Stepping Up Transformer Efficiency

ELECTRIC POWER RESEARCH INSTITUTE

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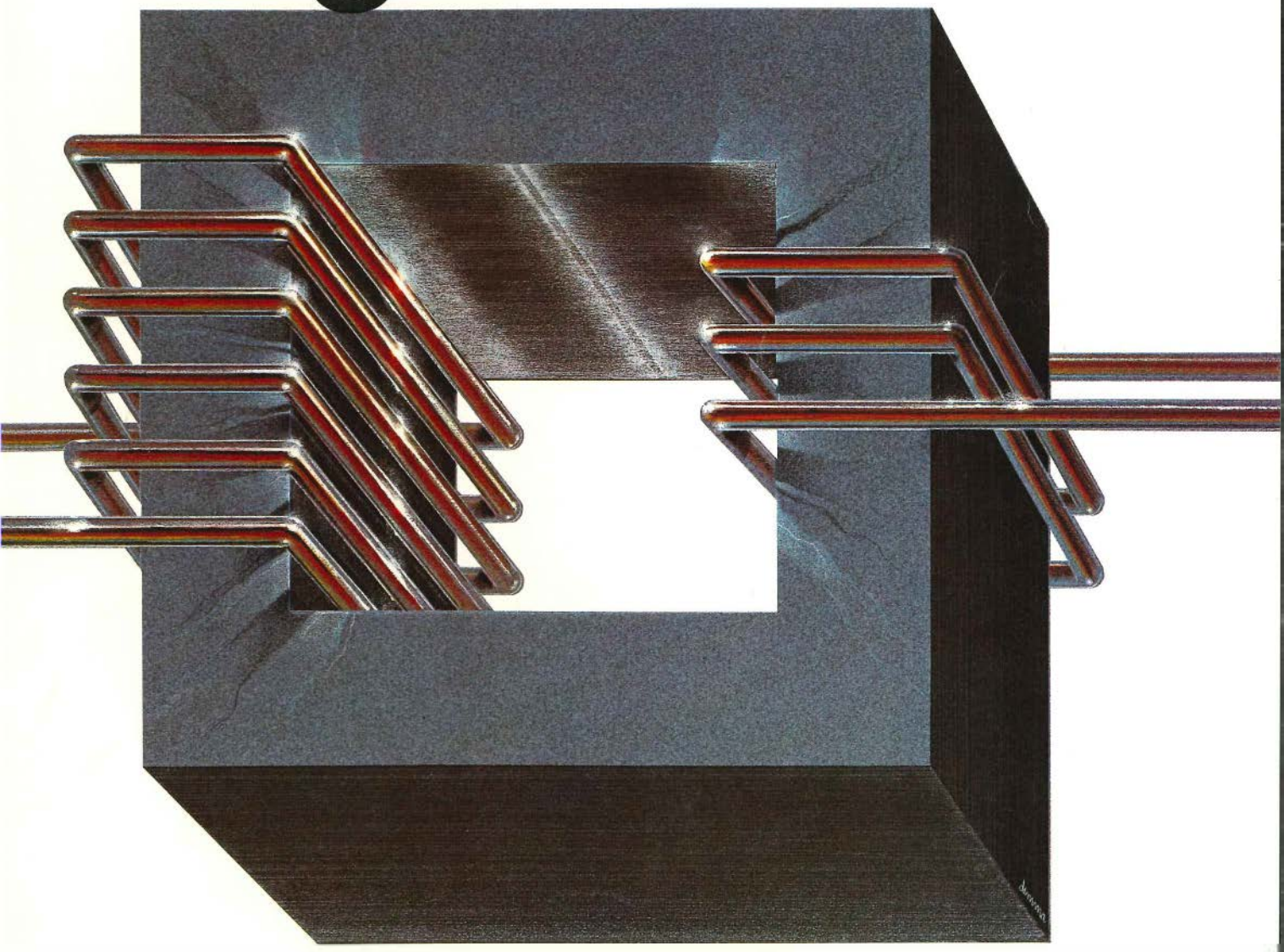

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EPRI JOURNAL Staff and Contributors
Brent Barker, Editor
Ralph Whitaker, Feature Editor
Nadine Lihach, Feature Writer
Jenny Hopkinson, Feature Writer
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Graphics Consultant: Frank A. Rodriquez

Robert A. Sandberg, Director
Ray Schuster, Assistant Director
Communications Division

Address correspondence to:
Editor
EPRI JOURNAL
Electric Power Research Institute
P.O. Box 10412
Palo Alto, California 94303

Cover: Transformers are links in the chain of power delivery, establishing and connecting the sequence of voltages necessary for minimum overall cost for rights-of-way, conductors, structures, and electrical losses.

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A Fresh Look at Transformers

It is difficult to conceive of electricity supply on today's scale without the use of transformers. Undoubtedly, they are central to the reliable, efficient, and economical delivery of electric energy. The basic concept is simple: windings around a magnetic core with the voltage directly proportional and the current inversely proportional to the turns ratio between primary and secondary windings.

But cursory reading of any advanced publication on transformers, discussion with a designer, or a tour through a manufacturer's plant reveals how complex and involved are the tasks of designing and delivering reliable transformers. Although many advances have been made since transformers were invented, several old problems remain and have assumed greater importance in today's society. Two examples are flammability and audible noise. For professionals in electric power technology, two additional problems figure significantly: electrical losses and reliability. All require a fresh look with the aid of modern materials and modern means of transformer performance analysis.

Because of the skyrocketing costs of generating plants and their fuels, electrical losses have become an especially important problem. The evaluated cost of losses exceeds the cost of the transformer itself. It is therefore logical that transformers are being built larger—to reduce core losses, they must be designed for an operating flux density well below the saturation level of the core. The *Journal*'s lead article this month discusses transformer electrical losses and the advent of materials to reduce those that occur in the core.

Nonflammable transformers will have a major impact on the siting, the size, and the cost-effectiveness of future substations. Both fire resistance and more efficient cooling are subjects of the article, as are transformer advances that are becoming possible with new materials.

For transformers, reliability is more a problem of predictable performance than of long life. Reliability can be improved by more basic information on the causes of failure and by earlier knowledge that a transformer has some internal problem that will lead to failure if unattended. EPRI has addressed these needs by sponsoring basic studies on oil, cellulosic insulation, and the interaction of mechanical and electrical stresses that lead to transformer failures. Further, EPRI has pursued new ways to instrument transformers, such as hot spot detectors, combustible gas monitors, and internal corona detectors—all with a good degree of success.

Audible noise is the subject of stringent new regulation by federal and state agencies. It has serious implications for transformer siting and cost. EPRI has developed the concept of audible noise shells that can be installed on transformers on a retrofit basis. They are now commercially available and are the most cost-effective way to reduce noise by 12–15 dBa.

Most utility people agree that substations should be reliable and compact, requiring a minimum of installation effort. They would welcome substations that are also virtually maintenance-free, featuring low electrical losses, minimum audible noise, no external electric or magnetic fields, and fire and explosion resistance—in short, fully suitable for concealment in a basement or small building. EPRI's Substations Program is motivated by such an ideal. This requires significant advances in all substation components, but most of all, those that will flow from a fresh look at transformers.

Narain G. Hingorani, Manager
Substations Program, Transmission Department
Electrical Systems Division

Figuring the chances of success in a research venture is tough enough, let alone predicting its total cost and assigning a reasonable value to the results. A case in point is new technology for cutting core losses in transformers. How utilities put price tags on electrical losses is key to their judgment of the state of the transformer art. It's also fundamental to EPRI and others who undertake research to improve a class of electrical apparatus that is already highly efficient.

"Transformers: Gaining on the Losses" (page 6) considers electrical losses, their origins, and the means of evaluating them, along with striking examples of R&D that are likely to produce a new look in a mature technology. To review these subjects, Ralph Whitaker, *Journal* feature editor, drew particularly on the experience of Edward Norton, manager of several transformer research projects in the Substations Program of EPRI's Transmission Department.

Norton specialized in power transformer applications long before he came to EPRI in January 1975. From Brooklyn Polytechnic Institute in 1953, he joined the graduate training program at Allis-Chalmers Corp., beginning a 22-year association as application engineer, project engineer, and eventually as manager of applications. After 1966 his responsibilities included transformer market planning, training of personnel, contract negotiations, and technical liaison with utilities and other industrial customers for transformers.

