliable; and people respect the staff's expertise." He particularly commends EPRI's success in dealing even-handedly with such highly charged, politically visible issues as nuclear accidents, electromagnetic fields, risk assessment, acid rain, and transmission access.

The downside is that there is so much to do and resources remain limited. The Institute's research budget should be substantially increased, in Wilson's opinion, because the need is there and the benefits are there. He admits that a number of EPRI's members have been under severe financial pressure. "When the house is burning, you know, it's hard to do long-range work.

"But there's more to it in some other cases," he continues. "It's easy to get sidetracked and focus on short-term goals. In any industry it's easy to pay attention to this quarter's bottom line. I think you just have to make an internal commitment, a personal commitment, to the value of research."

Wilson has a clear picture of EPRI's day-to-day or year-to-year duties. The inputs are diverse, he again emphasizes, coming from so many sources, including the Advisory Council. "It's the Institute's responsibility to mold all that advice into a coherent program to serve member utilities. And that's a subjective task, really; it always will be."

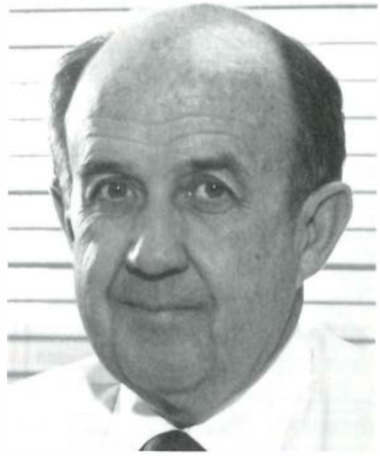
Then he ticks off an orderly three-step sequence: "allocate the funds, pursue the research, and disseminate the findings, whether it's information, or hardware, or software, or a new way to do something."

Wilson puts a twist on that last step. "It's not EPRI's role to force anyone to use its research results. But just turning over a report and walking away isn't enough, either," he adds, explaining that complete communication goes further. "It's like teaching: unless the student understands, you haven't taught. I think you have to make sure the report recipient understands what you're putting before him."

Whether a utility truly embraces what EPRI offers is an individual matter after that, of course. "There's always a little bit of the not-invented-here syndrome around. In my own career, I've always felt I should use help wherever it's available. Anything that helps me to do my job better, my client to run better, or my company to perform better should be analyzed, evaluated, and installed, no matter where it came from."

Wilson the teacher gives EPRI good marks on explaining what it produces. "And that can only be good for everyone, because when utilities know they're realizing benefits from the Institute's research, then they become more than supporters. They become cheerleaders." ■

This article was written by Ralph Whitaker and is based on an interview with Dean Wilson.



"Utility managers are caught up in the same forces as all industrial managers —having to adapt to change and make adjustments, some of them very quickly."

In Hot Pursuit of Cold Fusion

The scientific community remains galvanized by recent claims of nuclear fusion produced at room temperature with simple benchtop apparatus. Experiments sponsored by EPRI at Texas A&M University help strengthen the case for the existence of so-called cold fusion.

With its tantalizing mix of elusiveness and shining promise, nuclear fusion has long been the will-o'-the-wisp of modern science. The recently announced discovery of so-called "cold fusion" seems bound to further complicate this mystique. On the one hand, the potential benefits are simply too consequential to ignore: each cubic foot of seawater theoretically contains enough deuterium (a hydrogen isotope containing one proton and one neutron) to produce, through fusion, the energy equivalent of 10 tons of coal. On the other hand, definitive evidence that cold fusion has actually been achieved and could be used to generate useful amounts of heat is still lacking, despite several weeks of intense effort at an estimated 500 laboratories around the world.

The current flurry of excitement began on March 23, with a widely publicized announcement by scientists at the University of Utah that they had used a simple electrochemical cell to produce net energy from nuclear fusion at room temperature. Researchers Martin Fleischmann and B. Stanley Pons reported that they obtained 4 watts of heat, apparently from fusion, by supplying 1 watt of electric power to the cell, which consisted of a palladium rod surrounded by a platinum coil and immersed in heavy water. Their explanation was that a small electric current applied to the cell drove deuterium nuclei from the heavy water into the palladium rod, where they were held in the metal lattice and spontaneously fused. The maximum reported rate of energy production inside the palladium was over 20 watts per cubic centimeter—of the same order as the energy density in the core region of a standard nuclear reactor.

At about the same time, Steven Jones of Brigham Young University independently reported cold fusion experiments that produced neutrons but that were not set up to measure heat generation. The neutron production rate inferred by Jones was only about one hundred-thousandth of that inferred by Fleischmann and Pons.

Because of the potential importance of this discovery to the electric utility industry, EPRI responded immediately—obtaining and evaluating technical data on cold fusion experiments, funding attempts to replicate the Fleischmann-Pons results, and forming three teams of in-house experts to keep pace with swiftly moving events. "This research has been performed by highly respectable scientists, and its possible implications for electric power generation are so great that we must take the matter very seriously," says EPRI's president, Richard Balzhiser. "If cold fusion does prove to be a viable energy source, EPRI will work aggressively to develop it for utility use. If not, we will be in a position to keep utilities fully informed and help them avoid premature commitment of resources."

From star to lab

Fusion of light elements is the type of nuclear reaction that powers the stars. At normal atomic distances found in gases and solids, the electrically charged deuterium nuclei repel each other. Squeezing them close enough for stronger but short-ranged nuclear forces to take over and cause a fusion reaction is a difficult technical feat, normally requiring deuterium energies of a few thousand electron volts. Usually, phenomenally high temperatures have been used to accomplish this: in effect, researchers have been trying to reproduce solar conditions in the laboratory. Billions of dollars and decades of work have already been devoted to heating and compressing nuclei by using superconducting magnets and the world's most powerful laser beams.

All such attempts, however, have failed to achieve "break-even," the point at which the energy released from fusion exceeds the energy supplied to squeeze nuclei together. For this reason, EPRI has only been monitoring conventional fusion experiments, while actively investigating innovative approaches that would require substantially lower temperatures.

The first measurements of cold fusion rates, involving catalysis by short-lived atomic particles called muons, were reported in 1985 by Steven Jones of Brigham Young University. These particles, about 200 times heavier than electrons, are created in atomic accelerators and have the ability to bind nuclei of hydrogen isotopes in close proximity, enabling fusion to take place almost immediately after a muon-deuterium molecule is formed. By repeating the process, each muon can eventually catalyze many fusion reactions. Jones wrote a summary of muon fusion work for EPRI, which is currently sponsoring a small experiment and associated theoretical analysis at the University of Florida to investigate an approach to achieving break-even with this type of low-temperature fusion. Jones is an adviser to EPRI on this project.

A further step toward cold fusion was taken by the University of Utah team, which used a matrix of palladium atoms to bring a large number of deuterium nuclei close together. However, the energies characteristic of crystal lattices would seem to be thousands of times too weak to produce the amount of fusion inferred by Fleischmann and Pons. Also, the number of neutrons detected was some billion times too low to account for the heat released, assuming the usual fusion reactions were occurring.

"To get a power output of 4 watts, you would need about 10^{13} fusion reactions per second inside the palladium," says David Worledge, a physicist in the Nuclear Power Division who is coordinating EPRI's technical response to cold fusion. "At that rate, the neutron flux coming from the Fleischmann and Pons experiment would have been dangerously high, but they counted only a tiny fraction of this number of neutrons. We're still striving for an explanation."

What's going on?

According to Worledge, fusion of deuterium nuclei usually takes place in two ways, which have roughly equal probability of occurrence. The products of the first reaction are a neutron and the light isotope of helium (helium-3, containing two protons and one neutron). The second type of reaction yields a proton and a tritium nucleus. All the products except the neutrons would be quickly stopped by surrounding atoms and thus be hard to detect outside the metal.

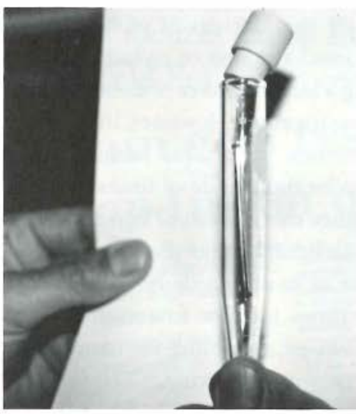
To explain the apparent suppression of neutrons, some theorists have speculated that a third type of fusion reaction—without neutron emission—might just be possible if the deuterium nuclei are held in a metallic lattice. The only products of this reaction, which does not usually occur in conventional fusion experiments, would be helium-4 and a very energetic gamma ray. Some speculate that instead of the energy being released as a gamma ray, it is released directly to the surrounding lattice as heat. There are currently no theoretical explanations of how such a strong coupling to the lattice might occur. If, given the special circumstances in the palladium lattice, this type of fusion is nevertheless occurring frequently, it could account for the heat observed.

Obtaining definitive evidence of fusion may thus require a detailed isotopic assay of the palladium to look for tritium and the two isotopes of helium that might be present in the metal after fusion reactions have taken place. Considering the small amount of such material produced by fusion (helium-3 is generated at the same rate as neutrons if conventional fusion is occurring) this "autopsy" approach could take significantly longer than experiments most workers have done to date.

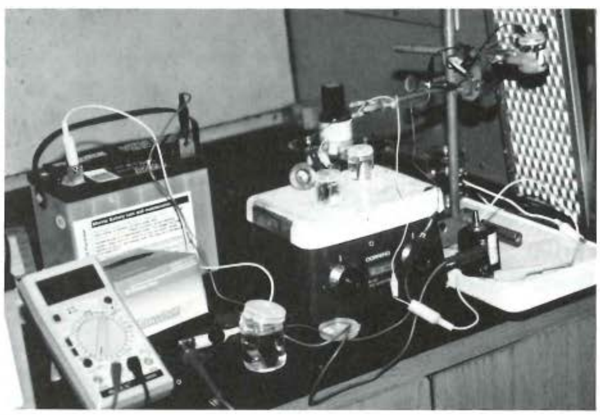
Another possibility is that only a very

Success at Texas A&M

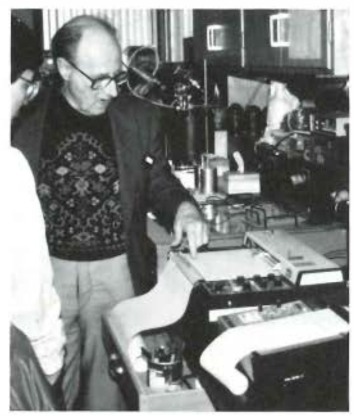
The claim of achieving cold fusion at the University of Utah sparked hundreds of replication attempts by scientists around the globe. A few days after the Fleischmann-Pons announcement, researchers at Texas A&M University working under EPRI contract on advanced fuel cell systems were authorized to try to reproduce the elusive phenomenon. Mobilizing four teams of specialists, Texas A&M became one of the first to partially replicate the original cold fusion experiment. The university has since reported the first measurement of tritium, which would be difficult to explain without invoking nuclear reactions.



One cell



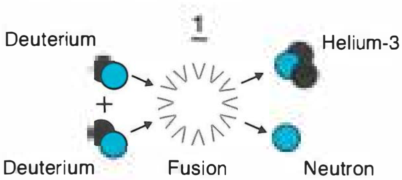
Cell setup

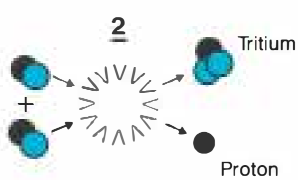


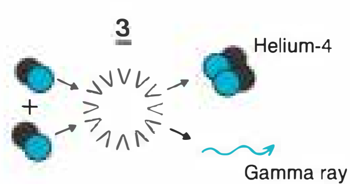
Calorimetry readouts

Formulas for Fusion

A fusion reaction can reconfigure the neutrons and protons of deuterium nuclei in two ways—one producing helium-3 and a free neutron **(1),** and the other producing tritium and a free proton **(2).** Each of these reactions is thought to occur about half the time. However, most of the replication experiments have not been able to measure the high level of neutron emission expected to result from the first type of reaction. Some scientists have speculated that the palladium lattice promotes the likelihood of a third—normally unobserved—reaction type, which produces helium-4 and a relatively high energy release in the form of gamma rays **(3).** Which, if any, of these reactions are actually taking place in the cold fusion experiments should become apparent from isotopic assay of the palladium rods.







small number of fusion reactions are actually taking place and that the heat observed by Fleischmann and Pons came from some yet undetected chemical reaction. The rate of heat production in the experiment could easily be supported by a chemical reaction, but there is a problem with this interpretation. The heat production apparently endures for many days, long after all the palladium and hydrogen would be completely consumed in a chemical reaction. The total heat produced, if calorimetric measurements are correct, is many times larger than what could be expected from such a complete chemical reaction.

Difficulty of replication

In the weeks following the Fleischmann-Pons announcement, numerous laboratories have attempted to replicate the Utah experiments. Partial—but inconsistent—evidence that seems to support the cold fusion concept has now come from such disparate places as Hungary, China, Italy, India, Stanford University, and the University of Moscow. So far, however, no one has been able to fully substantiate the claim that net energy is indeed being produced from cold fusion.

By taking advantage of two existing contracts involving electrochemical research on fuel cells at Texas A&M, EPRI's Rocky Goldstein quickly commissioned experiments to test the reported findings. On April 9, one Texas A&M team announced that it had produced net energy from an electrolytic cell using palladium and heavy water. The researchers announced further progress on May 8, reporting production of neutrons, net heat, and tritium (found in the electrolyte) from a large series of tests. Although such results cannot be considered definitive proof of fusion, they would be difficult to explain with any other type of reaction.

David Worledge explains that resolution of the many questions raised about cold fusion may come slowly for several reasons. A variety of conditions—which Worledge calls "knob turning"—can affect electrochemical cells, so that considerable time may be required to optimize a fusion experiment. Whether the palladium rod is cast or extruded, for example, has been reported to affect the outcome. Also, neutron analysis is notoriously difficult, particularly at very low count rates, where cosmic rays and even the presence of a nearby brick wall containing small amounts of uranium may change the background reading. Finally, calorimetry—the science of measuring heat production—can also be subject to numerous external influences that require careful scrutiny.

"You need good equipment and skilled people in each of these areas—electrochemistry, neutron/gamma measurement, and calorimetry—to investigate cold fusion adequately," says Worledge. "Few laboratories excel in all three. In addition, good isotopic analysis of fusion products may require charging rods up with deuterium for several weeks. Many factors are involved in replicating the Utah experiments; you can't expect accurate results from carefully executed experiments overnight."

Long road ahead

Tom Schneider, senior science adviser in EPRI's Office of Exploratory Research, points out that before there can be meaningful speculation about whether cold fusion will ever become a major power source, much more information must be gathered. "First, the reality of fusion reactions at room temperature must be firmly established—ruling out extraneous chemical reactions and calorimetry errors, making reliable neutron and gamma measurements, and conducting isotopic assays. Next, the extent to which cold fusion can produce net energy must be determined while accounting for all the energy costs, such as that involved in heavy water production, for example. Finally, a host of practical concerns would have to be addressed, such as finding cheaper substitutes for palladium, exploring possible accumulation of radioactive waste, and designing scaled-up and more effective versions of the present laboratory apparatus. Such larger units would need to give reliable energy output for long periods and avoid problems with materials compatibility and corrosion."

If the production of useful energy from cold fusion does prove feasible, electrochemical technology related to that now used in batteries and fuel cells is likely to be involved. EPRI has long been a leader in the development of this technology, which is particularly versatile in size and breadth of application. In general, electrochemical cells can operate at scales ranging from miniature to superindustrial, and EPRI's experience would be critical in helping utilities optimize cold fusion for commercial power production.

EPRI has already sponsored exploratory work related to both the replication of cold fusion and the analysis of possible fusion products. Such a hands-on approach puts the Institute in a better position to understand and utilize cold fusion developments as they come. Texas A&M and SRI International are currently contractors. An internal team of EPRI experts is also considering potential applications and investigating patent opportunities.

"It's still too early to tell whether cold fusion will ever achieve practical application, but even if it does, the commercialization process is likely to take many years," concludes Richard Balzhiser. "In any case, EPRI's access to a broad range of scientific expertise, together with ongoing research in both fusion and electrochemistry, places the Institute in an ideal position to evaluate further discoveries in this area and to exploit promising developments for utility use." ■

This article was written by John Douglas, science writer. Technical background information was provided by David Worledge and Joseph Santucci, Nuclear Power Division, and Fritz Kalhammer and Thomas Schneider, Office of Exploratory Research.

It's every power system dispatcher's nightmare. He is alone on a weekend graveyard shift when a lightning storm sweeps across the system, tripping transmission lines. The winking panel of lights before him springs to life with multiple alarms. A printer begins to chatter out information about remote circuit breakers automatically trying to reclose. And out in the night, a quarter-million people—most of them sleeping unaware—have lost power.

After years of experience, a seasoned dispatcher knows how to "tune out" the din of alarm bells and focus on just those signals that need immediate attention. A less experienced operator, however, can be overwhelmed. With a growing sense of urgency, he turns to a new computer technology known as an expert system. Within seconds the system tells him the probable location of the line faults and suggests what steps to take to restore the system.

Such expert systems are now beginning to emerge as a practical tool for helping operation and maintenance personnel deal with increasingly complex utility systems. They enable a utility to capture and preserve the knowledge of its best experts, keeping it always on hand. By encoding critical domains of human expertise for computer manipulation, expert systems can quickly sort through enormous amounts of data to provide a system dispatcher, power plant operator, or maintenance technician with provisional diagnoses of problems and a menu of possible corrective actions.

Expert systems are not designed to calculate exact solutions to specific technical problems, in the manner of conventional computer programs. Rather, they imitate human logic by applying a series of *If . . . then* rules based on past experience. In the scenario just discussed, for example, a dispatcher could use CRAFT, an expert system developed under EPRI sponsorship, to apply approximately 300 rules for fault isolation and service restoration.

For expert systems to fulfill their considerable promise in numerous electric utility applications, however, a substantial commitment to further R&D will be required. EPRI's work in this field is aimed at helping utilities use expert systems to capture the knowledge of their own best people and make it easily accessible. New programming tools are also being developed that can simplify in-house development of expert systems for a variety of utility applications. In addition, the process of technology transfer is being facilitated by expert systems that incorporate EPRI research results in a form that member utilities can immediately put to practical use.

What is an expert system?

Expert systems—like robotics, spoken language interpretation, and visual object recognition—make up a major division of artificial intelligence (AI), the branch of computer science that enables machines to perform more like human beings in limited ways. As a result, the field of expert systems has inherited considerable AI jargon, which is often unfamiliar to traditionally trained engineers, including those in the electric utility industry. Typically, for example, an expert system has

Computerized systems that capture the knowledge and mimic the reasoning of human experts hold much promise for utility application. EPRI has intensified its efforts to develop and demonstrate such expert systems for the industry and to help individual utilities tailor systems to their own needs.

been created by a *knowledge engineer* (programmer) using an *inference chain* (sequence of rules) based on information provided by a *domain expert* (someone with expertise in a technical area). Such rigid distinctions are steadily declining, however, and one of EPRI's goals is to make the development of expert systems easier for nonspecialists.