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Within days after the Three Mile Island accident in March, top electric utility people gathered in Chicago and drafted a major nuclear safety study to be directed by EPRI. Just a little over a month later, EPRI's Board of Directors ratified the formation of the Nuclear Safety Analysis Center. "NSAC: In-Depth Look at Three Mile Island" (page 12) traces this quick industry response. From her interviews with EPRI and NSAC management, *Journal* feature writer Nadine Lihach reports on the programmed scope of NSAC tasks: reconstruction of the TMI accident sequence, analysis of its causes, and development of generic technical strategies for avoiding similar occurrences.

■

How to dispose of the sludge from stack gas scrubbers? "Transfer" and "store" are quickly becoming apt descriptions, because soon there will be no more room for true disposal, and ponded sludge has ways of becoming an environmental burden. The problem is made more difficult by the reagents and water that contribute to the sludge volume and to the cost of handling it.

Some welcome new concepts are coming along, however: regeneration, conversion, by-products, and sale. Jenny Hopkinson, *Journal* feature writer, emphasizes these in "Shifting SO_2 From the Stack" (page 15), a review of new processes that aim for more economical waste management when scrubbers become nearly universal on new coal-fired power plants. Hopkinson's technical guidance comes from George Preston, manager of the Desulfurization Program in EPRI's Fossil Fuel Power Plants Department.

Preston has worked with scrubbers, their process chemistry, and their resource recovery potential since 1970, much of the time with Garrett Research and Development Co., Inc., until he came to EPRI in March of 1978. A chemical engineer with degrees from the California Institute of Technology (BS, 1964) and the University of California at Berkeley (PhD, 1970), he has developed computer models of scrubbing mechanisms, worked in scrubber design, supervised pilot operation of new scrubber technology, directed research in the recovery of fuel residues and municipal solid-waste constituents, and negotiated the licensing for commercial use of recovery technologies.

■

Disposition of scrubber sludge is by no means solely a problem for the future. The waste from today's flue gas desulfurization (FGD) processes poses many questions for many utilities that must specify systems today: How much sludge will there be? What is its composition? Where to put it? How to get it there? Answers are now available in EPRI's newly published *FGD Sludge Disposal Manual,* an early product of Institute research in handling solid waste. Its step-by-step solutions are reviewed by Nadine Lihach, *Journal* feature writer, in "Steps to Sludge Disposal" (page 19).

■

Energy and civilization: lockstep in fact or lockstep only in the fancy of abstract thinkers? Valid ever or valid never? These questions were raised and

evaluated for delegates to the Edison Centennial Symposium last April by a historian of science and technology, the University of Delaware's Professor George Basalla. His paper, "Energy and Civilization" (page 20), reveals a 200-year-old connection that has almost taken on a life of its own. But from the thinking of still earlier times, as well as from imperatives he sees today, Basalla raises questions that may uncouple this equation.

Professor Basalla has been on the Delaware faculty since 1970. He has degrees from Pennsylvania State University, Columbia University, and Harvard University, and has also taught at Harvard and at the University of Texas.

■

When loads shift, the design emphasis for structural foundations must also shift. This is the message of experience as electric utility transmission towers become larger but must deal with a high proportion of live-load components and still stand securely in widely varying soils. Some of the R&D directions are reviewed by Phillip Landers in "Research on Foundation Systems" (page 33).

Landers, a project manager in the Overhead Lines Program of EPRI's Electrical Systems Division, joined the Institute in January 1978 after 10 years with Florida Power & Light Co., where he specialized in transmission line design, including research on wind load criteria. Attending school during many of his years with the utility, Landers is a 1975 graduate of the University of Miami, receiving a bachelor's degree in civil engineering.

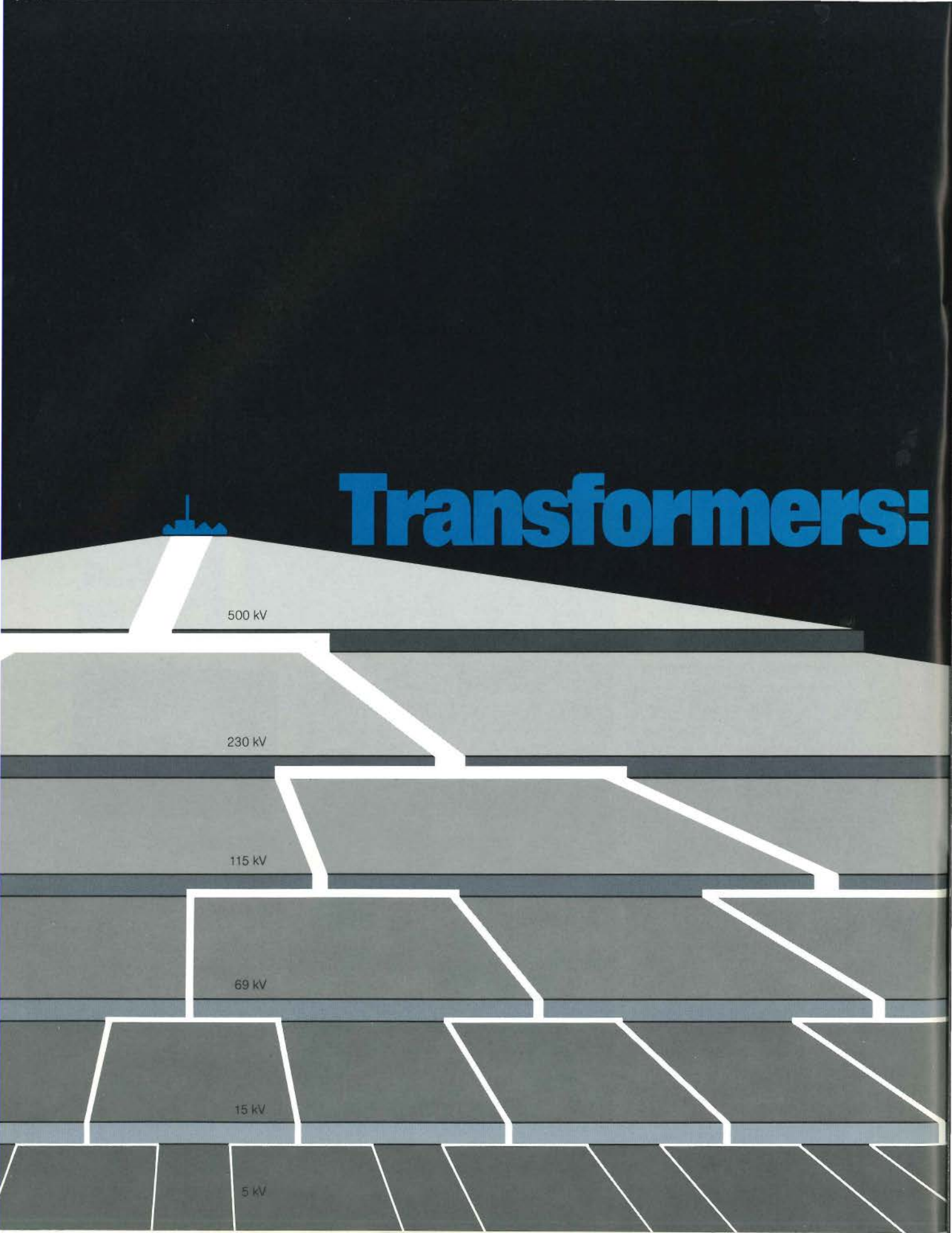
Norton

Landers

Basalla

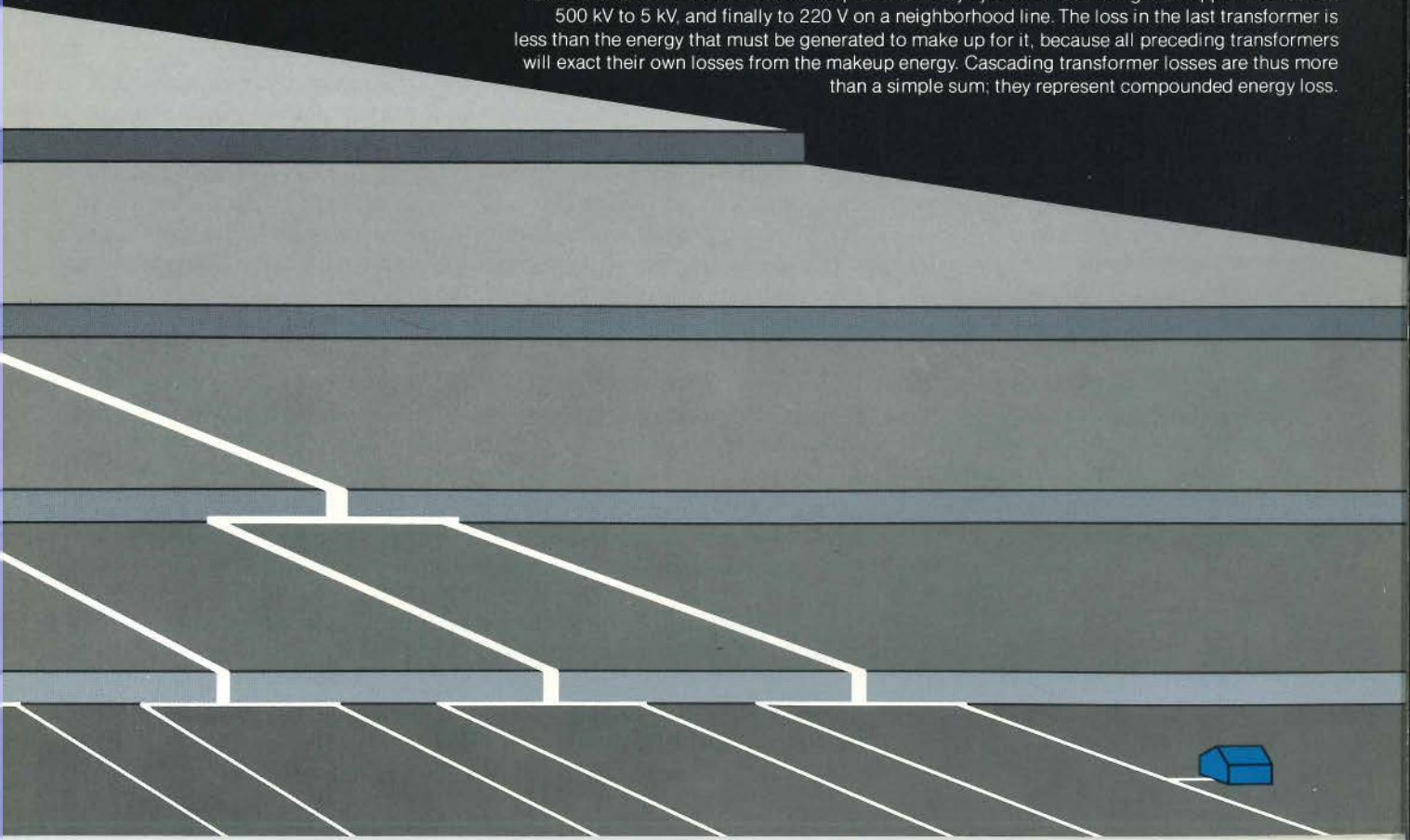
Preston

Transformers:



The visible signs of electric power transmission and distribution are deceptive in their uniformity. Driving the interstates on a cross-country vacation, one's attention is frequently drawn to the long, sweeping curves of transmission lines and the repetitive geometry of their towers that march across the land. The utility engineer sees behind that deceptive uniformity. Even in the most efficient power delivery system, he sees a continuum of gradual power losses along every span of line, plus an abrupt power loss at every successive transformer where voltage is stepped down. In fact, between the power plant and the end user, perhaps 11% of the peak generated energy may be lost along the lines and another 4% lost in the transformers.

Gaining on the Losses



Electrical losses cascade across this power delivery system as the voltage is stepped down from 500 kV to 5 kV, and finally to 220 V on a neighborhood line. The loss in the last transformer is less than the energy that must be generated to make up for it, because all preceding transformers will exact their own losses from the makeup energy. Cascading transformer losses are thus more than a simple sum; they represent compounded energy loss.

Many steps, many losses

Line losses depend mainly on the flow of current in the conductors. And electric power is essentially the numerical product of voltage and current. If the voltage is high, therefore, the current and the line losses are low. So line losses are routinely minimized by transmitting power as far as possible at high voltage, perhaps 765 kV or higher. Conductor size and right-of-way width requirements also influence this decision; they are greater at lower voltage for a given power level. They must therefore be balanced against distance and the line losses over that distance to determine the most economic voltage. In general, longer transmission distances and higher power levels justify higher voltages.

This is where transformers come in. They are the pressure regulators of electric power, trading (transforming) voltage and current values in the desired proportion for the most efficient delivery of power.

Power is generated at only about 25 kV. In a switchyard at the power plant, its voltage is immediately stepped up by a large factor for low-loss transmission in the 230–765-kV range. It must thereafter be stepped down again through many transmission, subtransmission, and distribution substations and pole transformers before it reaches the modest 110/220 V used in a residence. But transformers also introduce electrical losses.

Possible cost savings

Transformers are a mature technology, and electrical losses are only one aspect of transformer technology calling for R&D. Two others are fire resistance and cooling. If the improvements sought today are achieved and successfully applied, the outcome may well be a new look in this mature technology.

The measure of the new look is largely one of cost savings, though environmental benefits are also important. Primarily, these savings will flow from conservation of power by greater electrical efficiency in transformers and from the resultant conservation of generating capacity and of whatever fuel drives it at the power plant.

Savings will also appear in substation site and structural costs when transformers are more fire-resistant. It will then be possible to locate transformer substations closer to loads and to place transformers themselves closer to other apparatus.

Finally, life-cycle cost savings will accrue from more precisely measurable transformer life. More efficient cooling systems, minimizing internal hot spots and the gradual deterioration of insulation under overload conditions, will influence the timing and nature of maintenance and repair routines, all in the direction of predictability and economy.

Transformer efficiency ranges between 98% (for a small unit in a distribution system) and 99.5% (for a bulk power unit in a transmission system). The electrical losses in any single transformer are thus only 0.5–2%, distinctly below the 5–10% range found in much customer equipment outside utility systems. But because of the cumulative effect of successive transformers, total transformer losses throughout a system may drain away about 4% of the peak generated energy.

The incentive for reducing these transformer losses is the value of the generation and delivery capability that must be built and operated to make up for them. Transformer loss evaluation is therefore key.

Extra power plant capacity is one component in the value of transformer losses, and for large plants today, it may cost up to $1000/kW in capital outlay. But this is not all.

Energy costs, the costs of power plant fuel and operation, also enter the picture. These vary according to the realities of plant use over its lifetime, reducible to the cost per kilowatthour of energy produced. For evaluating this component of transformer losses, energy costs at best depend on forecasts of plant operating hours and at worst on guesses of fuel cost escalation. For a given amount of system generating capacity, these costs can be reduced by more efficient transformer operation. Expressed in capital-

A METALLURGIST'S VIEW OF TRANSFORMER CORE LOSS

Highly enlarged specimens of two transformer core materials reveal differences in the magnetic domains (or regions) and their walls, which must move in response to the alternating excitation of transformer voltage. Top: Many domains appear as narrow stripes in a 1-mm photomicrograph of conventional silicon iron. Bottom: Only two major domains appear in a 1-mm scanning electron micrograph (enhanced for contrast) of amorphous metallic "glass" now under EPRI-sponsored development. Within the silicon iron domains are many crystalline grains whose boundaries impede domain wall motion. Amorphous materials lack such crystalline structure, so less energy is lost in effecting domain wall movement, even though (as in this sample) the individual domains are larger. ***Photos courtesy Allegheny Ludlum Steel Corp. and Allied Chemical Corp.***

ized cost per kilowatt, they also measure the worth of developments to reduce transformer losses.

For example, a single large generator transformer may be rated at 500 MVA (equivalent to 500 MW). Its 0.5% losses therefore represent 2.5 MW, easily worth $5 million at an overall capitalized value of $2000 per kW (combined capacity and operating values). The transformer itself might cost only $2.5 million, but if its design were to reduce the loss by only 0.1%, it would achieve a savings of 500 kW, or $1 million.