Stripped to bare essentials, each expert system has at least three main components. A *knowledge base* contains both the specific facts about an application and the rules that apply in various situations. An *inference engine* controls problem solving by selecting and executing rules and determining when a solution has been found. The *user interface* provides a convenient format for entering additional data and for describing possible solutions or scenarios.

As an illustration of how an expert system works, suppose that data coming from a generator show the temperature of a critical component to be 300°. The knowledge base contains information indicating that this component's normal temperature is 250°. One of the rules encoded in the inference engine might be: "*If* component temperature exceeds normal by 50°, *then* sound alarm." Once this rule is executed, the user interface would alert the operator and might provide a message saying, "64% probability that hydrogen cooler is blocked; suggest checking the cooler before shutting unit down."

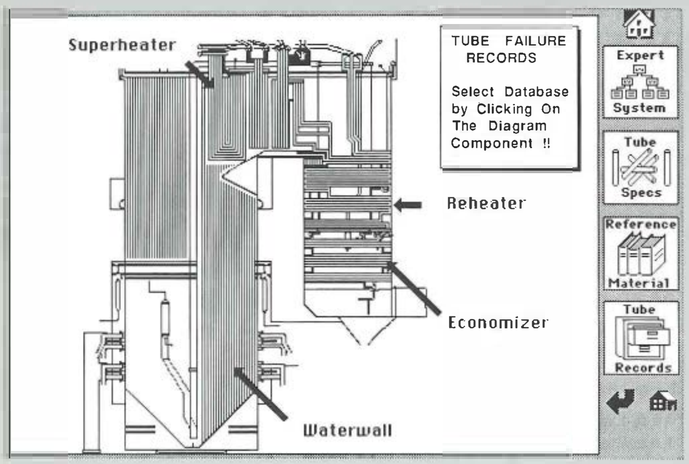
This same problem could be solved by using conventional computer programming techniques, but the expert systems approach has three advantages. First, AI programming languages make it easier to encode *If . . . then* rules, in some cases reducing programming time by orders of magnitude. Second, because the inference engine and the knowledge base have been separated, new rules and facts can be incorporated without having to completely reprogram—as might be the case with a conventional computer code.

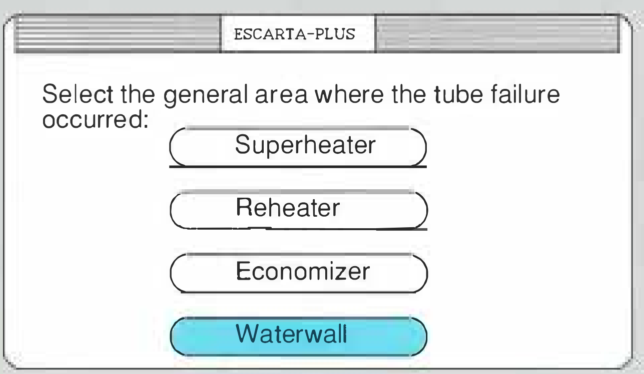
Finally, with expert systems the process of problem solving is mainly probabilistic and intuitive, an approach well adapted for complex problems with many uncertainties. In the above example the expert system, drawing on past experience, would tell an operator that a blocked hydrogen cooler is the most likely cause of a particular generator problem, whereas a conventional computer program might go through a much lengthier calculation to model generator performance in great but irrelevant detail.

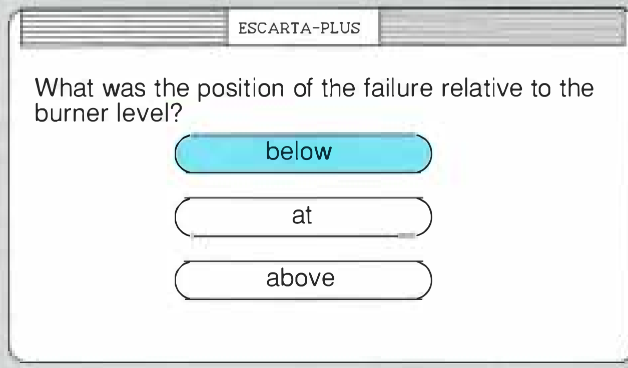
Delivering On-Line Expertise

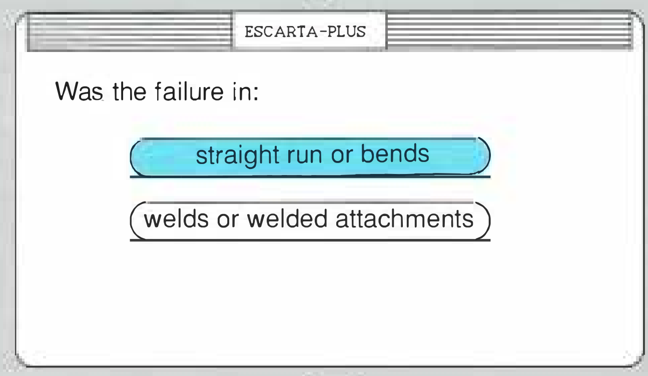
Expert Troubleshooter for Boiler Tube Failures

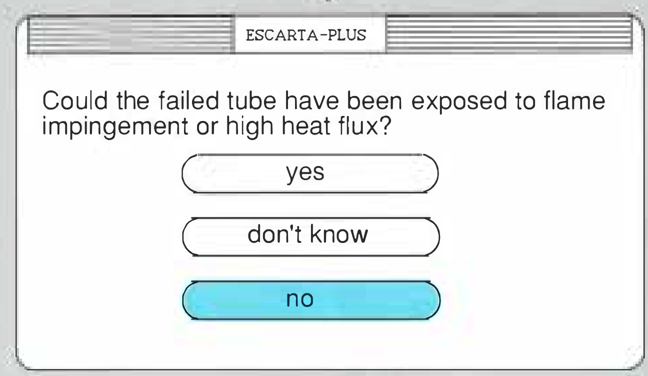
EPRI's Boiler Tube Maintenance Workstation incorporates an expert system that queries the user about the circumstances of a boiler tube failure and provides a preliminary analysis of the failure mechanism. The expert system, called ESCARTA, first divides the boiler into four main regions: waterwall, superheater, reheater, and economizer. Then it asks the user a series of questions about the location and appearance of the failed tube and about potential initiating events. Subsequent questions elicit progressively more detailed information. As an additional aid to the user, the workstation will be coupled to a 35-mm slide projection or video disk system to display images of failed tubes.

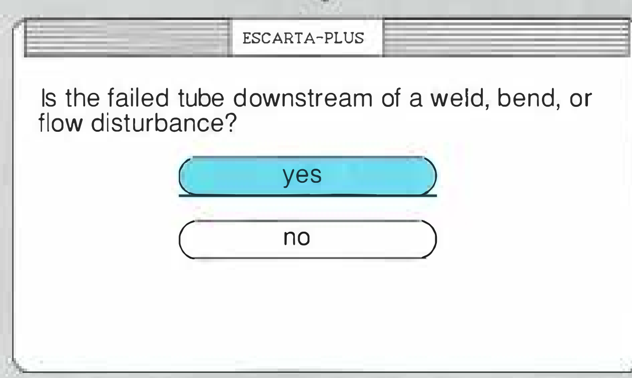










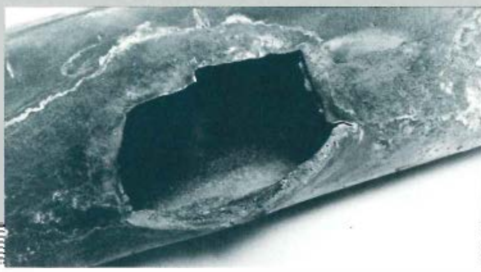


ESCARTA-PLUS

Is there significant external wall thinning?

yes

no



Is the fracture appearance 'window opening' or 'thick-edged split'?

yes

no

ESCARTA-PLUS

Probable failure mechanism is:

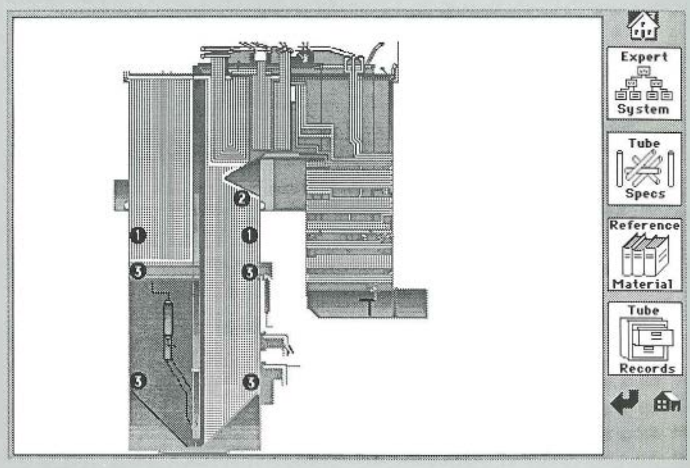
Hydrogen damage

ESCARTA-PLUS

Typical locations of tube failures due to hydrogen damage

Water-cooled carbon steel tubes can experience hydrogen damage at locations that:

- have flow disruptions such as welded joints with backing rings or protrusions, bends, or deposits.
- have horizontal or inclined tubing.
- have high heat flux.



ESCARTA-PLUS

Does the tube failure fit this description?

yes

no

ESCARTA-PLUS

Confirmed failure mechanism is:

Hydrogen damage

The advantages of fuzzy thinking

The power of expert systems comes from their ability to mimic the human reasoning process in specific ways, providing answers to problems that may be less precise than those calculated by conventional computer programs but that are probably more relevant and easier to understand. From the user's point of view, the approach is heuristic—that is, the search for solutions is based largely on approximate rules of thumb that can be updated as further experience is gained. Structurally, the process is facilitated in expert system software by the separation of rules, data, system control, and user interface into different modules.

This kind of "fuzzy" thinking is particularly useful in dealing with problems characterized by incomplete, ambiguous, or conflicting data. In generator maintenance, for example, some particular symptom of trouble—such as rising coil temperature—could result from any of several causes, ranging from broken strands to blocked ventilation. Conversely, a single event—such as condensation of moisture inside the generator—could lead to a variety of symptoms, ranging from clogged drain lines to arcing. Troubleshooting is difficult, as data flow continuously from 150 to 250 sensors in the generator and its auxiliaries, and diagnostic rules are scattered among voluminous manuals and charts. By using a commercially available expert system to sift through the extensive data and apply more than 2500 rules per unit, TU Electric reports saving $20 million a year through the increased availability of seven generators.

"Expert systems could begin a new era in utility operations by integrating controls, diagnostics, computers, and accumulated human knowledge," says Murthy Divakaruni, who coordinates expert systems work in EPRI's Generation and Storage Division. "There are 1200 fossil power plants in the United States—many of them in the middle of nowhere, attended by only a few people. As the plants get more complex, these people need help. Not many of these utility personnel have time to digest EPRI research results. Expert systems will help ask the right questions in seeking assistance. We're seeing a lot of grass-roots interest in expert systems—from engineers, operators, and utility managers. This is partly because they can query the system and, if necessary, verify the responses."

David Cain, who guided the early development of expert systems in the Nuclear Power Division, agrees but urges caution: "Utility systems are becoming so complex that no human can keep up with all the details. Expert systems can help, but we need to avoid failures in diagnosis that could discredit them. Codifying human knowledge is difficult, and there are still misunderstandings about what

Portable Expertise

The SA•VANT delivery vehicle brings expert knowledge to the field in a portable, easy-to-use package. Built to operate in rugged environments, the unit contains a state-of-the-art microcomputer, printer, and keyboard; separate displays for text and video; and a voice input/output system. The video display can present schematic diagrams and motion sequences of equipment. Graphic overlays allow the user to add dimensions and labels to the video pictures. The knowledge base is stored on an optical disk, which can be replaced for different expert systems applications. A single technician can transport the suitcase-sized unit to equipment in the field—for example, the control cab of a gas turbine.

expert systems can accomplish. Keep in mind that these systems are just devices to process well-defined logic in a very narrow range of tasks. If you had a scale of reasoning with a rock at zero and a human at the upper end, expert systems would rank somewhere down near the earwig."

Because of these limitations, EPRI's work in expert systems is focused primarily on developing a few applications that can meet specific utility needs and quickly prove their worth. Although these applications are generally related to problems of operation and maintenance, specific emphasis varies considerably among the different areas of utility concern. Work on expert systems for nuclear applications initially concentrated on the safety issues that can arise when plant operators face information overload during emergencies. Since the success of these first efforts, nuclear applications have been extended to cover a broad range of training, operations, and maintenance. Expert systems for fossil power plants generally aim at improving the availability and performance of aging facilities. And expert systems development related to power system operations is directed toward improving diagnostic capabilities that could result in faster repairs and better system security.

Expert Systems for Power System Operations

One leading example of grassroots cooperative effort in expert systems development began when dispatchers at Puget Sound Power & Light suggested the need for an expert system to isolate the faulted section in multitapped transmission lines. The resulting product, called CRAFT (customer restoration and fault testing), is now on-line at Puget Power, helping to restore power after faults that occur on any of the utility's 19 transmission lines. CRAFT was developed by researchers at the University of Washington under EPRI sponsorship. Online implementation has been cosponsored by EPRI, Puget Power, and the National Science Foundation.

CRAFT is now ready for commercialization, and EPRI is actively pursuing licensing agreements toward that end. Before the system can be used at other control centers, however, some customization will be required to access needed information from highly specialized data bases. Vendors of energy management systems for control centers are expected to incorporate CRAFT as an integral part of their more advanced products. As an alternative, individual utilities may eventually be able to add CRAFT to their existing energy management systems.

EPRI has also sponsored the development of more experimental expert systems related to power system operations. Union Electric, for example, has worked with researchers at the University of Missouri to assess the suitability of PROLOG—the AI programming language favored in Europe and Japan—for creating expert systems that can be linked to power flow programs written in FORTRAN. One part of this work included the development of a demonstration expert system for volt/VAR dispatch, which was tested with data from a 330-bus computer model of the Union Electric power system. □

Responding to utility needs

The dispatcher's nightmare described earlier has provided the focus for expert systems work in the area of power system operations. Although utility control centers have numerous computerized tools to facilitate normal operations, during emergencies dispatchers may be confronted with 200 alarms and a system that is changing more rapidly than a human can react. As a result, control center operators have emerged as early champions of expert systems related to emergency response and have sometimes actively participated in their development.

"Our focus is on expert systems as an interface between dispatchers and the energy management system," observes Narain Hingorani, vice president for EPRI's Electrical Systems Division. "By monitoring the power system and comparing its performance against certain criteria, the expert system can alert operators to developing conditions without distracting them with lots of extraneous information."

Program manager Neal Balu adds that studies involving the use of various programming approaches complement the primary research thrust. "Expert systems are not very easy to develop from scratch," he notes. "Special purpose programming languages like PROLOG and LISP are often used to develop expert systems, and at present we are exploring the use of PROLOG, an AI language already popular abroad."

Another approach to the problem of programming expert systems, now being pursued for nuclear applications, is to develop appropriate expert system "shells" —software that provides an easy method for entering rules and has a built-in control system for applying them. Using an appropriate shell, an engineer can create an expert system applicable to his own specialty without first having to master AI programming conventions.

To provide such a shell for small-scale

utility applications, EPRI's Nuclear Power Division has developed the Small Artificial Reasoning Tool (SMART). This shell is designed to run on a personal computer and enable novice users to construct their own small expert systems. SMART also contains features that allow advanced users to construct more complex programs. For larger-scale utility applications, the division has sponsored the Plant Expert System (PLEXSYS), which enables users to represent complex facilities in a schematic format similar to that used in computer-aided design. For example, PLEXSYS enables an engineer to use drawings of pipe layouts and schematics of instrumentation directly in developing an expert system for monitoring some aspects of plant performance.

"EPRI has a strong role to play in providing technology and coordination for utility efforts to develop and use expert systems," says John Taylor, vice president for the Nuclear Power Division. "I'm particularly intrigued by the potential SMART has for enabling utilities to build their own expert systems. By providing this sort of framework and technical support for the development of specific expert systems applications, we can greatly amplify the effectiveness of our own research activities, while sharing royalties from the new applications."

The use of expert systems in fossil fuel power plants is a "natural evolution" of current trends toward employing more complex control and monitoring systems to improve plant performance and maintenance, according to Tony Armor, a senior program manager in the Generation and Storage Division. "The industry has already installed extensive monitoring devices that track heat rate and detect signs of incipient mechanical failure," he says. "Now we can improve the interpretation of the data from these devices, using expert systems. The immediate benefits include improved overall plant efficiency and the avoidance of some catastrophic failures in key components. Eventually, expert systems can help integrate the process controls needed for coal 'refineries,' which will produce synthetic fuels and chemical feedstocks in addition to electricity."

Generators represent a particularly critical plant component for which extensive monitoring data are already available but not fully analyzed. "There is about one catastrophic generator failure each year," says program manager J White. "Many of these failures—which can cause a $50 million forced outage—could be avoided by using expert systems." Such a system will begin field testing this year. Another diagnostic expert system, for the on-line detection of rotor cracking in steam turbines, is now ready for licensing and may be commercially available by 1990.

In the area of combustion turbine power plants, EPRI has developed a portable system called SA·VANT for delivering expert knowledge to the point of use. Intended for operation in rugged environments, SA·VANT offers, in one package, all the interface media (including interactive video and voice commands) needed to deliver a fully functional expert system. "The intent of this project was to test an expert system in a gas turbine power plant to establish that it could help the technician perform troubleshooting tasks," states Al Dolbec, senior program manager in the Combustion Turbine Program.

Clark Dohner, project manager, adds, "From the very beginning it was recognized that half the problem in being able to use expert systems in a power plant environment was the man-machine interface. So a great portion of the effort was spent in solving this problem with a portable, easy-to-use system." And, as project manager George Quentin points out, the interface advances are not task specific: "SA·VANT has the ability to deliver other expert systems to the plant floor for any power plant application. Utilities have found that SA·VANT's high-resolution display makes it very effective for field maintenance and training new experts."

Such branching out is key to EPRI's overall goal of enhanced technology transfer. "Our intent is to use expert systems to capture the knowledge base utilities have built up over the years," declares Kurt Yeager, vice president, Generation and Storage Division. "Expert systems can serve as a time-contractor—reducing vast quantities of data to manageable size and compiling the expertise of the industry in an accessible form. EPRI can help focus utilities' efforts to develop and test such systems, then provide a mechanism for transferring the technology rapidly."

Future directions

Now that EPRI has developed several expert systems and demonstrated their worth in practical utility applications, Institute involvement in this area is expected to grow rapidly. To make the most efficient use of limited R&D resources in a diverse and highly specialized field, an interdivisional AI Coordination Committee has been formed. The chairman of the committee, Bill Sun, says its goal is to "provide internal coordination and enhanced technology transfer. We have been able to minimize overlap between divisions by reviewing each other's proposals and projects, and we have also conducted joint seminars for utilities to help them learn what's available."