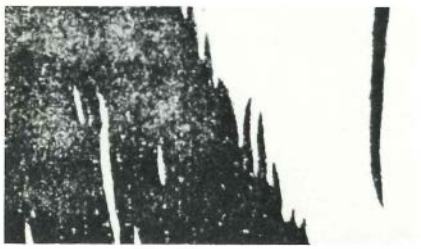
Origin and cost of losses

Loss evaluation is not simple. The nature

Determining the system costs of transformer losses is a key step in evaluating the worth of new core

of the losses must be considered. Some are more amenable to reduction, based on their origin, their dependence on the size (rating) of the transformer, and on the mode of transformer use. One type of loss occurs in the wire windings of the transformer. The other occurs in the transformer core, which electromagnetically links the windings to boost or reduce the voltage.

Winding loss varies with the transformer load factor, which is a measure of the time the unit is working to serve load. During off-peak hours, residential distribution transformers are lightly loaded, little current flows in their windings, and the winding loss is relatively low. Furthermore, this loss varies approximately as the square of the current (i.e., cutting load by one-half cuts the winding loss by three-fourths).



Core loss, on the other hand, is independent of load; it depends on voltage. And since a transformer's voltage rarely varies, this loss is always present; it is also called no-load loss.

Evaluated differently by various utilities and inevitably influenced by their assumptions of load factor, winding loss may be priced at $500–$1500/kW. Core loss, on the other hand, may be priced at $1000–$2000/kW; this higher range reflects the fact that core loss is continuous.

Not only are loss percentages subject to scale economies (proportionately less in larger units) but transformer costs also follow this pattern. A 1000-MVA transformer may cost $4–$5/kVA; a 50-MVA transformer, $6–$8/kVA. Distribution transformers, still smaller, may run $8–$10/kVA, and pole transformers, $12–$14/kVA. It becomes a point of optimization to decide where higher transformer costs can be incurred—and how much—in order to reduce the loss by a given amount.

Losses may be reduced by increasing the size of transformer core and/or windings. This means more materials, a larger unit to transport, and a larger site. It's more efficient, but it's bigger and it costs more. Loss evaluation may well justify it. The important point is that even for an optimized transformer design, the capitalized cost of losses over the transformer's life generally exceeds the cost of the transformer itself.

New core metallurgy

Technical advances may cut losses and the cost of the transformer itself. These are the goals of EPRI research on a new, amorphous magnetic material for cores. This alloy lacks the crystalline structure of conventional steels. Its metallurgical structure is atomically random—in effect, homogeneous. It therefore offers far less resistance to the alternation of magnetic fields that must occur in the core with each ac cycle, and it is not so subject to the formation of swirling eddy currents, both of which drain away energy as unproductive heat.

The potential benefit from the use of the amorphous material is a 60% reduction of the core loss in a transformer. What this means in economic savings can be seen in terms of the core steel assembled and sold each year, which now totals nearly 280,000 tons and represents annual core losses of about 390 MW (at a unit loss of 0.7 W per pound of core). A 60% loss reduction, valued at only $1000/kW, would amount to 234 MW, or more than $230 million annually throughout the life of future transformers incorporating the new metal. And this does not include a possible reduction in the cost of the new alloy and, therefore, of the transformer itself.

Amorphous cores for transformers are not yet a reality. One problem is to develop production technology specifically suited to the manufacture of amorphous material for cores. Another problem is to prove the material in the design, construction, and evaluation of transformer cores.

Both R&D avenues are now being followed in a pair of EPRI-sponsored projects. Their payoff is at least five years away, and EPRI's program manager, Narain Hingorani, rates the chances of overall success at about 50%.

Allied Chemical Corp. invented the amorphous alloying technology involved in the EPRI-funded project and has used it successfully in several commercial specialty products carrying the trade name Metglas or Metshield. The company is now developing alloy formulas suitable for cores and adapting its production techniques for the pilot manufacture of continous strip 2 in wide. (Strip 7 in wide will be developed later for use in transformers.) The basic methodology involves pouring molten alloy on a high-speed wheel. The alloy then automatically and uniformly flattens as it solidifies, streaming forth at 30–60 mph in the form of flat metallic tape. Its cost is expected to be competitive with the silicon steels now used in transformer cores.

naterials. System costs also motivate R&D on nonflammable, more efficient transformer coolants.

Complementing Allied Chemical's $6 million project is a $1.2 million EPRI contract with Westinghouse Electric Corp. to incorporate the Metglas strip into the cores of transformers for test and evaluation under utility operating conditions.

Cost of fire protection

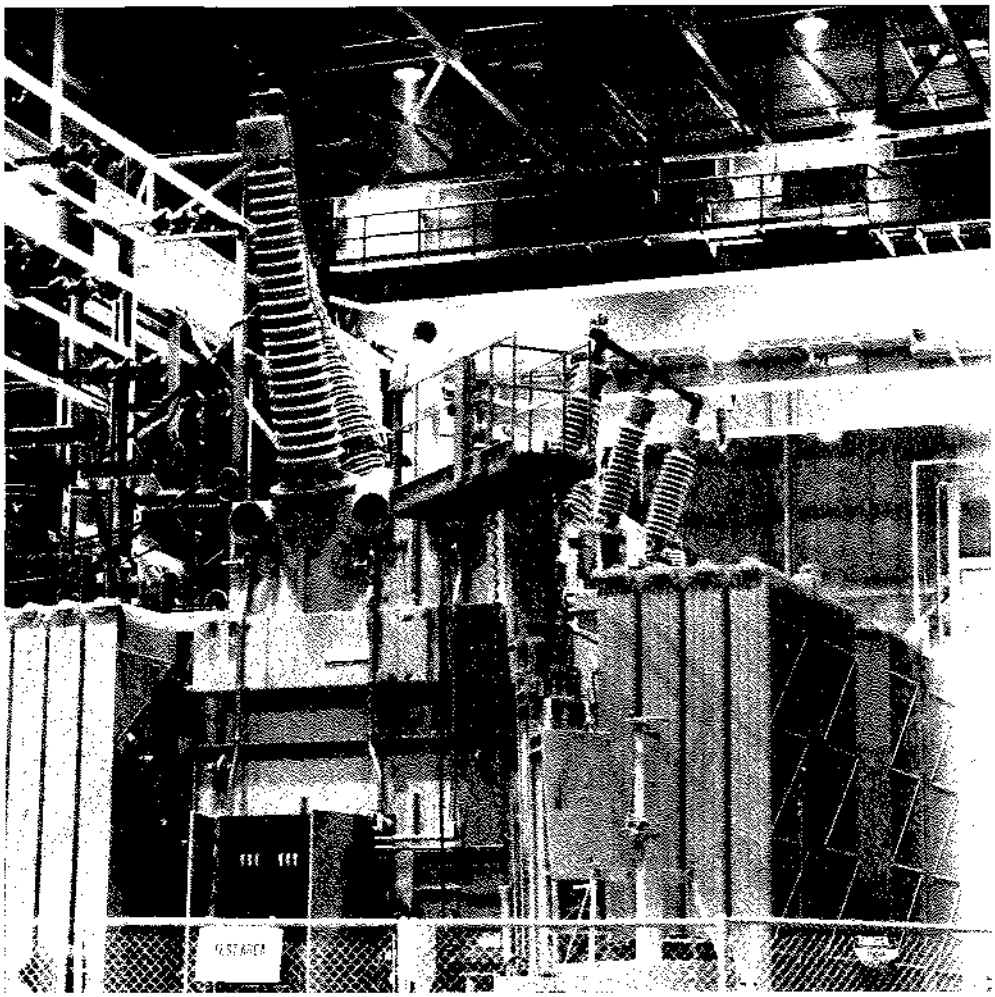
The second technological front for a new look in utility transformers is fire resistance. Closely related is more efficient cooling to remove the heat representing whatever fractional electrical losses cannot be avoided. Electrical losses are thus a factor in transformer cost itself, reflected in the provisions for temperature control.

Oil, the traditional liquid coolant and dielectric, is aided in its natural circulation in the transformer's surrounding tank by external fins and radiators, and even by forced-air fans. All these measures help, but they add size and cost, and none of them solves the perverse problem of flammability.

Ultimately, a transformer has some risk of internal failure. The cause may be an incoming power surge from an electrical fault elsewhere in the system, or it may be weakened insulation at a localized hot spot. The sudden pressure caused by a severe fault may result in a ruptured tank or bushing, the release of oil and hydrogen, and ignition of both by the short-circuit arc. High-speed relays, relief valves, lightning arresters, fuses, and breakers are preventative mechanisms that minimize this danger.

Additional mechanisms are a prudent provision against the explosive sequence that would follow a massive and rapid fault. Firewalls are often built to isolate transformers; berms and curbs and drains are provided to contain and channel burning oil. To avoid these requirements, transformers with fire-resistant coolants, and even dry transformers, are

A bulk power transformer costs millions of dollars, and its efficiency falls only a fraction short of 100%. But depending on how a utility evaluates electrical losses, the losses over the transformer's lifetime may have a capitalized value greater than that of the transformer itself. ***Photo courtesy McGraw-Edison Co.***



used in some critical indoor applications. But their basic cost is unacceptable for the full range of utility needs, especially in large units.

These alternatives also detract from technology that is otherwise markedly reducing substation profiles. For example, in compact gas-insulated substations, apparatus other than transformers is housed in tanks filled with sulfur hexafluoride (SF_6) gas and thus are fully insulated from ground and one another, without reliance on intervening air space. The result is a 90% reduction in overall station volume. Fire-resistant transformer coolants will complement SF_6 insulation technology so that entire substations can even be housed inside buildings, without the cost burdens of concrete vaults and fire spray systems.

New coolant composition

Research for 20 years has addressed fire-resistant materials. Solutions have included air and nonflammable gases, liquids that vaporize at operating temperature, combinations of these, and also such synthetic liquids as silicones and polychlorinated biphenyls (PCBs). All were too costly, either by themselves or in their effect on transformer size and performance; and PCBs were found to be an environmental hazard.

Now, however, several synthetic liquids have been identified that variously combine the needed attributes of nonflammability, high dielectric strength, thermal and chemical stability, appropriate viscosity and specific gravity, and low cost.

A major example is tetrachloroethylene (C_2Cl_4), and its most straightforward use is as a direct substitute for most of the oil in a fully immersed transformer. The mixture of C_2Cl_4 and oil is nonflammable but has a lower freezing point than C_2Cl_4 alone, and less potential solvent action on other transformer materials. Most important, it vaporizes at about 120°C (250°F), and this action effectively and beneficially puts an upper limit on transformer temperature without hot spots. Moderate overload thus does not further heat and deteriorate the cellulosic or other solid dielectric used on windings.

The mechanism of two-phase cooling is basic: for a given volume of liquid, its phase change to vapor, at an essentially constant temperature, absorbs far more heat from the transformer core and windings than does an incremental temperature rise of either the liquid or vapor phase alone. Furthermore, two-phase cooling acts preferentially on the hottest spots in the transformer, thus preserving a uniform operating temperature throughout the unit and automatically adjusting coolant flow patterns—self-pumping action—to and from the transformer walls, where the vapor condenses and the coolant recycles as a liquid. Coolant pressure, rather than hot-spot temperature, becomes the operating variable that determines transformer load limit. Finally, the external temperature need be only a few degrees below 120°C to cause coolant condensation, permitting two-phase cooled transformers to operate in higher ambient environments without forced circulation and forced-air fans.

EPRI-sponsored R&D to date has successfully demonstrated two-phase cooling up to 5-MVA scale, and projects are under way that will extend the work to 50–100-MVA units. Cost goals are size dependent. For the 5-MVA transformer, costs so far are within the desired 95–120% range, based on equivalent oil-immersed units. For the larger units, costs will very likely meet the program goal of equal cost. Savings in overall substation cost are the incentive for utilities to adopt this technology.

A variant of the fully immersed design employs a lesser quantity of a different two-phase coolant in conjunction with noncondensible SF_6 gas. The SF_6 provides dielectric strength under cold-start conditions, before sufficient heat is generated to vaporize the liquid coolant and gain the benefit of its dielectric properties. Such a unit, however, is even more explosion-resistant because of the far greater volume occupied by compressible gas than by noncompressible liquid.

Still cooler, still reliable

Core materials and coolants are not the only R&D frontiers of transformers. Solid dielectric materials continue to be sought that will insulate better and longer under varied loadings, in contact with dielectric liquid coolants, and in dry transformers where they function alone.

Two DOE-sponsored projects represent significant potential. One calls for the design of an advanced transformer featuring sheet-wound coils; an insulation system combining compressed gas and polymeric materials; and (for units rated over 500 MVA) a separate, sealed liquid cooling system. The other project is a feasibility study of a superconducting transformer. Superconductivity, the extremely low-temperature phenomenon of virtually zero electrical resistance—and thus of zero winding loss—may be useful if losses involved in the refrigeration process can be sufficiently reduced. EPRI is already applying superconductivity in the sponsored development of a generator, with the results of that work expected to influence the priority of superconducting transformer development.

Success on any of these technical fronts will enhance transformer performance, perhaps reducing the cost of the transformer itself. And to the extent that losses are cut, utilities are quick to realize system-specific values in conservation of power plant capacity and its cost of fuel and operation.

One encompassing criterion for all new developments is reliability. It must not be compromised. In fact, if there is a third technological aspect of the new look in transformers, it would be the methods and hardware that are also under development to enhance the predictability, control, and longevity of transformer operation.

Edwin Zebroski, NSAC director

NSAC: In-Depth Look at Three Mile Island

Through the Nuclear Safety Analysis Center, the electric utility industry hopes to learn what happened at TMI, how it happened, and what lessons it might hold for future nuclear safety.

The Three Mile Island accident commanded scrutiny from all quarters: the Nuclear Regulatory Commission, a presidential commission, congressional committees, nuclear manufacturers, the press, and others. Not the least of the scrutinizers was the electric utility industry itself. Conscious of its responsibility for the public's safety and of the importance of preserving the nuclear energy option, the industry had to know what had happened at TMI, how it happened, and how to minimize the possibility of such accidents happening anywhere again. And the industry needed answers fast.

Within days of the beginning of the TMI events, top people in the electric utility industry gathered in Chicago to draft a major nuclear safety study to be directed by EPRI. The group included representatives from nuclear utilities and several industry organizations: the Edison Electric Institute (EEI), the American Public Power Association (APPA), and the National Rural Electric Cooperative Association (NRECA). The Atomic Industrial Forum was also represented, as was EPRI.

"By the end of the meeting," reports David Saxe, director of EPRI's Administration Division, "there was general agreement that EPRI should plan immediately for a group to make a study of the Three Mile Island accident." The scope of the investigation would include an independent assessment of what had happened at TMI and what lessons could be learned.

Within weeks, the Nuclear Safety Analysis Center (NSAC) jelled. EPRI prepared a preliminary plan of technical activity, and necessary advisory groups were formed. One was the Utility Scientific Advisory Council, composed of non-utility nuclear experts who could provide broad, objective technical advice to the new organization. Another group was an ad hoc subcommittee of EPRI's Research Advisory Committee. This subcommittee, made up of senior nuclear industry people, would also provide technical ad-

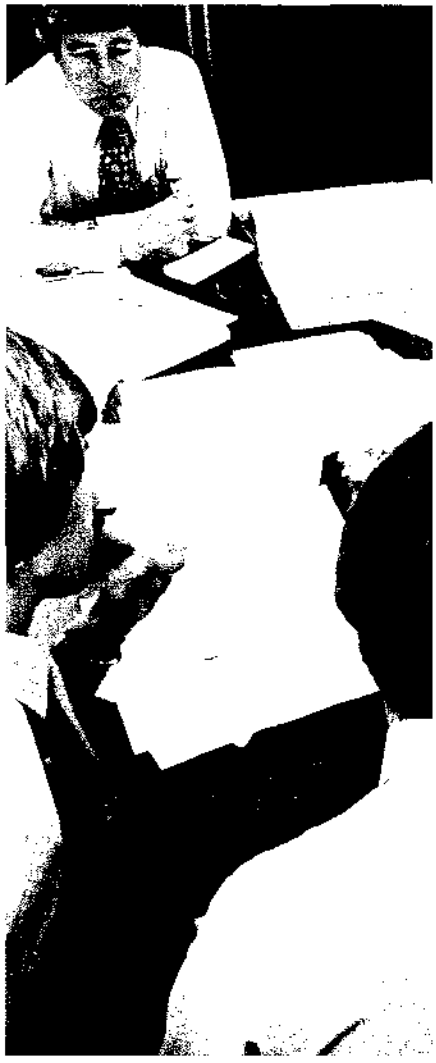
vice. Yet a third advisory group would be the TMI Ad Hoc Nuclear Oversight Committee, whose overview interests extend to other industry activities besides NSAC.