A more formalized coordinating effort is expected to begin in mid-1989 with establishment of the Knowledge-Based Technology Applications Center (KBTAC). Although the center is being established by the Nuclear Power Division, its purpose is to encourage utility participation in the development of expert systems to meet a wide variety of needs. Bill Sun, who is directing this effort as well, says that the center "will provide a clearinghouse for information on existing expert systems and a facility where utilities can come and build their own systems, if necessary." Already several utility requests have been received for potential KBTAC projects to develop expert systems for a

Expert Systems for Equipment Maintenance and Operations

An expert system for the on-line diagnosis of rotor cracks in steam turbines has been developed under EPRI sponsorship by General Electric and is now being used at the Port Everglades plant of Florida Power & Light. Laboratory tests indicate that the new expert system can diagnose a crack when its depth is less than 5% of the rotor diameter—in time to take corrective action and probably save the rotor. A licensing agreement for the system is now under negotiation, with commercial availability expected in 1990.

To help improve generator performance, Ontario Hydro and SRI International have developed a generator expert monitoring system under EPRI sponsorship. The first field test of the system is expected to begin this year at the Nanticoke station of Ontario Hydro, with a second field test to follow at Niagara Mohawk's Oswego station, probably in 1990. An important aspect of this expert system is its unique installation advisor module, which can be used to configure the software to analyze data from various generator models. The module is also used to input generator design and construction details, as well as individual utility policies and practices.

EPRI's aim in this project is to provide utilities with their own in-house generator diagnostic capability. The generator expert monitoring system is expected to become commercially available sometime in 1990.

EPRI has also designed a self-contained portable unit for delivering all types of expert systems for power plant field applications. SA·VANT, the briefcase-size user interface, contains a 386 laptop computer, a high-resolution video display, a plasma-type text display, optical-disk storage of knowledge base and visuals, special-function keypad, voice input/output, and an 80-column miniature printer.

Developed by Honeywell under the guidance of two EPRI project managers, Clark Dohner and George Quentin, SA·VANT was originally designed as a platform to deliver an expert system for use in the field by plant technicians. The SA·VANT system was successfully demonstrated in a pilot application for gas turbine maintenance at Jersey Central Power & Light's Gilbert station. It applied expert system software developed by General Electric to detect ground faults in the gas turbine controls.

Quentin is directing field tests of the SA·VANT unit this year at Jersey Central's Sayreville station to diagnose the cause of startup failures in combustion turbine peaking units. EPRI has applied for a patent on the SA·VANT delivery vehicle, which will be used for a wide variety of applications, such as boiler tube failure analysis and turbine borescope inspections.

EPRI has also been involved in evaluating a commercially available expert system called ESCARTA for preventing boiler tube failures. Developed by Karta Technology under the guidance of EPRI project manager Stephen Gehl, ESCARTA is based on two EPRI reports—a manual for investigating and correcting boiler tube failures (CS-3945) and guidelines for boiler tube inspection (CS-4633, Vol. 1)—and on hundreds of recent technical papers. EPRI has already sponsored successful demonstrations of ESCARTA at five member utilities. □

range of applications, from routing cables through a plant to making improved safety assessments.

Sun also points out two other major expert systems initiatives getting under way in the nuclear area. One involves an agreement with the Nuclear Regulatory Commission to work with EPRI on the verification and validation of expert systems. This work, scheduled to begin in 1989, is aimed at ensuring that expert systems do not give wrong advice and that they meet both user and regulatory performance standards, Sun says. The second initiative concerns work with the National Aeronautics and Space Administration to adapt its Knowledge-based Autonomous Test Engineer (KATE) expert system to utility applications.

In the fossil power plant area, a comprehensive five-year R&D plan for expert systems has been drawn up by the Generation and Storage Division. The plan is based on the prioritization of proposed projects by a formal working group of utility representatives, manufacturers, architect-engineers, and expert systems consultants. As a result of this work, EPRI has announced seven technical areas where expert systems can assist fossil plant staff. Initial products, scheduled for delivery in 1990, will include expert systems related to fossil plant thermal performance, turbomachinery diagnostics, and feedwater heater and condenser diagnostics.

Many of these will be installed at the EPRI Monitoring and Diagnostics Center. Located at the Eddystone plant of Philadelphia Electric, this facility tracks the key symptoms of deteriorating mechanical conditions in boilers, turbines, generators, and balance-of-plant equipment. Also, an expert system for turbomachinery vibration monitoring, developed by EPRI project manager John Scheibel, is undergoing tests at Florida Power & Light. Projects in water chemistry, demineralizer operations, and plant system inspections are scheduled to start in 1990.

An operator aid that uses NASA technology to simplify, filter, and prioritize alarms in order to emphasize the significant ones. *EPRI Project Manager: Joseph Naser, (415) 855-2107, Nuclear Power Division*

This workstation, called BMW, diagnoses boiler tube failures and integrates various EPRI research projects for boiler inspection and maintenance. It features the expert system ESCARTA, which queries the user about the circumstances of a tube failure and provides a preliminary analysis of the failure mechanism. *EPRI Project Managers: Steven Gehl, (415) 855-2770, and John Scheibel, (415) 855-2850, Generation and Storage Division*

A decision and information tool to aid utilities in minimizing component life-cycle costs through appropriate engineering and economic analyses, application of pertinent technical data, and problem-solving guidance of experts. It includes training and tutorials for all elements of a component's life cycle. *EPRI Project Manager: Floyd Gelhaus, (415) 855-2024, Nuclear Power Division*

NASA's Knowledge-based Autonomous Test Engineer (KATE) performs system monitoring, signal validation, fault location and diagnostics, and automatic control and reconfiguration. It was evaluated and applied to an alarm processing system for the reactor coolant pump seal injection system. The KATE technology has been enhanced and is available for utilities under the name ProSys. *EPRI Project Manager: Joseph Naser, (415) 855-2107, Nuclear Power Division*

CRAFT identifies and isolates the faulted section in multitapped transmission lines. *EPRI Project Manager: David Curtice, (415) 855-2832, Electrical Systems Division*

EOPTS is a computerized system to help operators select and apply operating procedures during plant emergencies. *EPRI Project Managers: David Cain, (415) 855-2112, and Bill Sun, (415) 855-2119, Nuclear Power Division*

A project to develop and document guidelines for verifying and validating expert systems. *EPRI Project Manager: Joseph Naser, (415) 855-2107, Nuclear Power Division*

An off-line system to diagnose possible feedwater heater failure modes and performance problems. *EPRI Project Manager: John Tsou, (415) 855-2220, Generation and Storage Division*

A diagnostic tool for improving a generator's operation, reliability, and availability on the basis of all available monitoring information. An installation advisor module allows utilities to tailor GEMS for plant-specific applications. *EPRI Project Managers: Murthy Divakaruni, (415) 855-2409, and J White, (415) 855-2310, Generation and Storage Division*

An on-line system that advises operators about the causes for deviations from target heat rate values. It was developed by using EPRI heat rate logic diagrams and decision trees in addition to expert knowledge. *EPRI Project Managers: Steven Gehl, (415) 855-2770, and Murthy Divakaruni, (415) 855-2409, Generation and Storage Division*

An expert system to serve as a decision aid for low level waste operations. *EPRI Project Manager: Floyd Gelhaus, (415) 855-2024, Nuclear Power Division*

An expert system for use in the control room, together with performance monitoring systems, to diagnose condenser performance–related problems. It is based on 39 past EPRI R&D reports. *EPRI Project Manager: John Tsou, (415) 855-2220, Generation and Storage Division*

A microcomputer-based system to aid plant engineers in identifying operating trends and problem areas before the complete failure of emergency power systems. *EPRI Project Manager: Joseph Naser, (415) 855-2107, Nuclear Power Division*

This project is developing a core shuffle planning system to determine an efficient crane movement sequence for moving fuel and inserts in PWRs and fuel and control blades in BWRs. *EPRI Project Manager: Joseph Naser, (415) 855-2107, Nuclear Power Division*

An expert system planning tool for utilities in inspecting boilers, turbines, and various balance-of-plant equipment; used for periodic inspection and predictive/preventive maintenance. *EPRI Project Managers: Steven Gehl, (415) 855-2770, and John Scheibel, (415) 855-2850, Generation and Storage Division*

This project is developing field-grade expert systems for performing diagnostics for critical plant equipment and improving plant capacity. *EPRI Project Manager: Bill Sun, (415) 855-2119, Nuclear Power Division*

REALM is an expert system for assessing a nuclear plant's overall safety situation in order to assist site emergency coordinators. *EPRI Project Manager: Glen Snyder, (415) 855-2710, Nuclear Power Division*

A portable expert system delivery vehicle for bringing expert knowledge about power plant maintenance to the point of use in the field. *EPRI Project Managers: Clark Dohner, (415) 855-2501, and George Quentin, (415) 855-2524, Generation and Storage Division*

PC-based diagnostic guidance for improving nuclear plant thermal performance. *EPRI Project Manager: Norris Hirota, (415) 855-2084, Nuclear Power Division*

An expert system for performing assessments and diagnostics for such turbomachinery auxiliaries as pumps, fans, and compressors. *EPRI Project Managers: Richard Colsher, (215) 971-7105, and John Scheibel, (415) 855-2850, Generation and Storage Division*

Collects and interprets turbine vibration data, advises operators about 26 possible failure modes, and identifies possible corrective actions. *EPRI Project Manager: John Scheibel, (415) 855-2850, Generation and Storage Division*

Expert Systems for Nuclear Safety and Performance

One of the first full-scale expert systems designed for critical nuclear power plant application is the Reactor Emergency Action Level Monitor (REALM). During an accident at a nuclear facility, REALM could sift through the large quantities of data on plant behavior and assess the severity of the situation. Specifically, REALM would help utility management determine the appropriate emergency action level for initiating relevant activities outlined in the site emergency response plan.

Developed with EPRI funding by Technology Applications, Inc. (TAI), REALM is now being installed on-line at Consolidated Edison's Indian Point Unit 2, which served as the development host site. Although REALM was initially designed for a dedicated AI workstation, the acceptance of such special computers in power plants has been questioned, and a version of REALM was recently created for the IBM AT microcomputer. REALM has been commercialized by TAI and is expected to find applications outside the utility industry for assessing accidents at such facilities as chemical plants and oil refineries.

Another critical aspect of nuclear plant safety involves efforts by control room operators to prevent transient events from developing into more serious accidents. To aid such efforts and reduce the chances for human error, EPRI has developed the Emergency Operating Procedure Tracking System (EOPTS), based on guidelines of the Boiling Water Reactor Owners Group.

Initial development used the KuoSheng BWR of Taiwan Power as a model, and EOPTS is now running online at the company's training facility. The time-saving power of EOPTS was demonstrated dramatically during evaluation tests at the simulator facility at KuoSheng. One crew used conventional flow charts to respond to four transient-event scenarios, while a second crew used EOPTS. Preliminary results indicate that the use of the expert system cut response time by 60–75%.

The first use of EPRI's programming shell SMART to build an on-line expert system for nuclear plants resulted in the Water Chemistry Expert Monitoring System (WCEMS). Developed by NWT Corp. for Rochester Gas & Electric, with technical support from EPRI, WCEMS uses real-time data to diagnose chemistry conditions in the feedwater, steam generator, and steam circuit of a pressurized water reactor. The expert system has been implemented at Rochester's Ginna PWR, where it accepts data continuously from 26 monitors, in addition to periodic input from detailed analyses of water samples.

With the cooperation of Duke Power, EPRI is developing a diagnostic expert system for nuclear plant emergency diesel generators. The system consists of a data acquisition subsystem that gathers and stores data from the diesel generator and an expert system that retains symptom-based and physics-based knowledge. This system, which is designed to enhance diesel generator availability and reliability, is scheduled for full-scale testing at Duke Power's McGuire nuclear plant at the end of 1989. □

In addition to specific diagnostic capabilities, Murthy Divakaruni says that expert systems will also eventually be focused on two expanding areas. One, intelligent computer-aided engineering, will use expert systems to ease the design and construction of new power plants. The other, executive decision support, will apply expert systems to help utility managers answer questions related to typical types of problems: Should this older plant be shut down, life-extended, or repowered? Should it be cycled? How much money should be invested in the plant over the next 2, 10, or 20 years?

The Electrical Systems Division has recently invited proposals for the development of new expert systems in both the power system planning and operations areas. Emphasis, according to project manager David Curtice, is being placed on projects that will enhance system reliability, performance, and economy. Two or three projects are expected to be chosen for an initial, one-year prototype development phase, to begin in 1989, Curtice says. Then the one or two most successful will be supported through an anticipated three-year commercialization phase, which will involve cost sharing by a host utility.

Tony Armor sums up the reasons for EPRI's growing commitment to expert systems this way: "Utilities are being attracted to expert systems mainly because of the people-oriented benefits they can provide. Some experts are retiring and taking their knowledge with them. Others are being overwhelmed. And none can be in all the places they are needed at once. Computerized expert systems can help utilities both preserve their accumulated human expertise and extend the capability of their human experts."

This article was written by John Douglas, science writer. Technical background information was provided by Murthy Divakaruni, Generation and Storage Division; Bill Sun, Nuclear Power Division; and David Curtice, Electrical Systems Division.

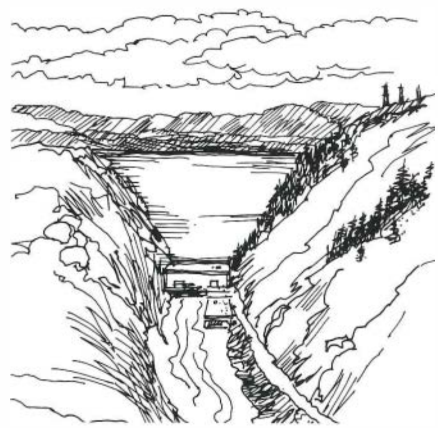
TECH TRANSFER NEWS

Dam Research Leads to Changes in Federal Criteria

A major area of EPRI's hydro research paid big dividends last December when the Federal Energy Regulatory Commission announced significant reductions in its criteria for dam safety. EPRI research on dam safety issues played a significant role in FERC's conclusion that it was appropriate to modify the safety-factor criteria for gravity dams for the probable maximum flood (PMF) loading condition. The change in the criteria (documented in Chapter 3, "Gravity Dams," of *Engineering Guidelines for the Evaluation of Hydropower Projects*) resulted in a reduction of the PMF safety factor from 2.0 to 1.5. In other words, dam strength needs to be 50%, rather than 100%, more than the destabilizing forces during the PMF.

"The research by EPRI substantially influenced our decision to take this step to reduce the factor-of-safety criteria," says Ronald A. Corso, FERC director of dam safety and inspections. "We view the progress to date and the prospects for improved investigatory and analytical methods from the research sponsored by EPRI as a positive step toward a better understanding of dam safety problems. EPRI research efforts and dam safety workshops and seminars have been instrumental in raising the level of understanding of dam owners, engineering firms, and regulatory agencies about many of the more controversial dam safety issues. As a result, dam owners have shown an increased willingness to use state-of-the-art investigatory, testing, and analytical methods to evaluate the stability of dams."

EPRI's dam safety program has produced a guide to help utilities use the sampling and measuring techniques required to determine site-specific stability parameters. EPRI and member utilities are using this guide at 20 gravity dams to take core samples for independent tests, examine drain conditions, and measure uplift water pressures under the dams and relate changes in reservoir levels to changes in pressure. These measurements indicate the total loading on dams—forces that cause sliding or an overturning effect—and also provide key stability data, such as cohesion between a dam and its foundation, concrete material strength, and foundation condition.



The procedures documented and applied by EPRI have demonstrated that dams dating as far back as the early 1900s have excellent concrete and a strong dam-foundation bond. The EPRI techniques show how to distinguish between open cracks and tight rock joints and how to prevent mechanical breakage due to the drilling process used to extract test samples. The consistency of EPRI's test results has confirmed the validity of the guide and provided confidence that dams are generally stronger and more stable than expected. EPRI's contractors are now compiling a data base of measurements from dams of different ages, regions, and foundations so that dam owners taking their own measurements will have a basis for comparison.

The change in criteria implemented by FERC will eliminate or reduce the requirement for utilities to anchor gravity dams to a rock foundation. The cost for posttension anchoring can range from $0.5 million to $8 million per dam, depending on dam size and stability. While not all anchoring can be or should be avoided, Corso points out that "preliminary estimates indicate that this reduction in safety-factor criteria will significantly reduce the cost of dam safety modifications." Given that there are about 1200 gravity dams operating under FERC license, total industry savings could run in the tens of millons of dollars. Nationwide savings could be even more substantial, since there are at least 10 times that many non-FERC dams that could benefit from the research.

According to James Birk, director of EPRI's Storage and Renewables Department, "FERC's Division of Dam Safety and Inspections has been very willing to reexamine its criteria when it is provided with objectively developed technical data. Furthermore, FERC greatly simplifies our hydro technology transfer program by providing us a single direct application of our R&D data and results. Our next goal is to provide FERC with an objective methodology for arriving at realistic design precipitation levels to replace the probable maximum precipitation values determined by the National Weather Service. If we're successful, industry savings could significantly exceed those associated with the change in the factor-of-safety criteria." ■ *EPRI Contact: Douglas Morris, (415) 855-2924*

Energy Utilization Seminar

More than 350 utility professionals gathered to examine end-use technologies and tools at the first "Win With Service and Value" symposium in San Francisco last month. Sponsored by EPRI's Customer Systems Division, the event showcased EPRI end-use products and services. The symposium featured presentations, exhibits, and technical help clinics on new and emerging residential, commercial, and industrial technologies, as well as on methods to assess end-use markets and influence demand.

The keynote speakers at the symposium addressed the impact of accelerating technological change on social culture and examined how these changes affect utilities and other businesses. Robert Leone, a professor at the Boston University School of Management and the author of *Who Profits: Winners, Losers, and Government Regulation*, discussed techniques of competitive and managerial analysis and their application to business problems. Social critic Alvin Toffler, the author of *Future Shock*, offered an analysis of interconnections between corporate, societal, and technological change, advancing the argument that businesses that are responsive to these connections often succeed where others fail.

Other events at the symposium narrowed the focus to technology and changes within the electric utility industry and showcased EPRI and utility research products. "EPRI's vision in the Customer Systems Division is driven by the need to develop the most energy efficient products for society, with the least risk to the health of our environment," said EPRI President Richard Balzhiser.

This point was driven home by Robert Dietch, vice president for engineering, planning, and research at Southern California Edison, who in his address identified electric vehicles as the kind of technology that makes sense for everybody involved. "Since EVs would normally be charged during off-peak hours, customers would benefit from the low-cost off-peak rates," said Dietch. "SCE would benefit from the added revenues and the resulting increased load factor. And air quality should improve because, with SCE's current generation, EVs are 98% cleaner than their internal combustion counterparts." Contributing to the hands-on aspect of the symposium, EPRI encouraged attendees to drive two SCE-owned GM G-Vans outside in the parking lot. A Chrysler TEVan and a G-Van belonging to EPRI were also available for inspection. SCE is initiating a program to facilitate the introduction of up to 500 G-Vans into commercial fleet markets in the Los Angeles area. ■ *EPRI Contact: David Rigney, (415) 855-2419*

EPRI Catalogs Lighting System Software

Energy-efficient lighting technologies developed in the last 10 years offer utilities new opportunities to reduce on-peak lighting load and increase off-peak energy sales. In addition, utilities can help their customers design lighting systems that reduce energy costs and increase worker productivity, safety, and comfort. *Personal Computer Software for Lighting Design and Analysis* (EM-5463), a new EPRI report, describes 22 commercially available computer programs for designing indoor and outdoor lighting systems. Intended for use as a software screening tool, the report will assist utilities in meeting their demand-side management and customer service needs.