One month from TMI

On May 3, just a little over a month after TMI, EPRI's Board of Directors formally ratified the formation of the center. The organization reports to the president of EPRI and to the EPRI Board of Directors. It is separate from EPRI's technical divisions—including the Nuclear Power Division. EPRI President Floyd Culler points up the reasons behind this deliberate separation: "We set it up so NSAC would not unduly drain resources from the existing Nuclear Power Division, although support from that group is essential. We wanted NSAC to maintain an independence of view and to be able to move with speed into accident analysis and suggested improvements for safe reactors."

This separate identity extends to separate funding for the center: NSAC will be supported by special contributions from the utilities. NSAC's budget for the rest of this year is tentatively set at $3.5 million.

Initially, about 30 nuclear power experts are working at the center, which is based at EPRI's Palo Alto, California, headquarters. Many of these experts are drawn from the ranks of the Nuclear Power Division; the rest come from utilities, nuclear equipment designers and manufacturers, national laboratories, architect-engineers, consultants, and nuclear specialists from the U.S. Navy. If necessary, Culler is prepared to see the center grow to as many as 40 or 50 employees. Edwin Zebroski, formerly director of the Nuclear Systems and Materials Department, is NSAC's director. Robert Breen, formerly assistant director of the division's Safety and Analysis Department, is deputy director.



The work at hand

NSAC's extensive workplan includes both near- and long-term goals. The most immediate of these is now essentially complete: to provide staff, data, and analyses to Metropolitan Edison Co. and General Public Utilities Corp. during the TMI recovery period. For instance, NSAC specialists provided assistance to TMI management and operators to bring the reactor to a stable, long-term cooling mode.

The precise sequence of events at TMI is also getting speedy attention at NSAC. In the weeks after TMI, EPRI nuclear staff and others closely connected with the events at Harrisburg labored to reconstruct what had happened. A preliminary summary report has been completed; a more detailed, annotated report is being prepared with the help of computer sequence recorders, staff interviews, and equipment surveys.

After the "what" has been satisfactorily established, NSAC will report on the possible causes of the accident and identify the key safety issues. "Because of complex interactions, the true root causes will take several months to determine, and some aspects may remain ambiguous for a year or more," Zebroski estimates. During the process of safety analysis and through consultation with owners and designers, NSAC staff will look for areas of possible improvement in power plant technology and operation. As the safety analyses and studies of TMI are completed, system, equipment, and operations improvements will be suggested. "It's essential that we provide accurate and penetrating analyses of the nuclear safety issues raised by TMI and that we ascertain how the reactor systems might be better designed, and how they might be operated with greater safety," asserts Culler. "At the same time," he cautions, "we have to be careful that our technical imagination does not carry us beyond reality, that we don't invent real solutions to imaginary problems." Validation of nuclear safety is essential to the preservation of the nuclear option, according to Culler.

To ensure that nuclear safety findings are available throughout the industry, the new center will also function as a clearing-house for nuclear safety information that results from the TMI accident and similar safety reviews and studies by reactor owners and other groups. NSAC activities will be coordinated with those of the presidential investigating commission, the NRC, and the utility and nuclear industry trade organizations: "We'll stay in close touch with each one of these organizations, and encourage them to exchange information with us," explains Saxe. Information on studies and work in progress in these groups will be available through NSAC; Zytron, a computerized data retrieval system recently acquired by EPRI, will expedite the information exchange.

Radiation effects on human health—particularly low-level chronic and single-dose effects—is yet another near-term area of interest to utilities. Radiation studies will continue to be performed by the Environmental Assessment Department of EPRI's Energy Analysis and Environment Division.

Other important areas

As the results of NSAC and similar studies develop, other important areas of inquiry emerge. One such area is improved control and monitoring instrumentation for nuclear power plants. Another is the interface between operator and machine; NSAC is developing guidelines for information display and auxiliary real-time analyses in support of operator decisions under unusual conditions. The center might also examine operator training possibilities and relay study results to the industry groups responsible for training. Technical support options for emergency response systems are also under consideration.

Nuclear specialists from other countries have expressed interest in NSAC activities, and representatives of groups outside the United States will be contributing to the work at Palo Alto.

"Safety is achieved by close attention to the details of design and by following carefully developed operating practices, using informed and knowledgeable people," sums up Floyd Culler. Through its study program, NSAC can help to improve the safety and reliability of nuclear power plants.

Shifting SO_2 From the Stack

What form should the by-product of SO_2 removal take? Today's response is to redesign stack gas scrubbers so they produce a more readily disposable waste.

Gypsum stacking.

Sulfur oxides do not just disappear, once removed from the stack gases in a power plant; they become part of copious waste sludge, which demands acres of space for disposal. Because revised Environmental Protection Agency (EPA) regulations require all new coal-burning plants to install scrubbers, the accumulation and disposal of sludge discharged from lime/limestone scrubbers throughout the country may become a serious economic obstacle.

EPA's revised New Source Performance Standards, announced in May of this year, implementing the Clean Air Act Amendments of 1977, significantly tighten restrictions on plant emissions. Researchers anticipate even stricter regulatory trends in the future and are developing and testing new designs for scrubbers that do not produce sludge, though still maintaining or improving the efficiency of SO_2 removal.

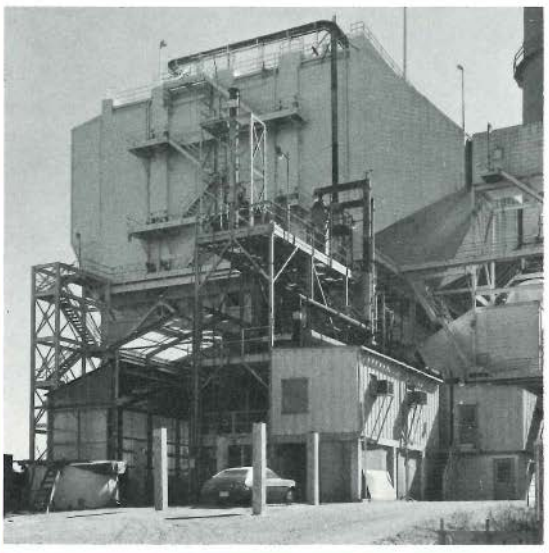
The drive for better scrubbers is backed by the push for improved waste disposal and operating reliability and

also by national policy on levels of SO_2 emissions as the nation moves toward greater reliance on coal. Fossil-fired power plants produce 58% of all sulfur oxide emissions in the United States (National Air Pollution Emission Estimates, EPA, July 1978). That percentage could be reduced if western, low-sulfur coals were burned instead of eastern, high-sulfur coals. But utilities in the East mainly burn local coals to avoid the high cost of transporting low-sulfur coal from the West and to help maintain employment levels of miners in the East. Because of these economic considerations and because the National Energy Plan calls for increased coal use, the need for research into better processes for scrubbing sulfur oxides from the exhaust gases of power plants has become urgent. Annual budgets for national research into flue gas desulfurization (FGD) are in the tens of millions of dollars for the next few years.