According to the report, advances in personal computer software allow designers to analyze more combinations of lighting services, units, positions, and directions than was possible with traditional analysis tools. The report categorizes software by analytical approach: point methods, which determine the illumination at a particular point by considering the contribution from each light source; zonal cavity methods, which determine the average illumination within a given space at a specified height; and economic analysis methods for modeling lighting system acquisition, operation, and maintenance costs. ■ *EPRI Contact: Karl Johnson, (415) 855-2183*

EPRI Technology Assists in Aerospace Inspections

In the extensive inspection programs instituted after the space shuttle Challenger disaster and two Titan III explosions in 1986, NASA and the U.S. Air Force employed two EPRI-developed nondestructive examination technologies as part of their efforts to ensure the integrity of the insulation bond in their solid rocket boosters. The IntraSpect/98 ultrasonic scanning and imaging system was used to inspect the entire surface of shuttle solid rockets for insulation disbonds and was also used to inspect the complete inventory of large solid rockets in other NASA and USAF installations.

The IntraSpect/98 system, based on ultrasonic inspection techniques, digitizes and stores the radio-frequency waveform and provides real-time images. It consists of a computer-controlled, four-channel ultrasonic instrument; a data acquisition system; an AMAPS scanner; a scan controller; and data processing and display systems. NASA also employed MINAC, a portable, high-energy radiographic system that incorporates electron linear accelerator technology on a miniaturized scale.

Both devices were originally developed for the inspection of nuclear power plant piping. This unusual transfer of the technology to a completely different industry appears to have been very successful: approximately 45 IntraSpect/98 systems and 12 MINACs have been purchased by aerospace firms. ■ *EPRI Contact: Gary Dau, (415) 855-2051*

Risk Assessment and Management Methods

QuickTANKS: Storage Tank Risk Management

by Victor Niemeyer, Environment Division

Utilities use approximately 15,000 underground tanks for the storage of gasoline, diesel fuel, fuel oils, and other materials. Underground storage offers the advantages of low fire and explosion risk, protection from damage by traffic or vandalism, and efficient use of space. However, underground tanks and their piping systems are subject to corrosion and structural failures that can lead to leaks, and because they are underground, leaks can go undetected for long periods.

Leak costs, including the expenses of site investigation, excavation and construction, soil removal and disposal, groundwater cleanup and treatment, and postcleanup monitoring, can be quite large. It is not unusual for a leak cleanup to cost $100,000, and in some cases, utilities have spent over $500,000.

The problem facing the underground tank manager is to provide cost-effective fueling and storage services while controlling the risks. This requires balancing expenditures for newer and better tanks and more stringent leak detection systems against the potential costs of leaks. The key choices for the manager of existing tanks are when to replace or upgrade them and how much leak detection to conduct until then. For new tanks or the replacements for old tanks, the key issues are selecting the appropriate type of corrosion protection for the tank and selecting an effective leak detection system.

Risk management and TANKS

In September 1988, EPA released new regulations for underground tank systems (including piping). These rules provide schedules for replacing or upgrading existing tanks and for beginning leak detection programs. They also provide numerous restrictions on new tanks and leak detection systems.

Even so, the new regulations provide tank managers with a good deal of latitude for balancing expenditures against possible risk reduction measures. In the following important areas of decision making, the manager still has considerable discretion:

- Prioritizing tanks for replacement
- Selecting type and timing of leak detection used prior to replacement
- Deciding whether to replace or upgrade existing tanks
- Selecting the type of replacement tank and leak detection system
- Identifying tanks that should be eliminated without replacement

In many cases a utility can save money in the long run by taking a proactive tank management stance and doing more than the regulations require. For example, the extra cost of upgrading bare steel tanks ahead of the EPA schedules can be more than offset by reductions in expected leak cleanup costs. For a utility with several hundred tanks, the benefits from a tank management strategy that selectively goes beyond the minimum requirements can be in the millions of dollars. However, such a strategy must be tuned to the utility's tanks, tank locations, and other utility-specific factors.

EPRI's Underground Tank Risk Management Model, TANKS, is a decision support tool that runs on standard IBM-compatible personal computers. It was developed to help managers accurately and systematically evaluate tank management alternatives. The model is composed of three components: a user-friendly interface, an analytical model based on decision analysis that does the calculations, and a supporting data base that gives users critical information for analyzing their tank management options.

The model helps the user estimate, for a wide range of options, all the major costs of tank ownership: capital expenses (e.g., new tank cost), ongoing expenses (e.g., labor to operate leak detection), and the highly uncertain, but potentially large, leak-related costs. The sum of these costs for each option can then be compared in order to identify management alternatives with the lowest overall expected costs. TANKS specifically addresses leak uncertainties, the accuracy of leak detection systems, and the cost of cleaning up leaks.

ABSTRACT *Leaking underground storage tanks can cost a utility millions of dollars in expenses and cleanup costs. The QuickTANKS computer code, which is based on expert system software, offers utilities the capability of evaluating decisions concerning the selection of new tanks and the replacement or upgrade of existing tanks, with a limited input of time and analytical effort.*

QuickTANKS

It is sometimes difficult, however, for a utility's staff to carry out a detailed risk management analysis with TANKS. Constraints on human resources, management budgets, and time often make such analysis impractical even when the expected payback seems large. In such instances a utility would benefit from a tool that provides some assistance but requires considerably less time and effort to use. The desire to make insights and results of TANKS analyses quickly accessible to utilities in this situation led to the development of the QuickTANKS program.

QuickTANKS provides tank management recommendations and cost estimates based on data containing results from the analysis of approximately 2000 risk management scenarios with the TANKS model. The program guides the user through a simple question-and-answer dialogue and works with the user's answers to find the set of most similar TANKS scenarios stored in its data base. QuickTANKS then reports the least-cost management strategies and their costs from that set.

Given the overall goal of offering valuable assistance within a limited period of time, QuickTANKS should meet a number of requirements. First, QuickTANKS must provide assistance that is pertinent to the decisions currently facing tank managers. Because regulations play an important part in these decisions, QuickTANKS was designed to address questions concerning cost-effective planning under recently released EPA regulations.

A second design requirement is that QuickTANKS must be easy to learn and use. This is integral to its function of transferring insights and assistance to utilities that have limited resources to devote to tank management issues. Ease of use requires convenient documentation and reporting functions, as well as a short time to startup and run.

A third requirement is a general awareness concerning the robustness of the QuickTANKS recommendations. Approximations and assumptions are required because the user is only expected to provide a limited amount of information. To help the user fully understand the model's results, it is important that QuickTANKS give the user an indication of the sensitivity to changes in these approximations and assumptions. A related requirement is to make the basis of QuickTANKS recommendations available to the user for examination.

Figure 1 The QuickTANKS program is a cost-effective decision tool aiding utilities in the management of risk for underground storage tanks. In this sample case QuickTANKS recommends tank replacement in 1993, when leak-detection equipment is first required by EPA regulations. The total life-cycle cost of $34,000 represents the present value of all costs out to a 30-year planning horizon and includes operation and maintenance costs, new tank costs, and the estimated leak-related costs. The leak-related costs are broken out separately and include liability, cleanup, and other costs.

Recommended strategy:

Replace or upgrade the tank in 1993, when leak detection is first required.
Earlier leak detection is not cost-effective.

Estimated lifecycle costs (expected present value):

Total lifecycle costs:	$34,000
Leak-related component of total:	$ 6,000

Results are not sensitive to selected sensitivity variables or age approximation.

(F3 = Review question responses)
(F7 = View sensitivity variable and age approximation information)
(F8 = Display cost estimates for other management options)

Using QuickTANKS

QuickTANKS constructs its data input from the user's answers to simple multiple-choice questions. The questions are specific and in ordinary language, so they are easy to answer. Questions are presented one at a time, one per screen, so screens are not crowded or confusing. The user is asked to specify both the issues that are of concern and the specific tank and site situation. Prerelease testing has shown this interface to be extremely easy to use.

The first QuickTANKS menu screen asks the user to choose between two principal topics that QuickTANKS can address: what to do with an existing tank, and what technologies to select for new and replacement tank systems. Once the topic is selected, the user begins answering questions that describe the specific tank, tank site, and management requirements. Once QuickTANKS has enough information, one of several result screens appears. Figure 1 shows a result screen identifying the most cost-effective management strategy for a five-year-old bare steel tank, at a site that is moderately sensitive to leaks.

In addition to explanatory text and cost estimates, result screens can offer more detailed information. By pulling up different screens, the user can view sensitivity results or cost estimates for management alternatives at the site and begin to develop a sense of how sensitive cost estimates and recommendations are to changes in the answers. QuickTANKS includes sensitivity analysis capabilities that allow users to explore these options.

QuickTANKS also provides a feature that creates ready-to-run data sets in the TANKS model. After describing a situation in QuickTANKS and viewing the results, the user can create a TANKS data set, or "case." The created case is almost identical with the TANKS case that was used to generate the QuickTANKS results and is ready for examination or running from within the TANKS model.

This feature permits the user to view all assumptions that were used, and to change or customize the analysis, if desired. This feature also enables the user to pursue a QuickTANKS analysis in more detail by easily moving to a TANKS analysis. In fact, even if the primary tool of an analysis is the TANKS model, QuickTANKS can be used as a convenient way to provide initial data sets.

Future benefits

Though advanced software design should continue to make the benefits of risk management more accessible to utilities, utility staffs cannot always dedicate the effort needed to learn about and use new decision support software, even when the benefits may be large. For this reason it is important to complement complex tools with ways to facilitate transfer and use of beneficial information.

QuickTANKS makes results obtained from risk management analyses quickly accessible to assist with tank management. While QuickTANKS does not provide the detail of a customized analysis, it offers valuable assistance to the user who cannot complete or get started in a full analysis.

Power System Design and Analysis

Electromagnetic Transients

by Mark G. Lauby, Electrical Systems Division

High-speed electromagnetic transients are often the controlling factor in the design and operation of a power system. Traditionally, studies of electromagnetic transients were performed with special analog computer models known as Transient Network Analyzers (TNAs). In the late 1960s Dr. Herman Dommel at the Bonneville Power Administration (BPA) developed a digital computer replacement for the TNA—the Electromagnetic Transients Program (EMTP). At present the program is used worldwide by over 150 utilities, manufacturers, universities, and laboratories.

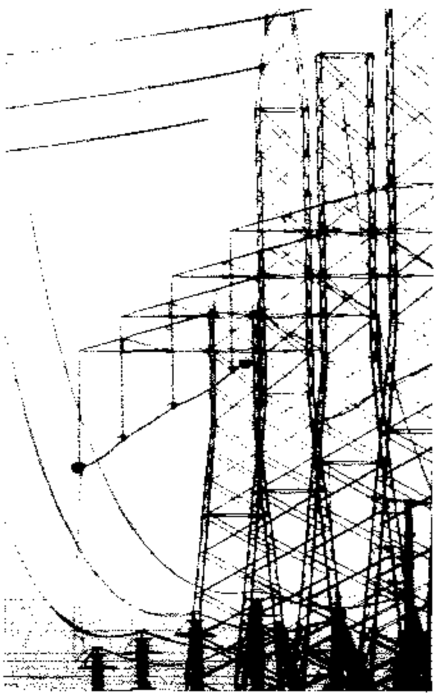
The EMTP is a versatile and flexible computer program for simulating electromagnetic, electromechanical, and control system transients on multiphase electric power systems. The program provides capabilities for convenient and inexpensive in-house studies of high-speed power system transients. Its wide range and variety of modeling abilities allow simulation of transients ranging from microseconds to two seconds in duration.

The EMTP has unique features for simulating electric power systems. Most of the EMTP's input data requirements are different from, and more extensive than, those for programs that model load flow, short circuit, and stability. Because EMTP is multiphase, can simulate nonlinear elements, and in general, uses more-detailed models, it can accurately simulate high-frequency, short-duration transients. The EMTP comes supplied with auxiliary programs to help the user set up the input data for transmission lines (Figure 1), cables, transformers, surge arresters, and nonlinear inductors. It is designed to run on VAX, PRIME, IBM-VM, IBM-MVS, and Apollo computers.

The EMTP can be used to study both design and operating problems. Design functions include insulation, coordination, equipment rating, protective device specification, and control system design. Unexplained outages and equipment failures are typical operating problems. Applications include lightning surge analysis, switching surge analysis, analysis of shaft torsional oscillation, insulation coordination, ferroresonance analysis, design of HVDC and SVC controls, analysis of transients and harmonics, and various types of steady-state analysis.

ABSTRACT *During the last two decades, utilities have relied on the Electromagnetic Transients Program for accurate simulation of high-frequency, short-term transients. Partly because of the efforts of the Bonneville Power Administration, this flexible, multiphase program for studying problems of power system design and operation has become the industry standard for transient analysis. To increase versatility and user friendliness, a recent cooperative effort between EPRI and the international EMTP Development Coordination Group has expanded the software and enhanced the documentation, program maintenance, and training available to users.*

Figure 1 The Electromagnetic Transients Program (EMTP) is a flexible, multiphase program with a large number of applications, including system design and simulation, control system design and simulation, and insulation coordination.



One of the EMTP's major advantages is its flexibility; the user defines the system to be simulated by building up models of system components. This flexibility enables an experienced user to apply the program to a wide variety of studies. Output from a transient simulation includes, in addition to machine and control system variables, plotted bus voltages, voltages, currents, and energy dissipation for any branch.

History of development

Over a period of 15 years the BPA developed and expanded Dommel's EMTP with help from other utilities and universities. The program became the industry standard for studies of electromagnetic transients. But because it grew rapidly to meet the needs of individual studies, the EMTP was inadequately documented and tested and became difficult to use. It also lacked several new models necessary for the study of certain important phenomena and the latest technology. By the late 1970s it was apparent that the EMTP needed broad-based support for development, distribution, and use.

With the formation of the EMTP Development Coordination Group (DCG) in 1982, program development activity began to meet the expanded needs of EMTP. The DCG—composed of BPA, the Canadian Electrical Association, Hydro-Québec, Ontario Hydro, U.S. Bureau of Reclamation, and the Western Area Power Administration—was formed to expand the EMTP software and to enhance the documentation, program maintenance, and training available to users. EPRI joined the development effort in 1984. In response to the need for education, EPRI and the DCG cofunded a summer short course on use of the EMTP at the University of Wisconsin.

The results of an EPRI user survey of more than 70 utilities (RP2149-1) showed a wide variation in the amount and sophistication of use. The objectives of the survey project were to identify needed program enhancements and prepare a plan for implementing them. Of the 18 enhancements recommended, the most critical concerned software and documentation that would enhance user understanding of EMTP applications and simplify input and output. User friendliness was by far the most desired improvement. The high-priority enhancements included: rewriting documentation for users, writing source code documentation, providing convenient data input, improving the transformer model, performing additional program testing, providing expanded output capability, and expanding steady-state solution and initial condition capabilities.

At the conclusion of the survey, it was decided that EPRI would undertake development and maintenance of user documentation and an input processor and would conduct a validation test program. Development of most new technical features was deemed best left to the DCG or others. Subsequently EPRI and the DCG initiated a development plan (RP2149) on January 1, 1984.

The goals of the DCG/EPRI development effort were to give users a well-documented code and good support, provide inexperienced users assistance in using the program, simplify program instructions, add models and user features, speed up and simplify the EMTP software, test and distribute new versions of the EMTP, and develop an interactive data input processor (EMTPIN).

Asea, now Asea Brown Boveri (ABB), joined the DCG as an associate member in 1984, and Japan's Central Research Institute of the Electric Power Industry (CRIEPI) joined in 1985. Associate members of the EPRI development effort include Electricité de France (EDF), which joined in 1987, and American Electric Power Service Corp. (AEP), which joined in 1988.

EPRI/DCG EMTP, Version 1.0

In January 1987 EPRI issued an extensively tested and enhanced version of the latest EMTP distributed by BPA. One primary enhancement of the new version was increased user support. Users were encouraged to report bugs and could rely on the expertise of the world's top experts to fix them. Another enhancement was fuller documentation—in the form of a comprehensive set of EPRI-developed manuals.

The EMTP Review, a newsletter published by the University of Wisconsin at Madison, College of Engineering, is available free of charge to all organizations possessing the EMTP Version 1.0. This version provides the following other enhancements:

- Correction of bugs found in earlier versions
- Software to calculate loss of life in turbogenerators
- Improved rotating machine models, including induction motors
- A program to calculate frequency-dependent network equivalents
- Improvements to transmission line models
- Fully operational test cases

EPRI/DCG EMTP, Version 2.0

In mid-1989 EPRI and the DCG will release an enhanced version of the EMTP—Version 2.0. In addition to other benefits, the new version will be accompanied by a report on field-test comparisons and will include the newly developed EMTP interactive input processor (EMTPIN). EMTPIN is available on the PC and the VAX computer.

Version 2.0 contains approximately 175 program modifications to fix bugs in Version 1.0. Other enhancements are as follows:

- Revised comprehensive set of manuals
- New line constants support program
- New harmonic initialization feature
- Improved three-phase load-flow feature
- New arc model
- New SiC arrester model
- Nonlinear elements
- Multiport equivalents
- Corona model
- HVDC basic model
- Improved plotting capability
- Air gap mode
- Deletion of obsolete or unreliable models
- Revised set of test cases

Work on EMTPIN (RP2149-10) began in June 1987. The objective was to simplify data preparation, making the program easier to use and reducing the number of errors due to incorrect input. Researchers designed the stand-alone input processor for use on IBM personal computers (or compatibles), and VAX. A link can then be established to load the files onto other computers. The package allows the user to build EMTP cases interactively, using a series of full-screen/pop-up menus. The input data can be used to build files compatible with EMTP input requirements, or the data can be saved in a data base that is part of the EMTPIN package. EMTPIN will be provided free of royalty charges to all DCG and EPRI members.

Call for new associate members

EPRI invites the participation of new associate members in the EMTP development effort. The benefits of membership include input to program development, access to an enhanced and debugged version of EMTP, and continued user support and maintenance.

Air Quality Control

Full-Scale Retrofit of a Low-NO_x Burner System

by David Eskinazi, Generation and Storage Division

NO_x emissions from electric utility power plants fired by fossil fuels have been subject to control in the United States for nearly two decades. At present, federal regulations control only plants built since 1971, when New Source Performance Standards (NSPS) took effect, but some older plants may be subject to state or local emissions limits. Congress, however, is now considering legislation to control emissions from all plants built before 1971. These pre-NSPS coal-fired boilers produce approximately 70% of the emissions from all fossil-fuel-fired power plants.

EPRI is sponsoring research, development, and demonstration of cost-effective NO_x control options for fossil-fuel-fired power plants, with emphasis on in-furnace retrofit technologies for the three most common pre-NSPS coal-fired boiler designs: tangentially fired, wall fired (with circular burners and with cell burners), and cyclones. Reliable data on cost, performance, and applicability gathered from full-scale demonstrations will be essential to utilities faced with decisions about control technologies for these existing boilers.

A full-scale demonstration with a tangentially fired boiler burning pulverized coal has been under way for nearly two years at Kansas Power & Light Company's (KPL's) Lawrence Energy Center Unit 5. Tangentially fired boilers constitute about 40% of the pre-NSPS capacity and produce about 30% of the NO_x emissions from pre-NSPS coal-fired plants. Short-term test results indicate that a retrofit low-NO_x burner system can reduce NO_x in the 30–50% range at high loads with no apparent adverse effects on power generation.

The demonstration used Combustion Engineering's pollution minimum (PM) low-NO_x firing system, which combines low-NO_x

ABSTRACT *Low-NO_x burners represent a promising retrofit technology for controlling NO_x in fossil-fuel-fired boilers installed before the New Source Performance Standards went into effect. EPRI is sponsoring full-scale demonstrations to determine the commercial applicability of low-NO_x burner systems for such boilers. Short-term results from a tangentially fired pulverized-coal boiler at Kansas Power & Light Company indicate that this low-NO_x burner system, together with overfire air, can reduce NO_x by up to 30–50% at high loads with no major impacts on power generation.*

burners with overfire air (OFA) and marks the first time that a PM-firing system has been retrofit on a full-scale utility coal-fired boiler. In earlier EPRI-sponsored tests at pilot scale, this combustion system reduced NO_x 40–60% with good combustion efficiency.

The KPL project, supported in part by the Kansas Electric Utilities Research Program, is being conducted in four stages: preretrofit testing, burner system installation, postretrofit parametric testing, and long-term evaluation. The first three stages have been completed. The final phase, to be completed in the fall of 1989, will determine longer-term patterns in emissions and boiler performance under daily operating conditions.

Burner installation

Lawrence Unit 5, rated at 400 MW, was put into service in 1970. Its output was reduced to 320–340 MW after KPL switched from the design coal to a low-sulfur coal with a lower heating value. Unit 5 currently burns a midwestern bituminous coal typically containing 0.9% sulfur.

The boiler is a four-corner (single-furnace) unit with five elevations of burners. Figure 1 compares the previous standard tangentially fired burner windbox (Unit 5) with the low-NO_x PM burner windbox and overfire air assembly. For the retrofit, the four original 30-ft-high windboxes were replaced with 34-ft-high windboxes, each containing a vertical array of five PM burners and two OFA ports. The added length results from the replacement of single-nozzle burners with dual-nozzle PM burners and from the space required for the "close-coupled" OFA ports.

Fitting the longer windboxes required cutting longer openings in the furnace walls. In addition, a second level of OFA, called separated OFA, was installed above the main windbox. New ductwork had to be installed for both levels of OFA, which were designed to supply up to 25% of the combustion air.

Other modifications included adding and restructuring coal piping to feed the increased number of nozzles in the low-NO_x burners and enlarging the blades of the exhaust fans that deliver primary air and pulverized coal to the burners.

Test results

Figure 2 shows NO_x emissions before and after the retrofit. The scattered data points in Figure 2 show preretrofit NO_x emissions under normal load dispatch conditions at Unit 5. This variation in emission levels is typical of pre-NSPS boilers, in which the amount and distribution of combustion air are manually controlled. Some combinations of control settings may produce more NO_x than others by increasing the amount of combustion air, especially near the flame.

The preretrofit, tuned performance band in Figure 2, defined after two to three months of extensive testing, reflects operation at near-optimum thermal performance and consequently the lower boundary of emission levels during normal load dispatch for this specific site. These conditions established the baseline emission levels, which were 320–400 ppm. Because of high-quality coal and operation at less than peak load (i.e., cooler burning), these tuned levels represent the lower end of emission values found among tangentially fired boilers.

The postretrofit, low-NO_x band shows that the PM firing system reduced NO_x emissions at high load by about 30–50% below the tuned performance levels, to a range of 180–260 ppm. The diversion of combustion air to OFA was the dominant factor in achieving the NO_x reduction, and increasing OFA flow caused a steady decrease in NO_x emissions. At low load, however, the PM system did not show much, if any, NO_x reduction relative to baseline. The reasons for this behavior are still being investigated.

A primary concern when modifying a boiler combustion system to reduce NO_x is the potential effect on boiler performance. At Lawrence Unit 5, the PM system caused no major observable impacts on key performance indicators—although at maximum NO_x reductions, higher excess air requirements decreased boiler efficiency by up to 0.3%.

Changes in heat absorption for major heat transfer elements were minor and easily accommodated with adjustments in the burner system. The most significant changes in heat absorption occurred in the waterwalls, where up to a 10% increase was measured. Furnace outlet temperature (FOT) and heat absorption in the other sections changed only slightly. The increase in percentage heat absorbed by the waterwall is attributable to increased radiant heat from the PM firing system's larger flame volume and higher flame temperature. As a result, FOT dropped 30–40°F from baseline FOT of 2300–2400°F; this phenomenon was not a major concern, considering that FOT at Unit 5 before the retrofit could vary by up to 100°F due to changes in waterwall slagging.

These changes in FOT and heat absorption were considered site-specific. Retrofitting the

Figure 1 Standard burner windbox and low-NO_x pollution minimum (PM) burner windbox for a tangentially fired boiler as viewed from inside the furnace. An elevation of PM burners includes a fuel-rich nozzle and a fuel-lean nozzle. Apertures labeled *air* are for secondary air. Apertures labeled *gas* are used when natural gas is burned instead of coal. Oil ignitors are not shown.

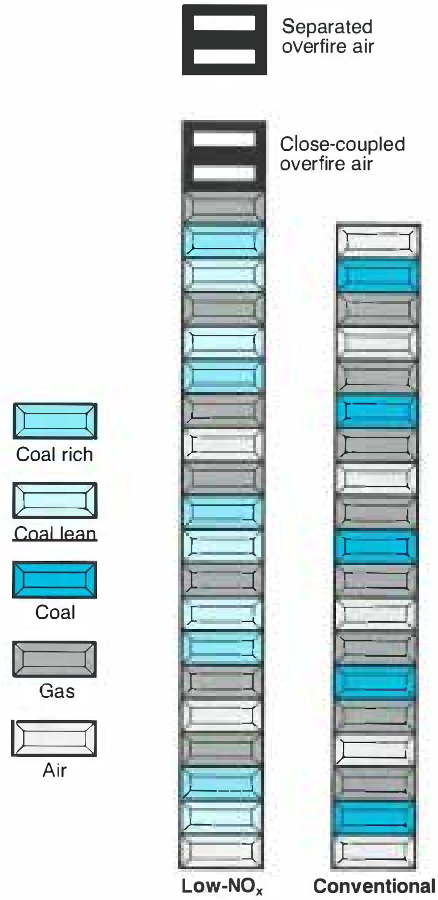
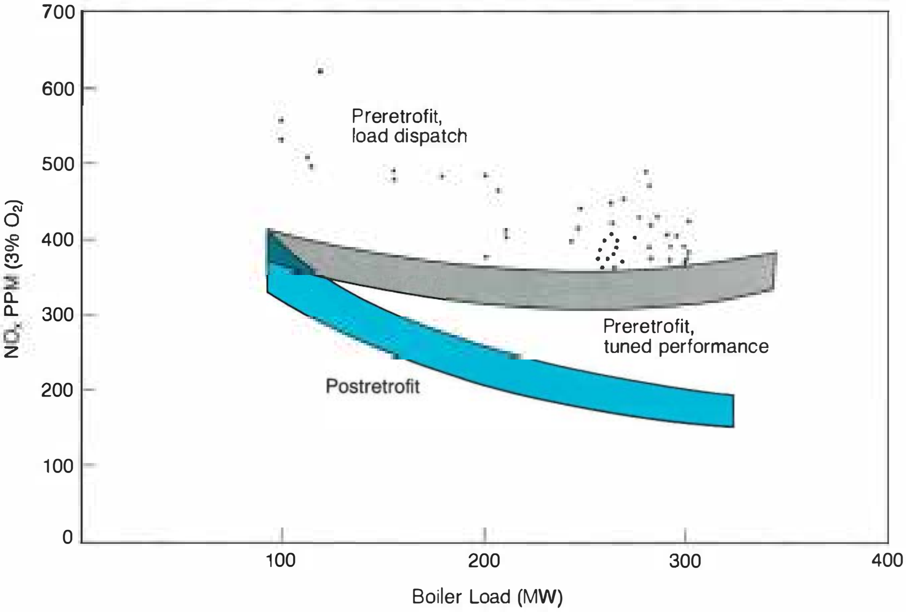


Figure 2 NO_x **emissions from pre- and postretrofit Lawrence Unit 5 for a range of boiler loads. These short-term results indicate that burner optimization can reduce** NO_x **emissions. Morever, the PM low-**NO_x **firing system can reduce** NO_x **by 30–50% at high load, with a less significant reduction occurring at low load.**



PM system on other units might cause greater or lesser effects, depending on coal, slagging characteristics, design, placement of windboxes, and other physical constraints. In general, shifts in FOT of less than 100°F are expected with the PM system. This variation should be acceptable for a large segment of the pre-NSPS tangentially fired boilers.

Minimum excess oxygen (O_2) requirements, as determined by the onset of high carbon monoxide concentrations in the flue gas, increased to 2.7–3.0% with the PM firing system from 2.0–2.3% with standard burners. Comparable increases in minimum O_2 can result from changes in coal properties or firing configuration.

In addition, minimum O_2 stayed at 2.7–3.0%, up to about 20% OFA flow, but rose as OFA was further increased to maximize NO_x reduction. The amount of NO_x reduction desired from a specific unit would determine the necessary penalty in excess O_2, if any.

Although O_2 levels at the economizer generally vary with time, postretrofit O_2 levels fluctuated over a broader range than before the retrofit. The cause of this fluctuation is not fully understood, but it is believed to be related to changes in upper furnace mixing brought about by the overfire air.

These results indicate that the PM firing system may be appropriate for tangentially fired boilers when NO_x reductions of up to 50% are required. However, results to date are from short-duration tests using precisely controlled operating procedures and furnace settings. During the coming year, data will be gathered over longer test periods under normal load-dispatched operating conditions. The cost of this low-NO_x technology and its retrofit applicability to the pre-NSPS tangential boiler population will be assessed during the same period.

Nuclear Plant Operations and Maintenance

PWR Steam Generator Sludge Maintenance

by C. L. Williams, Nuclear Power Division

Sludge is an accumulation of solid impurities on the secondary, or shell, side of steam generators in pressurized water reactors (PWRs). This accumulation of solid impurities can lead to operational and corrosion problems, which reduce the steam generator's reliability. Corrosion problems occur when trace amounts of dissolved aggressive impurities (e.g., chloride and caustic) reach high levels within the porous regions of the sludge and subsequently attack the tubes, causing pitting and stress corrosion cracking.

To control tube damage, it is necessary to use controlled chemistry to reduce the generation and flow of impurities into the steam generator. It is also necessary to remove the sludge that does form within the steam generator. Water treatment is widely employed to control feedwater chemistry, but it cannot remove all impurities or prevent corrosion. The two most common methods of sludge extraction are chemical dissolution (chemical cleaning) and mechanical removal (primarily lancing with high-pressure water jets).

Sludge characteristics

Sludge can accumulate anywhere there is a low flow velocity within a steam generator. The typical locations for sludge in recirculating steam generators (RSGs) include the tube surfaces, support/baffle plates, and tubesheet. In RSGs, most sludge is deposited in an irregular pattern on the tubesheet within the tube bundle. The amount of sludge collected between refueling outages can vary widely—estimates range from 25 lb to as much as 1000 lb per steam generator—and

ABSTRACT *Significant tube damage can be caused by the buildup and deposition of solid-particle impurities within pressurized water reactor steam generators. Carried into the steam generator by the feedwater system, the sludge can be removed mechanically with high-pressure water or through chemical dissolution. Research in sludge characterization, inspection, and mechanical removal is part of the utility effort to avoid this type of tube damage and subsequently improve power plant performance.*

is dependent on plant design, materials of construction, feedwater chemistry, and plant operating characteristics.

For once-through steam generators (OTSGs), a significant portion of the sludge is formed from impurities that have collected on the tubes and subsequently spalled off. These flakes of scale, as well as coalesced particulates, are deposited on the lower tubesheet, on the tops of the support plates, and in the broached flow passages of the tube support plates. Blockage of these flow passages leads to increased pressure drop and, ultimately, a loss of generating capacity.

The chemical characteristics of sludge found in steam generators depend on a number of factors and are highly variable from plant to plant. The major constituents of sludge are the corrosion products from the materials of construction used in the secondary coolant loop. Iron oxides, primarily magnetite, form a significant portion of the sludge at all plants. If copper alloys are used in the plant components (e.g., condenser tubing, feedwater heaters, or moisture separator reheaters), the sludge will typically contain significant amounts of copper. Other chemical constituents of the sludge depend on such factors as the nature of the water treatment used, the source of makeup water, and past operating history, such as the occurrence of condenser leaks and off-normal chemistry conditions for the feedwater.

Sludge location, height, composition, and morphology were summarized in an EPRI survey of utility responses cosponsored by Consolidated Edison Co. of New York and the Empire State Electric Energy Research Corp. (ESEERCO). While there was little quantitative data reported on the morphology of sludge existing within the generators, the reported heights of sludge on the tubesheet, with all 23 utilities responding, varied from estimates of nil to 18 inches. The descriptions of the in-generator sludge ranged from highly mobile (silt-like) suspensions to sticky (clay-like) to hard (concrete-like) deposits. Eight of the utilities surveyed reported on the particle size or characteristics of samples removed from sludge-lancing filters.

The physical morphology of the actual in-generator sludge (Figure 1) from which these lancing filter samples were derived is unknown. Some plants also reported the presence of hard, adherent magnetite deposits (specific mechanical properties unknown) in and around the flow passages of tube support plates. The characteristics of these deposits were based upon visual observations using fiber optics.

Sludge inspection

The inspection techniques used to characterize the sludge information are varied among the service vendors and utility practices. These include eddy-current testing (ECT), elementary visual probes, and remotely operated robots for visual inspection. ECT is widely used for indicating the extent and location of such steam generator tube defects as wastage, pitting, and intergranular attack. The detection and measurement of sludge by ECT is a by-product of these tube defect inspections.

The survey of utility experience with ECT for

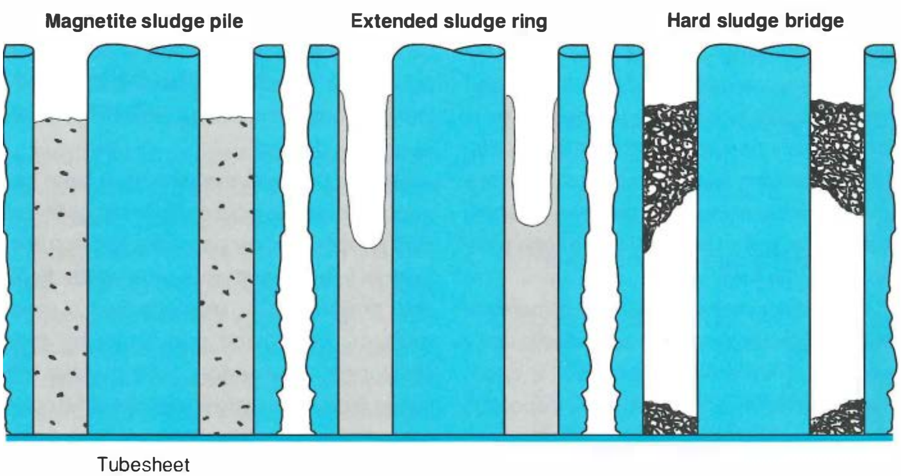


Figure 1 Hypothetical sludge pile configurations. The tube cross sections featured show probable sludge pile scenarios in and around flow passages: the first tube is encircled by the most common form of sludge found in all plants, magnetite with dispersed metallic copper; the second tube has extended rings of sludge; and the third tube has bridges of hard sludge separated by open voids.

sludge inspection showed mixed opinions. Nearly all of the 23 utilities surveyed responded with some dissatisfaction regarding the use of ECT for sludge estimates or recommended that improvements be made.

The dissatisfaction usually focused on the uncertainty associated with interpreting and correlating eddy-current signals to sludge description (amount, location, type of sludge). The difficulty of interpreting signals has led to uncertainty and a reluctance by many utilities to place much faith in ECT sludge data. In addition, masking effects of metallic copper deposits on the tube surfaces and the uncertainty associated with distinguishing between tube deposits and more widely distributed sludge piles, have added to ECT's reputation for unreliability and inconsistency.

The ECT sludge techniques offered by service vendors are mostly based on laboratory development efforts. While there is uncertainty about the ECT frequencies that should be used for detection of sludge, some laboratory work suggests that ECT frequencies of 10 kHz or lower may be more sensitive for detection of sludge.

Under controlled laboratory conditions, the results indicate that the signal for simulated sludge is almost twice as strong at 0.5 kHz as at 1 kHz, and at 1 kHz is significantly better than at 10 kHz. The laboratory tests also indicate that the complicating effects of metallic copper on the eddy-current signal can be reduced at the lower frequencies.

Sludge compositions, distributions, and morphologies vary considerably within a single steam generator and from site to site. Hence, trending analysis (e.g., indication of a change in the sludge pile between outages) may be the limit of practical ECT sludge technology in the field.

Visual inspections using video cameras or fiber optic probes are used by utilities to verify whether or not a steam generator is clean. The disadvantages of most visual inspection techniques are their relatively small access area (compared with the total area of the tubesheet), poor quality of image, difficulty in operating, and high radiation exposure to personnel.

The constraints on the inspectable area are caused by the limited number of access ports through which the inspection devices must be inserted, and the difficulties associated with physically positioning the optical devices within the complex geometry of the tube bundle. The visual inspection devices and techniques offered by service vendors have been developed in the laboratory and, to a limited degree, used in the field for measuring sludge pile heights on the tubesheet.

One vendor developed an inspection tool resembling a hockey stick. The tool's shorter curved leg is manually inserted through the hand holes in the generator shell and shroud. Equipment external to the steam generator provides for viewing and recording the information supplied by the fiber optics. A direct-viewing lens at the external end of the fiber optics allows for data recording by both video and 35mm film cameras.

Mechanical removal of sludge

Most plants use some mechanical (nonchemical) method for sludge removal. The three basic mechanical methods are blowdown, gas pressure, and lancing.

The blowdown method makes use of a draining system built into the steam generator. This is the blowdown pipe that is located across the tubesheet in the nontubed region (the blowdown lane) between the two legs of the U-tube bundle. The blowdown typically removes only the sludge that exists as suspended particulates, leaving the sludge that adheres to surfaces in place. Correspondingly, the amount of sludge removed is much lower than desired.

Two gas pressure methods have been developed for removing magnetite deposits and sludge from the flow passages and top surfaces of tube support plates: the "water slap" and "pressure pulse" methods. Both of these methods, considered proprietary by their developers, use devices with quick-acting valves that release large volumes of nitrogen gas at approximately 1000 psi below the water surface in partially filled generators.

The rapid release of gas produces a large bubble that violently displaces the surrounding water. The displaced water surges through the flow holes, dislodging deposits that have formed in and around these orifices and flushing the loosened deposits, as well as sludge that has collected on the top surfaces of the tube support plates, into suspension. Once in suspension, the particles of magnetite deposits and sludge are removed by a recirculation system. These gas-pressure methods have been applied to both once-through and recirculating steam generators.