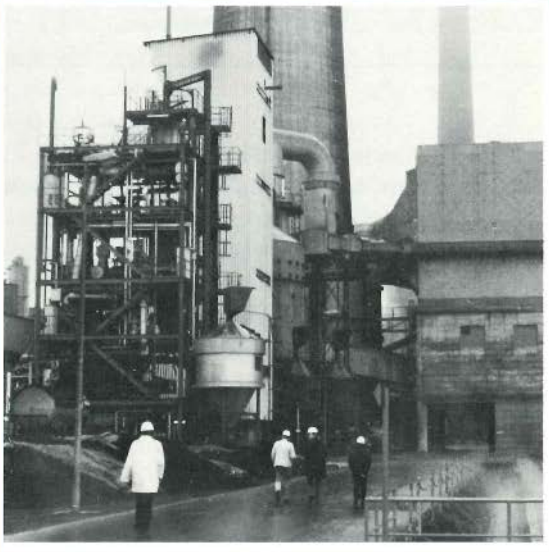
Current FGD technology, lime/limestone scrubbing, has a long operating history, despite its drawbacks. But recent federal legislation, specifically the Resource Conservation and Recovery Act and the Toxic Substances Control Act, has emphasized its big disadvantage: waste sludge. Sludge is the by-product from a scrubber's reagent slurry (solids suspended in water), fly ash, and the chemicals, such as SO_2, that the slurry has absorbed from the stack gases. In recent years, a second generation of scrubbers has been developed as an improvement over the lime/limestone system. Some of the second-generation scrubbers, such as the dual-alkali process, are designed for improved reliability. Others, the Wellman-Lord process and the magnesia scrubbing process, for example, are aimed at eliminating the formation of sludge, and thus the problem of sludge disposal, by producing salable products (elemental sulfur, sulfuric acid, or gypsum).

But second-generation scrubbers have drawbacks, too. It is the advanced, or third-generation, scrubbers that are designed to get around those drawbacks

Chiyoda Thoroughbred-121 jet bubbler reactor, part of 20-MW prototype scrubber system at Scholz plant.



An FGD system that uses absorption–steam stripping, under construction at TVA's Colbert plant.



Prototype Resox system for reducing SO_2 to elemental sulfur, Lünen, West Germany.

and still produce marketable or readily disposable materials.

Three advanced systems that EPRI is involved with are now at the demonstration stage: the Chiyoda Thoroughbred-121 process, the absorption–steam-stripping–Resox process, and the aqueous carbonate system. All three are free of the sludge problem.

The basic scrubber

The lime/limestone system for removing SO_2 represents the major body of experience in scrubbing technology and, as such, forms the basis for most current scrubber systems.

The lime/limestone scrubber's traditional job is to promote intimate mixing and reaction of the SO_2-laden flue gas with the lime or limestone reagent, which is introduced into the scrubber as a slurry of 5–15% solids. Chemical reactions continue in the reaction tank. Reusable slurry is sent back to the scrubber, and makeup is added as necessary.

Part of the slurry from the reaction tank flows to the thickener, where solids are concentrated as sludge and removed. The sludge, which is composed of calcium sulfite and sulfate, retains as much as 50 wt% water. Clarified water from the thickener tank is returned to the scrubber for reuse.

The majority of FGD systems, both in operation and at the planning and construction stages, are lime or limestone because this method has been developed more extensively and still appears most economically attractive in many specific applications. The reagents—lime or limestone—are relatively inexpensive, and the SO_2 scrubbing process is moderately simple. However, the method also has a number of disadvantages.

Lime/limestone scrubbers require a significant amount of energy for reheating the saturated stack gases so they rise high enough from the stack to avoid a visible plume and heavy concentrations of SO_2 and other pollutants at ground level. Reheating also prevents corrosion of the stack lining. One disadvantage is that the energy consumed for reheat represents a considerable expense.

An additional drawback is the frequent and extensive maintenance needed for a lime/limestone scrubber. Chemical compounds often scale and plug the absorber and the mist eliminators. Pumps and pipes are prey to acid corrosion and slurry-induced erosion. Water is needed for periodic washing of the scrubber internals to prevent scaling and as a way to eliminate accumulated chlorides from the system. When the plant has to be shut down for cleaning of the subsystems, valuable generating time is lost.

The lime/limestone scrubber is limited to about 90% SO_2 removal in the short term and 85% or less as a long-term average. These percentage efficiencies may be inadequate to satisfy future regulations. In future research, reactivities of lime and limestone must be measured more accurately, and additives must be found to make lime/limestone more efficient in removing SO_2 and to prevent scaling. For example, magnesium added to lime or limestone creates a more soluble reagent that absorbs sulfur oxides better.

The major disadvantage of the lime/limestone scrubber, however, is the enormous amount of sludge it discharges. Sludges that are high in calcium sulfite tend to be thixotropic, or physically unstable, and are difficult to dewater. In a few cases, the reaction process has been modified to produce gypsum, which is more easily dewatered for handling and storage. Alternatively, the sulfite sludge can be fixated by adding fly ash and lime to produce a material like low-grade cement. Or an oxidation step can be added between the scrubber and the thickener to prevent solid wastes from becoming thixotropic by converting sulfite to sulfate.

But even when waste stability problems are solved, a utility has to make sure that it has enough land for ponding sludge or storing gypsum; the area needed can greatly exceed the area taken up by the power plant itself. In many cases, sludge ponds must be lined with an impervious material such as bentonite clay to prevent toxic chemicals from leaching into groundwater. The search for a dumping place can be tricky in a densely populated location, although a disposal site, once full, can sometimes be covered with soil and landscaped as a park or a golf course (*EPRI Journal,* October 1978, p. 38).

In rural areas, gypsum can be put to work on the farm. Mixed with soil, it can increase porosity and improve the chemical makeup so that the land becomes more productive.

Further into the future, utilities near coastal areas may have the option of burying their waste at sea. In an EPRI test project, researchers are evaluating the environmental, engineering, and cost aspects for chemically solidifying waste from coal-burning power plants into one-cubic-meter concretelike blocks that could be used to build an artificial reef (*EPRI Journal,* January/February 1979, p. 30). These reefs could then function like natural reefs—for fishing or as breakwaters to protect harbors and beaches.

The second generation

Scrubber system suppliers, backed by EPA and the utility industry, have developed better ways to recover or dispose of sulfur oxides from stack gases. For instance, a second-generation, commercially available scrubber (just started up at a new utility boiler) is the double-alkali process. In this case, a sodium-base alkali absorbs SO_2 from the flue gas, and the resultant liquor is reacted with a calcium-base alkali (lime or limestone) to precipitate calcium sulfite and calcium sulfate for disposal. The sodium-base alkali is thus regenerated for recycling to the scrubber. The advantage of this concept is that the liquor is a clear solution, which eliminates most of the scaling, plugging, and erosion associated with slurring scrubbing. The process also provides excellent SO_2 removal rates and has energy requirements that are relatively low compared with other second-generation FGD processes.

On the other hand, the double-alkali process is a complex one. It also produces

a huge amount of high-moisture calcium sulfite sludge with soluble sodium salts that have the potential to leach into surface or groundwater.

The Wellman-Lord system is another second-generation scrubber that is commercially available. It is in operation at two coal-fired utility boilers in the United States.

In this system, SO_2 is removed by reaction with sodium sulfite to form sodium bisulfite and some sodium sulfate. The sodium bisulfite is converted thermally back to sodium sulfite in an evaporator-crystallizer at 175–200°F (80–93°C).

The regenerated sodium sulfite is dissolved and recycled to the absorber. A purge stream of spent scrubbing liquor from the absorber is cooled to about 35°F (2°C) in a chiller-crystallizer, and a by-product mixture of sodium sulfate and sulfite is crystallized out of the solution. This crystalline purge, containing about 70% sodium sulfate, is dried and removed from the process.

Advantages of the Wellman-Lord process are the clear-solution scrubbing, which prevents scaling, and the capability to produce a liquid SO_2 or a sulfur product, both of which are marketable. The disadvantages are problems of sulfate disposal, energy consumption, and high maintenance, which is caused by the complexity of the process.

Still another second-generation system is magnesia scrubbing, in which the reagent is magnesium oxide slurry. The spent slurry containing magnesium sulfite is dried. The resultant dry solids are taken to a calciner (rotary kiln), which thermally decomposes the magnesium sulfite into SO_2 and regenerated magnesium oxide. The concentrated SO_2 can be condensed and sold, or it can be fed to a sulfuric acid plant.