However, the most common technique is sludge lancing, which uses high-pressure water jets to erode the sludge. The basic process involves inserting a device with water nozzles into the interior of the steam generator through an inspection port (hand hole) in the shell. Jets of water are then directed down the rows between the tubes. The jets dislodge the sludge from around the tubes and flush it toward an extraction device. Extraction nozzles suck up the sludge-water mixture, which is then piped out of the generator. Lancing, though the most common sludge removal technique, has received mixed reviews from utilities.

Sludge lancing has had adequate success in removing soft and, to a lesser extent, sticky sludge accumulations from the tubesheets of both RSGs and OTSGs. As the sludge becomes more cohesive, systems that lance in multiple directions appear to be more effective than those that lance in only one direction. Mechanical removal of hard sludge, however, is nearly impossible for most systems.

To address the need for increased accuracy in quantifying the sludge within a steam generator and for enhanced lancing efficiency, a joint research effort was undertaken by EPRI, Consolidated Edison Co. of New York, and ESEERCO.

The approach was to develop a remotely controlled device or system that could easily and repeatably gain access to nearly any location within the tube bundle at the tubesheet level. It was judged that once local access within the tube bundle was achieved, many difficult tasks could be accomplished.

Features of the system would include the ability to conduct detailed visual inspection deep within the tube bundle; ability to obtain samples of sludge for measurement of physical properties and determination of chemical constituents; ability to deliver full water pressure close to the sludge pile with little jet divergence for improved hard sludge removal; ability to lance sludge from the shadow regions created by the tubes with conventional unidirectional sludge lancing; and ability to be remotely operated for reduction in personnel radiation exposure.

The resulting system was named CECIL-3, the Consolidated Edison Combined Inspection and Lancing system. It is a teleoperated robot capable of performing important steam generator maintenance tasks, including detailed inspection, sludge lancing, and sludge sampling. CECIL-3 rides along the top of the blowdown pipe between the two legs of the U-tube bundle and is propelled along the pipe by the breast-stroke motion of its four spherical feet.

CECIL's first field trial was at Consolidated Edison's Indian Point 2 plant in October 1987. CECIL was used to inspect one-half of one of the four steam generators. The inspection covered each tube lane from column 20 near the inspection port to column 44 just behind the obstruction of the center tie rod. The inspection revealed a large sludge pile on the cold leg of the tube bundle but a hot leg with no sludge at all. The sludge pile was found to begin at row 5 or 6, away from the blowdown lane, and to rise rapidly in height.

Overall, this first field test of CECIL-3 demonstrated its capabilities for high-quality inspection and its potential for improved sludge removal, both with reduced personnel radiation exposure. ESEERCO, Con Edison, and other supporting utilities (Northern States Power and Public Service Electric & Gas) have built on this experience to develop and apply a new and improved version of the robot, named CECIL-4.

Future needs

Though current mechanical removal methods can satisfy some utility needs, removal efficiency is still best judged on how much sludge remains in the steam generators rather than on how much sludge was removed. ECT and visual methods are partially effective in examining sludge accumulations and are improved with remotely operated systems such as CECIL. To further aid future efforts, however, credible information on the amount, chemical characteristics, morphology, and location of sludge will be required for selecting and optimizing cleaning methods.

Safety Margins, Testing, and Evaluation

International Reactor Safety Studies

by Robert Ritzman, Nuclear Power Division

A major goal of EPRI's reactor safety program is to work with domestic and foreign organizations to establish a cooperative approach to providing strategies for preventing or mitigating the consequences of a severe accident. Two of the more recent EPRI programs are known as the LWR aerosol containment experiments (LACE) and the advanced containment experiments (ACE).

The LACE program was designed to test, and to produce a body of data for validating, current computer models that predict thermal-hydraulic and aerosol behavior in reactor containment buildings during severe accidents. Established in early 1985, with experimental portions performed from late 1985 through early 1987, the program investigated aerosol retention behavior under conditions that simulated various degrees of impaired containment function. Impairment, though unlikely, could result from failure to isolate, from breach due to excessive structural loading, or from direct bypass of the containment building. Aerosol interaction processes were expected to significantly reduce the consequences of such postulated accident situations, but large-scale confirmatory tests were needed.

Simulated-accident test results

A total of six large-scale tests were planned and completed in the Containment Systems Test Facility (CSTF) at the Hanford Engineering Development Laboratory in Richland, Washington. The CSTF has an 850-m^3 insulated containment vessel, steam supply, special aerosol generation equipment, instrumentation for measuring thermal-hydraulic conditions, and equipment for collecting and analyzing aerosol samples. The LACE test matrix is summarized in Table 1. The aerosol material used in the tests was a mixture of hygroscopic (water-soluble) and nonhygroscopic (water-insoluble) solids formed at high temperatures by the condensation of simulated reactor fuel and structural materials. The nonhygroscopic material was the major component, with particle sizes ranging from less than one micrometer to several micrometers.

The principal observations and conclusions that were recorded from the series of large-scale tests are as follows:

▫ The passage of aerosol material through a

Table 1
LACE PROGRAM TEST MATRIX

Test	Simulated Accident Situation
LA1	Containment building bypass—focused on piping and auxiliary building
LA2	Failure to isolate containment building
LA3	Containment building bypass—focused on pipe flow only
LA4	Late containment building failure with overlapping aerosol injection periods
LA5	Rapid depressurization with spiked pool
LA6	Rapid depressurization with aerosol injection

ABSTRACT *The results of severe accident and source term research projects sponsored by EPRI directly influence siting and emergency response planning for nuclear plants. In addition to enhancing the industry's understanding of nuclear power plant safety, the projects support U.S. utilities in establishing a technical basis for licensing activities.*

long pipe (simulating containment building bypass conditions) changes the aerosol characteristics to promote inherent retention processes in larger downstream volumes.

▫ The presence of steam in a containment will accelerate the deposition of aerosols. Rapid size growth, as a result of water attraction to the hygroscopic component, will increase sedimentation rates. In addition, the development of a condensing steam flux at the vessel walls will promote aerosol transport to and deposition on those surfaces.

▫ In modeling aerosol behavior, the assumption of well-mixed conditions appears generally valid, especially during periods when steam or other hot gases rise from lower levels of containment. Such a situation induces natural convection forces strong enough to keep the aerosol concentration reasonably uniform.

▫ The two components of the aerosol behaved somewhat differently in containment. The average removal rate from the containment building atmosphere was measurably greater for the hygroscopic material. In addition, nearly all of the hygroscopic material that plated onto the walls and other heat sink surfaces was washed by the condensate to the sump. However, most of the deposits of nonhygroscopic material remained near the location where it was plated.

▫ Rapid depressurization events appear to have relatively small potential for carrying large quantities of fission products out of reactor containment buildings. Fractional releases below 10^{-5} were observed for aerosol materials dissolved in water pools, and releases below 10^{-3} were observed for aerosols suspended in the containment atmosphere.

In addition to the experimental work, the LACE program included a computer code validation effort to assess the capability of several existing aerosol computer codes. A two-phase program was established. The first phase consisted of pretest calculations for each computer code to predict the envisioned test plan objectives for each LACE large-scale experiment. The second phase involved blind posttest calculations for each computer code and experiment.

As a result of this effort, substantial improvements were made in the aerosol and thermal-hydraulic computer codes needed to model aerosol behavior—and, equally important, in the ability to use the codes in a way that produces reliable calculations. The experience of using real data in blind posttest exercises was critical in judging computer code modeling and sensitivity. The LACE program was sponsored by an international consortium, organized by EPRI, consisting of 16 groups.

The ACE program

A new series of advanced containment experiments has been started at Argonne National Laboratory; Battelle, Pacific Northwest Laboratories; Westinghouse Hanford Co.; Oak Ridge National Laboratory; and Whiteshell Nuclear Research Establishment. The ACE program will complement the recently completed LACE program by investigating additional aerosol material generation and interaction phenomena, including the means of controlling release with passive filtering devices, at severe accident containment conditions. The ACE program objectives are to provide a comparative experimental basis for large-capacity aerosol filtration techniques; to provide data on vapor iodine sources and sinks in severe accidents; to determine fission product releases from molten corium–concrete interactions; and to develop and validate the applicable computer codes and models. Like LACE, the program is being sponsored by an international consortium—in this case 17 organizations.

The ACE program is divided into three phases. Phase A seeks to compare filtration techniques for aerosol removal by containment environment scrubbing systems that are currently being used or have been proposed. Six types of filtration system (pools, submerged venturi, submerged gravel scrubber, fiber metal, heat sink gravel, and sand bed) are being studied in 18 separate large-scale tests. The tests study decontamination factors and other key parameters (e.g., spectrum size) for a mixed hygroscopic-nonhygroscopic aerosol system. The experiments are in progress and are scheduled for completion in mid-1989.

Phase B will investigate several factors related to the retention of radioiodine by containment vessels during severe accidents. The work includes a combination of laboratory studies, intermediate-scale experiments, and large-scale tests. The laboratory studies, which are in progress at Oak Ridge National Laboratory, are producing basic data on the sorption and reaction of iodine species.

The intermediate-scale experiments, which will be done during the next two years at Whiteshell Laboratories in Canada, will determine the impact of radiation fields and hydrogen deflagrations on iodine volatility and resuspension. The large-scale tests, which are scheduled to be performed at the CSTF during the latter half of 1989, will evaluate the interaction between iodine vapor species and aerosol, as well as the time-dependent distribution of iodine under simulated containment accident conditions. The work is designed to produce data that will be used to qualify and validate severe accident iodine behavior computer codes.

Phase C is studying the interaction of molten corium with concrete. These tests involve ~300 kg of molten corium with simulated fission products and varying amounts of structural materials (e.g., Zr) and control materials (e.g., B_4C, AgInCd). The objectives are to measure the release of semivolatile fission products (e.g., species of Ba, La, and Sr), characterize the aerosols produced, determine concrete ablation rates, and coordinate computer code validation efforts.

Recently, the first of the eight experiments in the test matrix was completed (along with experimental validation of the test apparatus). Ten smaller-scale tests involving ~30 kg of molten corium were completed in March 1988. The data from these test series are currently being analyzed. About one large-scale (300-kg) test per quarter will be performed through 1990.

Land and Water Quality

FASTCHEM: A Hydrogeochemical Model

by Dave McIntosh and Ishwar Murarka, Environment Division

The disposition of chemicals in the subsurface is governed by the physical and chemical properties of the environment, the physics of (advective and dispersive) transport, and the geochemical and microbiological transformations involving solutes, subsurface materials, and fluids. Mathematical models can integrate these simultaneously occurring processes to provide a convenient means for predicting the development of chemical plumes from leachates. The coupling of geochemical and microbiological processes with advective-dispersive transport processes is difficult mathematically. In the computer code package FASTCHEM* (fly ash and scrubber sludge transport and chemistry), a two-step approach to coupling has been applied. Future enhancements await a better fundamental understanding of the processes.

The development of FASTCHEM began in 1986 after an extensive evaluation of available models (EA-3417, Vols. 1–3). The solid-waste environmental studies (SWES) project has completed a major milestone in delivering this interim package (EA-5870, Vol. 1). Developed by researchers at Battelle, Pacific Northwest Laboratories (RP2485-2), FASTCHEM models hydrologic and geochemical processes in a two-step, coupled manner to simulate the transport, transformation, and fate of selected inorganic constituents in the subsurface environment. Computations or simulations with FASTCHEM yield chemical concentrations over space and time in the saturated and unsaturated subsurface environment (EA-5870-CCM, Vols. 1–5; EA-5871; and EA-5872).

*FASTCHEM is an EPRI trademark.

Structure of FASTCHEM

FASTCHEM is modularly designed to provide several levels of prediction capability consistent with the availability of input data. Four modules—EFLOW, ETUBE, ECHEM, and EICM—are incorporated into the FASTCHEM structure.

The EPRI groundwater flow code, or EFLOW (EA-5870, Vol. 2), is a hydrologic transport code that simulates variably saturated flow in two dimensions—areal and vertical cross section. It is based on Darcy's law and uses a finite-element numerical analysis algorithm.

Because the code is configured to handle two-dimensional steady-state problems, heterogeneous hydraulic conditions in the subsurface can be simulated. The code is capable of handling seepage faces, infiltration, plant-root moisture extraction, and pumped or injection wells. The code can also be used for unsteady-state hydrologic analyses in a stand-alone mode.

The EPRI streamtube code, or ETUBE (EA-5870, Vol. 3), is a particle-tracking code that uses the steady-state flow field output of EFLOW. The code tracks particle movement to create streamtubes for solute transport through the hydrologic system. In the process of creating the pathlines, the code keeps track of location, moisture content, pore-water velocity, and the cross-sectional area of the streamtube created.

The output generated by ETUBE defines the boundaries within which the geohydrochemical coupling occurs. The ETUBE code can also be used in a stand-alone mode to provide a preliminary assessment of the zone of impact of contaminant plumes emanating from the surface.

The EPRI geochemical code, or ECHEM (EA-5870, Vol. 4), is an equilibrium geochemical code that simulates precipitation/dissolution, complexation, adsorption/desorption, and redox reactions. To perform these simulations, the code relies on an extensive thermodynamic data base that was constructed for this purpose (EA-5872). New thermodynamic data (EA-4544 and EA-5741) developed in the chemical attenuation studies (RP2485-3) and the leaching chemistry studies (RP2485-8) are incorporated in FASTCHEM.

The function of ECHEM in the FASTCHEM package is to allow users to obtain equilibrium geochemical initial and boundary conditions. In addition, it is used to select the relevant reactions for the particular application and to generate a site-specific thermochemical data base for the transport calculations. The development of a site-specific data base significantly enhances the computational efficiency of the coupled code. ECHEM can also

ABSTRACT *Assessing the impact of fossil fuel wastes on groundwater requires accurate predictions of the environmental distribution of the released chemicals. Through the Solid-Waste Environmental Studies project, EPRI has undertaken laboratory and field studies to quantify the many hydrologic and geochemical processes that control the migration and fate of dissolved chemicals. FASTCHEM, the recently completed interim computer code, integrates the results of these studies to provide assessment methods for use by utilities and regulators.*

be used as a stand-alone code to carry out equilibrium speciation calculations.

The EPRI interim coupled model, or EICM (EA-5870, Vol. 5), simulates hydrogeochemical transport in a two-step manner corresponding to advection-dispersion and geochemical processes. All calculations are performed using the streamtube data base generated by ETUBE, the site-specific thermochemical data base obtained from ECHEM or provided by the user, the initial and boundary conditions generated by ECHEM, and a user-supplied probability density function to represent longitudinal dispersion.

Figure 1 is a schematic depiction of the coupling process. The output from this code is the concentration of the chemical species along each streamtube as a function of time. The results from several streamtubes may be assembled to give a two-dimensional perspective of the concentration distribution.

The FASTCHEM modules can be accessed and their results processed through an IBM-PC workstation (EA-5871). Input data files are developed on the IBM-PC and sent to an IBM mainframe for use with EFLOW, ETUBE, ECHEM, and EICM. Once the simulation is completed, the output files are returned to the IBM-PC workstation for postprocessing. Tabular and graphic displays are included in the postprocessing capabilities of the FASTCHEM package.

Hierarchy of modeling options

The FASTCHEM package of codes represents a modeling capability that is based on a mechanistic approach to the transport processes in the subsurface environment; the package is quite complex and requires extensive input data.

Because such detailed information is not always available, options are provided for using FASTCHEM with less detailed information. Even in cases where detailed information is available, the user may want to perform a preliminary analysis that uses only a segment of the full data set. The code offers the user the option of doing such screening. A few of the options available are covered here.

The advection option requires the complete hydrologic input data file. The output would be the two-dimensional pressure and velocity fields and associated streamtubes. On the basis of the trajectory of the streamtubes originating at the base of the waste disposal site, one can determine the travel time and zone of impact of the plume. Such a screening makes it possible to assess the potential for environmental contamination and the need for a more complete simulation that includes geochemistry.

The full geochemistry and prescribed transport option requires the complete geo-

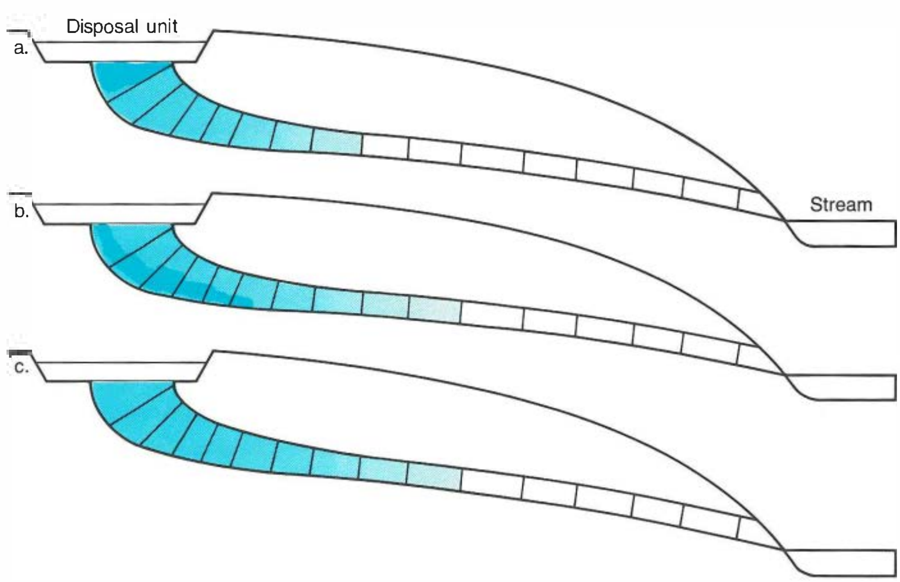


Figure 1 Coupling of transport and geochemistry in FASTCHEM. The initial distribution of solute in the streamtube (a) results from leachate infiltration out of the disposal unit into the aquifer. The reduction in chemical concentration in the streamtube (b) is caused by the advective and dispersive transport of solute along the streamtube over time. The final distribution of solute within each cell (c) is due to the geochemical attenuation that results from speciation, precipitation/dissolution, adsorption/desorption, and redox reactions.

chemical input data file, as well as estimates of velocity, dispersivity, and the trajectory of the streamtube to be considered. The output from such a screening enables the user to ascertain the impact that geochemical processes have on the initial concentration of each element of the leachate as it travels through the subsurface. The distributions or partitioning of elements in the aqueous and solid phases are the outputs of such a simulation.

Though the time of travel and extent of the plume are only approximated in such an analysis, the aqueous concentrations of elements could guide the decision for further, more detailed analyses.

The limited geochemistry and specified transport option refers to the use of a linear adsorption isotherm (k_d) approach for simulating geochemistry. For this case the distribution coefficient (k_d) for each sorbate and the aqueous masses of the components are required. The data required for specifying the transport are the same as those for the previous case. Again, this type of preliminary analysis is useful for assessing the degree of the problem and the need for a mechanistic approach to geochemistry. Operated in this simplistic mode the FASTCHEM package provides results similar to those of the computer code MYGRT (EA-4543-CCM)—an analytical model for simplified calculations of subsurface migration of chemicals.

The advection, dispersion, and full geochemistry option exercises the full capability of the FASTCHEM code. The model used in this mode outputs the spatial and temporal distributions of the concentration of each chemical component and complex. In addition, the masses and activities of the sorbates and solids are calculated for each cell as functions of time.

The FASTCHEM package underwent prerelease testing between October 1987 and August 1988 by members of EPRI's Science Advisory Committee for Land and Water Quality Studies. A technology transfer seminar was held in October 1988. The computer code is available from the Electric Power Software Center. Enhancements to FASTCHEM will address two- and three-dimensional advective and dispersive transport, along with the coupling of kinetic geochemistry to simulate complex reactions involving several solutes.

Power System Analysis

System Analysis Computer Programs

by Mark G. Lauby, Electrical Systems Division

In an interconnected power system, generators run in synchronism to maintain a supply of ac power at a constant frequency. Disturbances to the system, either small (e.g., load fluctuations) or large (e.g., transmission system faults), cause such characteristics as voltage magnitude, voltage angle, and system frequency to vary from their nominal values. If the power system is stable, the frequency variation caused by any disturbance eventually decays to zero. In an unstable system, however, the angles between generators increase and may eventually result in a loss of synchronism between generators. In extreme cases these variations could cause the collapse of an entire system, as in the 1965 Northeast power system collapse.

Moreover, interconnected power systems are becoming increasingly complex. For example, to optimize power system utilization and minimize customer electricity costs, utilities have had to implement complex control systems. At the same time, environmental and economic constraints are restricting the construction of transmission circuits. Consequently, expanded power transfer increases the stress on the system, and operation is closer to stability limits.

To predict system stability, determine operating limits, and provide input to the system design process, utility personnel conduct two types of power system stability analysis. The first type, small signal stability analysis, addresses system performance under small changes from a normal steady-state operating point. Since the resulting system changes are relatively small, system behavior is essentially linear, and methods of linear analysis are directly applicable. The second type of analysis, transient (large signal) stability analysis, addresses system performance following a severe system disturbance. These cases involve the analysis of nonlinear behavior and usually require step-by-step solution of the system's dynamic equations.

To help utilities perform these types of stability analysis, EPRI has developed the following computer programs:

- Small Signal Stability Package (SSSP)
- Extended Transient–Midterm Stability Programs (ETMSP)
- DC Modeling Program (DCMP)
- Load Model Synthesis Program Package (LOADSYN)
- Dynamic Equivalents (DYNEQ)
- Data Transfer and Conversion (DTAC)

SSSP has been designed for small signal stability analysis, while ETMSP and DCMP address transient stability analysis. LOADSYN provides load models for power flow programs and for small signal and transient stability programs. DYNEQ provides dynamic network equivalents for both small signal and transient stability studies, and DTAC converts power flow data from one program format to another. Together, these programs cover the spectrum of needs for power system stability analysis.

Small signal stability

In the early 1980s, Ontario Hydro developed the MASS (Multi-Area Small Signal) computer

ABSTRACT *Computer programs for power system analysis help utility personnel to accurately predict system stability under a variety of conditions and to design the controls needed to ensure that stability. EPRI has developed several useful system analysis programs, which address small signal stability, transient stability, load modeling, dynamic network equivalence, and data conversion. Already utility-tested and available, these programs are being enhanced to expand their capabilities and improve ease of use.*

program for determining the stability of small signal disturbances in small power systems. At the same time, EPRI developed AESOPS (Analysis of Essentially Spontaneous Oscillations in Power Systems), a program for determining small signal disturbance stability in large power systems. To form a complete package for small signal stability analysis, Ontario Hydro has enhanced MASS to include more detailed modeling; developed PEALS (Program for Eigenvalue Analysis of Large Systems), which uses the AESOPS algorithm to determine the stability of intermachine oscillations; and developed a method of inputting dynamic model data from a data base program (DATBASE). Together these programs form SSSP, a package that provides a consistent basis for analysis and enables system engineers to better understand small signal disturbances in individual and interconnected power systems (EPRI EL-5798; *Technical Brief* TB.ESD.41.7.88).

The Western Systems Coordinating Council has used MASS and PEALS to examine low-frequency interarea oscillation modes in its interconnected network. These studies confirmed the presence of several modes close to instability at or near 0.7 Hz and identified their sources. Members of WSCC then made adjustments in appropriate control systems to eliminate the problematic modes (EPRI *First Use* document FS8913C). In addition, New England Power Planning used MASS and PEALS to address dynamic response for transmission planning. Several other utilities field-tested SSSP over a six-month period.

Transient stability

To help analyze power system transients after a severe disturbance, EPRI has developed the Extended Transient-Midterm Stability Package, or ETMSP (EL-4610). Filling the gap between short-term and long-term dynamics, ETMSP extends transient stability analysis from a few seconds to a few minutes after a major disturbance. Like long-term dynamic analysis methods, the program models power plants and automatic generation control. At the same time, it computes individual shaft speeds and intermachine oscillations. ETMSP performs stability computations, analyzes output, and converts power flow and stability data into the appropriate formats. It helps utility personnel determine safe loading and operating procedures under stressed system conditions.

Philadelphia Electric validated transient results from ETMSP by using its in-house stability program, TRANSTAB, and successfully extended ETMSP use beyond the short-term dynamic range. Public Service Electric & Gas has also applied ETMSP. In this case, damage to a 500-kV transmission outlet at a plant caused a 9- to 11-month circuit outage. Following its existing operating guide, PSE&G reduced the plant's output to 65% of rated capacity. Using ETMSP, however, the utility determined that with power system stabilizers and a trip-a-unit scheme, it could safely increase the maximum plant output to 95% of full capacity during the outage, thereby reducing replacement power costs. PSE&G also used ETMSP to develop operating guides for use during and after the outage.

Although ETMSP can effectively analyze transient stability in ac systems, it does not address the growing need to model multiterminal dc links. The operating benefits of high-voltage direct current (HVDC) systems and the development of dc circuit breakers have increased utility interest in HVDC links with more than two terminals (multiterminal links) for system expansion. With these links, utility power delivery systems can act as powerful and flexible control elements, improving the performance of integrated ac/dc systems. However, the existing digital simulation models used to evaluate dc links are too limited to represent most multiterminal dc systems and controls.

To analyze the dynamic performance of integrated ac/dc systems, EPRI has developed DCMP, an ac/dc power flow and transient stability program (EL-4365). Building control models by using a selection of basic control functions, users can simulate a wide variety of HVDC controls and represent any conceivable network configuration. The New England Electric System and Manitoba Hydro validated DCMP by comparison with a detailed power system simulator. Moreover, New England Power Service Co. is using the program to model controls for a detailed simulation of the five-terminal HVDC system joining the northeastern United States and Canada (*First Use* FS8428C). The company is confident that its efforts will produce an excellent digital model, one that will support further system-related analysis—for example, studies of expansions, malfunctions, and the effects of changing control settings during factory tests and commissioning.

Analysis aids

The characteristics of system load are important factors in power system response to disturbances that change network voltage and frequency. Hence uncertainties in load modeling can be critical unknowns in the calculation of power transfer limits, for example, or in the determination of requirements for transmission system expansion. However, most load models now used in power flow and stability simulations are only loosely related to actual load characteristics or are chosen to yield the most conservative results or to minimize the modeling effort.

Therefore, EPRI developed LOADSYN to provide load models for power flow and stability programs (EL-5003). Driven by readily available data on residential, commercial, and industrial load mix, LOADSYN enables power system analysts to produce more accurate load models for system simulations. Better load modeling leads to increased accuracy in predicting power system behavior, which in turn leads to improved transmission system utilization. Program validation and testing at several utilities, including Rochester Gas & Electric, have been completed. In addition, Pacific Gas and Electric has successfully used LOADSYN to generate loads for input to ETMSP; this application is documented in *Technical Brief* TB.ESD.32.3.88 and a forthcoming issue of *First Use*.

The small signal and transient stability programs discussed above take a system model as input. Using a large-scale model for this purpose, however, requires a large computer memory and substantial development and computation time. The need for smaller equivalent models led to EPRI's development of DYNEQ. This computer program takes a transient stability data base (large-scale model) as input and develops an equivalent that is a fraction of the size of the full power system representation. By grouping coherent generators, this network equivalent retains the dynamic characteristics of the full system, providing a small yet accurate model.

Available in two versions—one for classical synchronous-machine models and one for detailed machine models—DYNEQ is being used at several utilities. For example, Pacific Gas and Electric used it to generate an equivalent for stability studies and reports a substantial reduction in computing time (*Technology Applications* 1421C).

Various power flow programs use different data formats to represent the bulk power system network and its components—a fact that hinders nationwide system model exchange. Among the several formats in use are the IEEE common format, the WSCC format, and the Philadelphia Electric format. In response to this situation, EPRI has developed DTAC, a code package that converts power flow data from one format to another. Several utilities have used DTAC, including Arizona Public Service and Public Service Electric & Gas.

Future work

EPRI is considering efforts to move toward a system analysis workstation and is planning enhancements to several of the programs. SSSP model enhancements will include a cross-compound turbine generator model, a user-defined turbine governor model, a static VAR compensator model, a user-defined stabilizer model, and nonlinear excitation output models for use with user-defined excitation controls. This work, as well as work to provide extended output analysis in order to enhance user productivity, will be completed this October. Moreover, a dynamic reduction program will be added to SSSP in 1990.

An improved version (2.0) of ETMSP with new documentation is planned. This new version will have greater modeling capabilities; for example, models on underfrequency load-shedding and distance relaying will be added, and the multiterminal HVDC modeling capabilities of DCMP will be incorporated. The version will also feature enhanced computational speed, parameterized dimensions enabling flexible system size, and enhanced input data format capability.

Enhancements to DCMP will include two new central scheduler routines and new user-defined control system building blocks. A stand-alone version will also be developed, enabling the dc models to be added to any ac power flow and stability software.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Consulting Assistance in Process Industry Analysis (RP2613-13)	$50,000 12 months	Chem Systems Inc./*I. Harry*
Affiliate Member Program (RP2613-14)	$74,300 12 months	Battelle Memorial Institute/ *R. Jeffress*
Development of an Electric G-Van Drive System (RP2664-12)	$1,015,700 13 months	Chloride EV Systems Ltd./ *G. Purcell*
Electrothermal Storage Technology (RP2731-7)	$20,300 4 months	Polydyne Inc./*J. Kesselring*
Functional Field Test of an Integrated Heat Pump Thermal Storage System (RP2792-17)	$40,000 15 months	Florida Power & Light Co./ *P. Joyner*
Design and Development of a Triple-Function, Two-Speed Ground Source Heat Pump (RP2892-7)	$100,000 15 months	Waterfurnace International/ *P. Joyner*
1989 Cogeneration Symposium (RP2950-4)	$50,400 8 months	Synergic Resources Corp./ *H. Gransell*
Electrical Systems		
Advanced Digital Line Protection Relay (RP1359-17)	$1,000,000 26 months	General Electric Co./ *L. Mankoff*
Demonstration Systems: Transmission Line Digital Protection and Control (RP1359-18)	$485,300 12 months	Westinghouse Electric Corp./*L. Mankoff*
Ethylene-Propylene Cable Insulation Investigation (RP2899-2)	$750,000 24 months	University of Connecticut/ *B. Bernstein*
Utility Communications Architecture (RP2949-1)	$1,388,300 13 months	Arthur Andersen & Co./ *L. Mankoff*
Investigation of Cable Jacketing and Shield Materials Capable of Mitigating Ingress of Ionic Impurities (RP2986-2)	$330,000 24 months	University of Connecticut/ *B. Bernstein*
Environment		
Acidity in Fogs and Clouds (RP2023-10)	$168,500 26 months	Harvard University/ *D. Hansen*
Hydrology and Acidity of Seepage Lakes (RP2174-15)	$20,000 3 months	KBN Engineering/ *R. Goldstein*
Technical Basis for Inventory of Global Combustion Source Nitrous Oxide Emissions (RP2333-4)	$182,900 24 months	Radian Corp./*G. Beals*
Ultrastructure of Candidate Magnetic Sense Organs (RP2965-8)	$294,800 36 months	California Institute of Technology/*C. Rafferty*
Exploratory Research		
Mechanistic Studies of Hot Corrosion in Utility Boilers (RP2278-10)	$197,100 23 months	Ohio State University/ *J. Stringer*
Crack Initiation and Arrest in Subsized Specimens (RP2426-22)	$130,000 11 months	Southwest Research Institute/*R. Viswanathan*
Measurement and Calculation of Oxide-Induced High-Temperature Crack Growth in Controlled Oxidizing Environment (RP2426-24)	$118,300 10 months	Failure Analysis Associates/ *J. Stringer*
Study to Reduce Cost of Bimetallic Tubes (RP2742-3)	$151,500 24 months	Babcock & Wilcox Co./ *W. Bakker*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Demonstration of a New Design for a Robust Solid Electrolyte Oxygen Sensor (RP8000-13)	$80,900 14 months	National Coal Board/ *J. Stringer*
The Application of Photoconductive Switches in AC Circuit Protection (RP8001-8)	$199,400 23 months	University of Florida/ *H. Mehta*
Measurement of pH and Potential in Supercritical Water (RP8002-18)	$50,800 6 months	SRI International/*R. Dooley*
Calcium Impregnation and Agglomeration of Coal (RP8003-18)	$69,500 10 months	Jet Propulsion Laboratory/ *C. Kulik*
Generation and Storage		
Power Plant Insulating Materials (RP1030-46)	$99,600 9 months	Science Applications International Corp./*J. Tsou*
Membership (RP1402-39)	$26,200 15 months	UKAEA/*G. Offen*
Effect of Quenching Media on Mechanical Properties on CrMoV High-Purity Rotor Manufacturing (RP1403-36)	$138,900 7 months	The Japan Steel Works Ltd./*R. Jaffee*
Test and Evaluation of Alabama Power PV Project (RP1607-7)	$20,000 36 months	Alabama Power Co./ *J. Schaefer*
Experimental Evaluation of EPRI Sodium/Sulfur Concepts (RP2123-16)	$393,800 24 months	SRI International/*G. Cook*
Engineering Evaluation of IGCC Power Plants (RP2221-20)	$190,000 10 months	Sargent & Lundy Engineers/*N. Hertz*
Computer-Based Training System for Fluidized Combustion (RP2303-30)	$25,500 2 months	HyperMedia Group/ *S. Drenker*
Utility Planning		
Decision Framework for Integrated Demand/Supply Planning (RP2317-3)	$100,000 10 months	M.S. Gerber & Associates; Temple, Barker, and Sloane, Inc./*H. Chao*
Independent Power Plants (RP2345-65)	$39,100 14 months	Utility Data Institute Inc./ *O. Yu*
Dynamic Pricing of Decentralized Power Systems (RP2996-5)	$30,400 12 months	Laurits R. Christensen Associates/*H. Mueller*
Nuclear Power		
RETRAN-03 Technology Transfer (RP889-10)	$300,000 11 months	Computer Simulation and Analysis Co./*L. Agee*
Advanced Fracture Mechanics Methods for Vessel Evaluation (RP1757-78)	$96,000 11 months	Novetech Corp./ *T. Griesbach*
Irradiation-Assisted Stress Corrosion Cracking (RP1930-14)	$569,900 38 months	Massachusetts Institute of Technology/*L. Nelson*
Modeling of Irradiation Embrittlement of Stainless Steel (RP1930-15)	$39,900 11 months	Modeling & Computing Service/*L. Nelson*
Technical Support of BWR Materials and Processes Issues Associated With IGSCC Mitigation (RP1930-16)	$20,100 10 months	Structural Integrity Association/*W. Childs*
PWR Corrosion Tests Using LOMI (RP2296-20)	$591,100 21 months	Westinghouse Electric Corp./*C. Wood*
Scrap Hardware Volume Reduction Demonstration (RP2717-10)	$71,300 7 months	Northeast Utilities Service Co./*R. Lambert*

New Technical Reports

Requests for copies of reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081. There is no charge for reports requested by EPRI member utilities, U.S. universities, or government agencies. Others in the United States, Mexico, and Canada pay the listed price. Overseas price is double the listed price. Research Reports Center will send a catalog of EPRI reports on request. For information on how to order one-page summaries of reports, call the EPRI Hotline, (415) 855-2411.

CUSTOMER SYSTEMS

Electrolytic Technology in the Metals Industry: A Scoping Study
EM-6098 Final Report (RP2570); $40
Contractor: EPRI Center for Metals Production
EPRI Project Manager: R. Jeffress

Food-Service Sourcebook: A Quick-Reference Guide to Industry Information and Sources
EM-6135 Final Report (RP2890-5); $32.50
Contractor: W. I. Whiddon & Associates, Inc.
EPRI Project Manager: K. Johnson

Pilot Test of the Crushed-Rock Storage Furnace, Vols. 1 and 2
EM-6144 Final Report (RP2731-2); Vol. 1, $32.50; Vol. 2, $40
Contractor: Science Applications International Corp.
EPRI Project Manager: V. Rabl

Microwave Vacuum Drying of Food Products
CU-6247 Final Report (RP2893-7); $100
Contractor: California State University, Fresno
EPRI Project Manager: A. Amarnath

Heat Pump Life and Compressor Survival in Diverse Climates
CU-6254 Final Report (RP2417-11); $200
Contractor: American Electric Power Service Corp.
EPRI Project Manager: C. Hiller

Utility Energy Strategies: The Role of Efficiency, Productivity, and Conservation
CU-6272 Final Report (RP2982-5); $100
Contractor: Energetics, Inc.
EPRI Project Managers: W. LeBlanc, P. Hanser

ELECTRICAL SYSTEMS

Security Enhancement System, Vol. 1
EL-6037-M Final Report (RP1712-5); $25
Contractor: ESCA Corp.
EPRI Project Manager: D. Curtice

Proceedings: Bulk Power System Voltage Phenomena—Voltage Stability and Security
EL-6183 Proceedings (RP2473-21); $70
Contractor: Carlsen & Fink Associates, Inc.
EPRI Project Manager: D. Maratukulam

Fumigant Effectiveness in Creosote- and Penta-Treated Southern Pine Poles
EL-6197 Final Report (RP1471-2); $25
Contractor: State University of New York
EPRI Project Manager: H. Ng

Evaluation of Diagnostic Techniques for Cable Characterization
EL-6207 Final Report (RP7897-2); $47.50
Contractor: Institut de Recherche d'Hydro-Québec
EPRI Project Manager: B. Bernstein

ENVIRONMENT

Field Investigation of a Flue Gas Desulfurization (FGD) Sludge Disposal Site
EA-5923 Final Report (RP2485-8); $32.50
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: I. Murarka

A Hierarchy of Dynamic Plume Models Incorporating Uncertainty, Vol. 2: Stack Exhaust Model (SEM)
EA-6095 Final Report (RP1616-28); $25
Contractor: A.R.A.P. Division of California Research & Technology, Inc.
EPRI Project Managers: G. Hilst, G. Beals

A Hierarchy of Dynamic Plume Models Incorporating Uncertainty, Vol. 3: Second-Order Closure Integrated Model Plume (SCIMP)
EA-6095 Final Report (RP1616-28); $32.50
Contractor: A.R.A.P. Division of California Research & Technology, Inc.
EPRI Project Managers: G. Hilst, G. Beals

A Hierarchy of Dynamic Plume Models Incorporating Uncertainty, Vol. 4: Second-Order Closure Integrated Puff
EA-6095 Final Report (RP1616-28); $32.50
Contractor: A.R.A.P. Division of California Research & Technology, Inc.
EPRI Project Managers: G. Hilst, G. Beals

Effects of Sulfur Dioxide and Ozone on Yield and Quality of Potatoes
EA-6164 Final Report (RP2371-2); $25
Contractor: Pennsylvania State University
EPRI Project Manager: L. Pitelka

Precision of the EPA Seven-Day Fathead Minnow Larval Survival and Growth Test: Intra- and Interlaboratory Study
EA-6189 Final Report (RP2368-2); $40
Contractor: Battelle, Columbus Division
EPRI Project Manager: J. Mattice

The Underground Tank Risk Management (TANKS) Model: User's Guide
EN-6231 Final Report (RP2595-1); $55
Contractor: Decision Focus, Inc.
EPRI Project Manager: V. Niemeyer

GENERATION AND STORAGE

Arapahoe Low-Sulfur-Coal Fabric Filter Pilot Plant, Vol. 3: Characterization of Sonic-Assisted Reverse-Gas Cleaning, May 1982–May 1984
CS-3862 Final Report (RP1129-8); $100
Contractor: Southern Research Institute
EPRI Project Manager: R. Chang

Laboratory Guidelines and Procedures for Coal Analysis, Vol. 2: Determining Coal Size Distribution by Wet Screening
CS-5644 Interim Report (RP1400-4, -6); $300
Contractors: Kaiser Engineers, Inc.; Pennsylvania Electric Co.; New York State Electric & Gas Corp.; Geochemical Testing, Inc.
EPRI Project Managers: J. Hervol, C. Harrison

Laboratory Guidelines and Procedures for Coal Analysis, Vol. 3: Establishing and Maintaining a Quality Assurance Program
CS-5644 Interim Report (RP1400-4, -6); $300
Contractors: Pennsylvania Electric Co.; New York State Electric & Gas Corp.; D. L. Streib & Associates
EPRI Project Managers: J. Hervol, C. Harrison

Utility Gas Turbine Combustor Viewing System, Vols. 1 and 2
AP-5956 Final Report (RP2102-2); Vol. 1, $32.50; Vol. 2, $25
Contractor: United Technologies Research Center
EPRI Project Manager: L. Angello

Evaluation of the 10-MW High-Sulfur Fabric Filter Pilot Facility, Vol. 1: Reverse-Gas and Sonic-Assisted Reverse-Gas Cleaning
CS-6061 Final Report (RP1867-4); $150
Contractor: Southern Research Institute
EPRI Project Managers: W. Piulle, R. Altman

Proceedings: 1988 Seminar on Fluidized-Bed Combustion Technology for Utility Applications
GS-6118 Proceedings (RP1179); $100
Contractor: Bechtel Group, Inc.
EPRI Project Managers: S. Tavoulareas, S. Drenker

Ash-in-Concrete Model Development
GS-6129 Final Report (RP2422-16); $47.50
Contractor: Dunstan, Inc.
EPRI Project Manager: D. Golden

Use of Coal Ash in Highway Construction: Michigan Demonstration Project
GS-6155 Interim Report (RP2422-7); $25
Contractors: Consumers Power Co.; University of Michigan; Soil and Materials Engineers
EPRI Project Manager: D. Golden

Major Options and Considerations for Repowering With Gas Turbines
GS-6156 Final Report (RP2565-18); $25
Contractor: Bechtel Group, Inc.
EPRI Project Manager: H. Schreiber

Development of an IGCC Power Plant Simulator
GS-6173 Final Report (RP2524-2); $32.50
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: G. Quentin

Use of Coal Ash in Highway Construction: Georgia Demonstration Project
GS-6175 Final Report (RP2422-4); $47.50
Contractors: Southern Company Services; Georgia Power Co.
EPRI Project Manager: D. Golden

Florida Power & Light Company's Study of Shell-Based GCC Power Plants
GS-6176 Final Report (RP2773-7); $47.50
Contractor: Florida Power & Light Co.
EPRI Project Manager: J. Fortune

Proceedings: Seventh Particulate Control Symposium, Vols. 1 and 2
GS-6208 Proceedings (RP1129-18); Vol. 1, $70; Vol. 2, $62.50
Contractor: Radian Corp.
EPRI Project Manager: R. Altman

Proceedings: Workshop on Pulse-Jet Baghouse Technology
GS-6210 Proceedings (RP1129-8); $100
Contractor: Southern Research Institute
EPRI Project Managers: R. Chang, R. Altman

Proceedings: Thirteenth Annual EPRI Conference on Fuel Science and Conversion
GS-6219 Proceedings; $47.50
EPRI Project Manager: H. Lebowitz

NUCLEAR POWER

ARMP-02 Documentation, Part II, Chap. 5, Vols. 1–5: EPRI-PRESS Computer Code Manuals
NP-4574-CCM Computer Code Manual (RP1690-1; RP1252-6, -10); Vol. 2, $70; Vol. 3, $47.50; Vol. 5, $25; Vols. 1 and 4, forthcoming
Contractors: GRP Consulting; S. Levy, Inc.
EPRI Project Manager: W. Eich

Supplemental Examination of Alternative Materials in a Model Steam Generator, Vol. 2: Correlation of Model 10 Defects With Eddy-Current Indications
NP-5928-M Final Report (RPS302-7); $25
Contractor: Combustion Engineering, Inc.
EPRI Project Manager: C. Shoemaker

CECIL: A Robot for Secondary-Side Maintenance of PWR Steam Generators
NP-5929 Final Report (RPS403-3); $32.50
Contractor: Foster-Miller, Inc.
EPRI Project Manager: L. Williams

Thermal Annealing of an Embrittled Reactor Vessel: Feasibility and Methodology
NP-6113-M Final Report (RP1021-1); $25
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: T. Griesbach

Irradiation Embrittlement of LWR Pressure Vessel Steels
NP-6114 Final Report (RP1021-7, RP2455-11); $47.50
Contractor: University of California, Santa Barbara
EPRI Project Manager: T. Griesbach

Intergranular Attack of Alloy 600: Simulation and Remedial Action Tests
NP-6115-M Final Report (RPS302-24); $25
Contractors: Commissariat à L'Energie Atomique; Framatome
EPRI Project Managers: P. Paine, D. Cubicciotti

Engineering Evaluation of Selective Ion-Exchange Radioactive Waste Processing at Susquehanna Nuclear Power Plant
NP-6120 Final Report (RP2414-15); $25
Contractor: Vance & Associates
EPRI Project Manager: P. Robinson

Demonstration of Reliability-Centered Maintenance, Vol. 1: Project Description
NP-6152 Interim Report (RP2970); $25
EPRI Project Manager: J. Gaertner

A Review of Plant Decontamination Methods: 1988 Update
NP-6169 Final Report (RP2296-15); $25
Contractor: Applied Radiological Control, Inc.
EPRI Project Manager: C. Wood

FATIGUEPRO™ On-Line Fatigue Monitoring System: Demonstration at the Quad Cities BWR
NP-6170-M Final Report (RP2688-3); $32.50
Contractor: Structural Integrity Associates, Inc.
EPRI Project Manager: T. Griesbach

Simulator Automated Testing and Reverification (SATAR) Program: Functional Requirements Specification
NP-6174 Interim Report (RP2054-2); $32.50
Contractor: General Physics Corp.
EPRI Project Manager: R. Colley

Feature-Based Imaging for Cast Stainless Steel Components: 1987 and 1988 Field Examinations
NP-6177 Final Report (RP1570-2); $25
Contractor: J. A. Jones Applied Research Co.
EPRI Project Manager: G. Dau

Procedures for Determining and Monitoring Simulator Operating Limits
NP-6179-M Final Report (RP2054-2); $25
Contractor: General Physics Corp.
EPRI Project Manager: R. Colley

Downstream Behavior of Volatile Iodine, Cesium, and Tellurium Fission Products
NP-6182 Final Report (RP2136-1); $32.50
Contractor: Argonne National Laboratory
EPRI Project Managers: R. Vogel, R. Ritzman

Testing and Analyses of the TN-24P PWR Spent-Fuel Dry Storage Cask Loaded With Consolidated Fuel
NP-6191 Interim Report (RP2813-16); $40
Contractors: Pacific Northwest Laboratory; EG&G Idaho, Idaho National Engineering Laboratory
EPRI Project Manager: R. Lambert

Investigation of an Emergency Diesel Generator Reliability Program: A Case Study of Crystal River Unit 3
NP-6193 Final Report (RP3000-23); $25
Contractor: ERIN Engineering and Research, Inc.
EPRI Project Manager: J. Gaertner

Material Specification for Alloy X-750 in LWR Internal Components
NP-6202 Interim Report (RP2181-4); $25
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: J. Nelson

Effective Plant Labeling and Coding
NP-6209 Final Report (RP1637-8); $40
Contractor: J. L. Seminara
EPRI Project Manager: H. Parris

Calculating Dynamic Crack Arrest by Static Analogy
NP-6223 Final Report (RP2455-14); $25
Contractor: Combustion Engineering, Inc.
EPRI Project Managers: D. Norris, G. Dau

Inspecting the Circulating Water System at Crystal River Unit 3 for Evidence of Microbial Corrosion
NP-6224 Final Report (RP2939-6); $25
Contractor: Babcock & Wilcox Co.
EPRI Project Manager: D. Cubicciotti

Analysis of the Sandia One-Sixth-Scale Reinforced Concrete Containment Model
NP-6261 Interim Report (RP2172-1); $40
Contractor: ANATECH Research Corp.
EPRI Project Manager: H. Tang

Technical Repair Guidelines for the Limitorque Model SMB-000 Valve Actuator
NP-6229 Final Report (RP2814-2); $47.50
Contractor: Advanced Technology Engineering Systems, Inc.
EPRI Project Managers: J. Lang, B. Brooks

PWR Secondary Water Chemistry Guidelines, Revision 2
NP-6239 Final Report (RPS405-2); $32.50
EPRI Project Manager: C. Welty

The EPRI Knowledge Acquisition Workshop Handbook
NP-6240 Final Report (RP2902-2); $32.50
Contractor: Science Applications International Corp.
EPRI Project Manager: J. Naser

Evaluation of Hydrogen Diffusion From Low-Level Radioactive Waste Containers
NP-6244 Final Report (RP2724-2); $25
Contractor: Science Applications International Corp.
EPRI Project Manager: P. Robinson

UTILITY PLANNING

Holding Costs for Fuel Inventories
P-6184 Final Report (RP1920); $500
Contractor: Charles River Associates, Inc.
EPRI Project Manager: S. Chapel

The EPRI Regional Systems Database: Version 3.0
P-6211 Final Report (RP1678); $62.50
Contractor: Coecorp
EPRI Project Manager: O. Gildersleeve

New Computer Software

The Electric Power Software Center (EPSC) provides a single distribution center for computer programs developed by EPRI. The programs are distributed under license to users. No royalties are charged to nonutility public service organizations in the United States, including government agencies, universities, and other tax-exempt organizations. Industrial organizations, including nonmember electric utilities, are required to pay royalties. EPRI member utilities, in paying their membership fees, prepay all royalties. Basic support in installing the codes is available at no charge from EPSC; however, a consulting fee may be charged for extensive support.

For more information about EPSC and licensing arrangements, EPRI member utilities, government agencies, universities, and other tax-exempt organizations should contact the Electric Power Software Center, Power Computing Co., 1930 Hi Line Drive, Dallas, Texas 75207; (214) 655-8883. Industrial organizations, including nonmember utilities, should contact EPRI's Manager of Licensing, P.O. Box 10412, Palo Alto, California 94303; (415) 855-2866.

AERAM: Air Emissions Risk Assessment Model
Version 1.0 (IBM PC); EA-5886-CCM
Contractor: IWG Corp.
EPRI Project Manager: Anthony Thrall

COOLAID: Thermal Energy Storage/Demand-Side Planning/ Load and Market Research
Version 2.0 (IBM PC); EM-6102
Contractor: Synergic Resources Corp.
EPRI Project Manager: Hans Gransell

DSWORKSTATION: Distribution Workstation
Version 1.2 (IBM PC)
Contractor: Power Computing Co.
EPRI Project Manager: Giora Ben-Yaacov

ERS: EPRI Regional System
Version 3.0 (IBM PC); P-6211
Contractor: Coecorp
EPRI Project Manager: Oliver Gildersleeve

SGA-SMECC: Substation Maximum Earth Current Computation
Version 2.2 (IBM PC)
Contractor: Georgia Institute of Technology
EPRI Project Manager: Gilbert Addis

WENS: Weather Normalization of Sales
Version 1.0 (IBM, IBM PC)
Contractor: Business Forecast Systems
EPRI Project Manager: Ray Squitieri

CALENDAR

For additional information on the meetings listed below, please contact the person indicated.

JUNE

28–30
1989 Cogeneration Seminar
Boston, Massachusetts
Contact: Hans Gransell, (415) 855-2855

JULY

1
ETADS: EPRI Tower Analysis and Design System Software
Haslet, Texas
Contact: Dick Kennon, (415) 855-2311

24–28
ETADS and MINIDES: Transmission Structural Software
Haslet, Texas
Contact: Paul Lyons, (415) 855-5329

25–27
Batteries for Utility Energy Storage
Newport Beach, California
Contact: Glenn Cook, (415) 855-2797

AUGUST

1
Workshop: Targeted Chlorination
Los Angeles, California
Contact: Winston Chow, (415) 855-2868

6–10
4th International Symposium on Environmental Degradation of Materials in Nuclear Power Systems—Water Reactors
Jekyll Island, Georgia
Contact: Dan Cubicciotti, (415) 855-2069

14–18
Structural Mechanics in Reactor Technology (SMIRT)
Anaheim, California
Contact: Gary Dau, (415) 855-2051

21
Utility Options for Meeting Dissolved-Oxygen Limits for Hydro Power Plant Discharges
Niagara Falls, New York
Contact: Chuck Sullivan, (415) 855-8948

22–24
Availability and Technology Improvements in Plant Auxiliaries
Minneapolis, Minnesota
Contact: Dave Broske, (415) 855-8968

29–31
Fossil Power Plant Construction
Cincinnati, Ohio
Contact: Murthy Divakaruni, (415) 855-2409

SEPTEMBER

6–8
Hydro Operations and Maintenance
Boston, Massachusetts
Contact: Chuck Sullivan, (415) 855-8948

14–15
Seminar: Gas Turbine Procurement
Atlanta, Georgia
Contact: Henry Schreiber, (415) 855-2505

27–29
Applying Structural Research Results
Haslet, Texas
Contact: Paul Lyons, (415) 855-5329

OCTOBER

1
Bulk Transmission System Adequacy Assessment
Atlanta, Georgia
Contact: Neal Balu, (415) 855-2834

3–5
FASTCHEM, FOWL, and MYGRT: Codes for Modeling the Release, Transport, and Fate of Solutes in Groundwater
Chicago, Illinois
Contact: Dave McIntosh, (415) 855-7918

3–6
PCB Seminar
San Diego, California
Contact: Gil Addis, (415) 855-2286

30–November 2
Technologies for Generating Electricity in the 21st Century
San Francisco, California
Contact: Sy Alpert, (415) 855-2512

NOVEMBER

14–16
Conference: Plant Maintenance Technology
Houston, Texas
Contact: John Tsou, (415) 855-2220, or Dave Broske, (415) 855-8968

28–December 1
Expo and Seminar: Meeting Customer Needs With Heat Pumps
Atlanta, Georgia
Contact: Mort Blatt, (415) 855-2457

Authors and Articles


Stahlkopf


DeVine


Worledge


Schneider


Santucci


Divakaruni


Sun

New Interest in Passive Reactor Designs (page 4) was written by Jack Catron, science writer, with technical guidance from two members of EPRI's Nuclear Power Division.

Karl Stahlkopf has been director of the Materials and Systems Development Department since 1980. He came to EPRI in 1973 after seven years in the Navy, where he specialized in nuclear propulsion.

Jack DeVine, senior program manager in EPRI's Advanced Light Water Reactor Program, has been on loan from General Public Utilities Corp. since January 1986. His work at GPU included emergency response, decontamination, and defueling work at the damaged Three Mile Island Unit 2, where he served as Recovery Engineering Director and later as Technical Planning Director. Prior to his move to GPU in 1970, DeVine was a naval officer assigned to construction and operation of nuclear submarines. ■

Dean Wilson: Welcoming the Opportunities of Change (page 14) combines reflections and suggestions by a chief executive whose 34 years in the changing world of heavy industry includes 8 years as a member of EPRI's Advisory Council. Ralph Whitaker, feature editor, interviewed Wilson for the article. ■

In Hot Pursuit of Cold Fusion (page 20) was written by John Douglas, science writer, with the assistance of technical managers in EPRI's Nuclear Power Division and Office of Exploratory Research.

David Worledge, a program manager for nuclear power risk assessment, has worked for 20 years in the physics of nuclear power fuels and processes. He came to EPRI's Nuclear Power Division in 1981 after nearly eight years with the United Kingdom Atomic Energy Authority, first in fast-reactor studies (including two years on a joint project at Sandia National Laboratories in New Mexico) and eventually as head of the agency's systems reliability service. Earlier at the UK Rutherford Laboratory, he worked on meson beam optimization for nuclear structure studies.

Tom Schneider, a senior adviser for exploratory research, coordinates EPRI-sponsored investigations in mathematical science and physics, including the assessment of today's rapid succession of findings in hot superconductivity and cold fusion. Schneider has been with EPRI since 1977 and has served as program manager for energy storage, assistant director of the Energy Management and Utilization Division, department director for energy conservation and end use, and (on a two-year loan) president of the Lighting Research Institute.

Joseph Santucci, manager of technology transfer in the Nuclear Power Division, coordinates the division's exploratory research activities. Since coming to EPRI in 1982, he has also managed core materials research projects and served as technical assistant to the division director. He formerly worked for four years at S. M. Stoller Corp., consulting with utilities on nuclear fuel cycle problems; before that he was a safety systems analyst for Burns and Roe on the Clinch River breeder reactor design. ■

Delivering On-Line Expertise (page 24) was written by John Douglas, science writer, in cooperation with research managers of three EPRI divisions.

Murthy Divakaruni is a project manager in the Plant Performance Program of the Generation and Storage Division, applying expertise in simulation software and instrumentation to diagnostic and control systems. He came to the program in 1986 after four years in digital control systems development for the Nuclear Power Division. Before 1981 he was with General Electric Co. for five years, working successively on solar, fossil fuel, and nuclear plant designs.

Bill Sun manages the Control and Diagnostic Program in the Nuclear Power Division. His specialty is thermal-hydraulic analysis in BWR safety systems. He came to EPRI in 1977 after more than four years with General Electric Co., where he was a technical group leader.

David Curtice is a project manager in the Power System Planning and Operations Program of the Electrical Systems Division. Before coming to EPRI in August 1987, he worked for 11 years at Systems Control, Inc., involved in the development of energy management systems and application software. ■

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