Advantages of this process are its moderate cost and its sulfuric acid product. Disadvantages are the slurry scrubbing with its material-handling problems, high losses of magnesium from the system, and the questionable reliability of the system because of its potential for scaling and the difficulty in controlling chemical reactions in the drier.

Advanced processes

Three advanced FGD technologies are being demonstrated as part of EPRI's Desulfurization Processes Program.

One of these, the Chiyoda Thoroughbred-121 process (CT-121), sparges, or bubbles, flue gas into a limestone slurry absorbent, producing a layer of froth. The SO_2 is absorbed in the froth and subsequently oxidized to sulfate, which combines with calcium from the limestone to form gypsum as a by-product.

Here is a system that combines low cost, simplicity, and reliability with a cheap reagent and a salable product. The gypsum can be disposed of by stacking, if local market conditions preclude its use in cement or wallboard manufacture.

Another advanced approach is the absorption–steam-stripping–Resox process, which recovers the scrubbed SO_2 by producing elemental sulfur without using a gaseous reductant. In this case, SO_2 is absorbed from the flue gas in a buffer solution; the solution is regenerated when the SO_2 is stripped from it with steam; and the concentrated SO_2 is reduced to elemental sulfur with coal as the reductant.

This system appears to be economically attractive and produces salable sulfur, which can be marketed directly or converted to sulfuric acid.

A third scrubber being demonstrated is the aqueous carbonate process, in which an aqueous solution of sodium carbonate, dispersed as fine droplets, absorbs SO_2 from the flue gas. The droplets are dried by the heat contained in the flue gas—a method known as spray drying.

The dried particles of sodium sulfite collect on a fabric filter bag or in an electrostatic precipitator and are then placed in a reducer bath of molten sodium carbonate with coal as the reductant. In the molten salt bath, sulfite is reduced to sulfide. The melt is tapped and quenched with water, forming an aqueous solution of sodium sulfide. This solution is then carbonated by using the CO_2 content of the reducer off-gas, producing both a hydrogen sulfide gas (H_2S) and an aqueous sodium carbonate solution. The solution is recycled to the spray drier and the H_2S is converted to elemental sulfur in a Claus plant—a technology that is commercially available. The advantages of this scrubber are the production of elemental sulfur without the need for natural gas as a reductant, the potential for regeneration of sodium compounds from other scrubbing processes, and the fact that reheat is not needed.

EPRI's Desulfurization Processes Program staff forecast that all three advanced systems will be ready for their first commercial orders during the two-year period 1983–1984.

The challenge of choice

New technologies are being developed to overcome the recognized limitations of lime/limestone scrubbers and to meet stricter regulations. These new technologies will give utilities a choice as to the ultimate form taken by the SO_2 removed from their stacks. Will it be sludge, fixated sludge, gypsum, liquid SO_2, sulfuric acid, or elemental sulfur? The choice will be made according to factors specific to each plant site. Does the plant use high- or low-sulfur coal? Are there restrictions on the local water supply? How much land is available for ponding or landfill? How far away is the nearest sulfur market?

Until recently, these and other site-specific considerations were important in the engineering design of a flue gas scrubbing system, but often were not crucial in the initial selection of an FGD strategy simply because lime/limestone scrubbing was all that was available. In contrast, utility planning and engineering staffs making FGD choices today must consider a myriad of site-specific factors at a very early stage because the dual-alkali and Wellman-Lord processes can be ordered now, and within the next three years, several advanced FGD processes will be added to the list of alternatives available for SO_2 control.

Steps to Sludge Disposal

Utility engineers mired in scrubber sludge disposal decisions may get a helping hand from a new EPRI manual.

To dewater . . . or not . . . is just one of the questions an electric utility must answer before it decides on a disposal system for power plant flue gas desulfurization (FGD) sludge. The utility also has to puzzle out how much sludge there will be, its composition, whether to use wet or dry disposal, where to put the sludge, and how to transport it. For utility engineers designing sludge disposal facilities, EPRI has published the *FGD Sludge Disposal Manual.*

Throwaway sludge

The manual, an early product of EPRI's solid-waste disposal program, focuses on so-called throwaway FGD systems. These systems trap a power plant's SO_2 emissions by scrubbing the gas with water and a reagent, such as lime or limestone. The mixed results: cleaner air and significant quantities of by-product sludge. "As a rule of thumb," advises Dean Golden, EPRI subprogram manager for solids by-product disposal, "about one ton of sludge is produced per megawatt per day."

While sludge may be incorporated into wallboard, cement fixative, or paving, markets in the United States for this by-product are limited, and most sludge ends up in disposal ponds or landfills. Many utility design personnel are trained in electrical or mechanical engineering rather than in the chemical and civil engineering pertinent to sludge disposal, explains Golden, so the manual provides "a way for them to get a handle on sludge."

The manual tackles sludge disposal step by step, beginning with a decision-path diagram that maps a utility's disposal alternatives. For example, beginning with scrubber bleed, a utility can opt to oxidize or not oxidize its waste. Then there is a choice of thickening/dewatering methods. Following that, there is the choice of whether to provide fixation. If fixation is selected, a fixative is chosen, perhaps alkaline fly ash or lime and fly ash. The selection process continues down the path until an entire system is plotted.

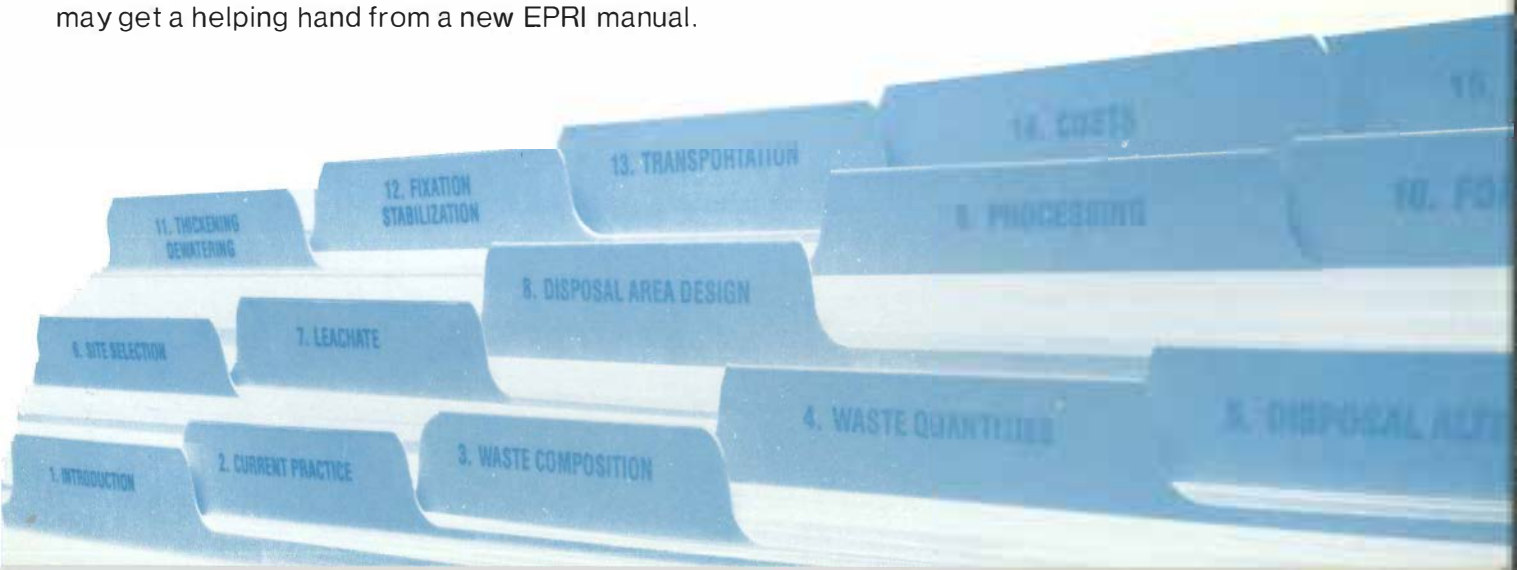
As the manual explains, processing, transportation, and disposal options are interdependent. The decision a utility makes at one point reduces the number of alternatives available elsewhere in the system, and so utilities must consider each choice carefully.

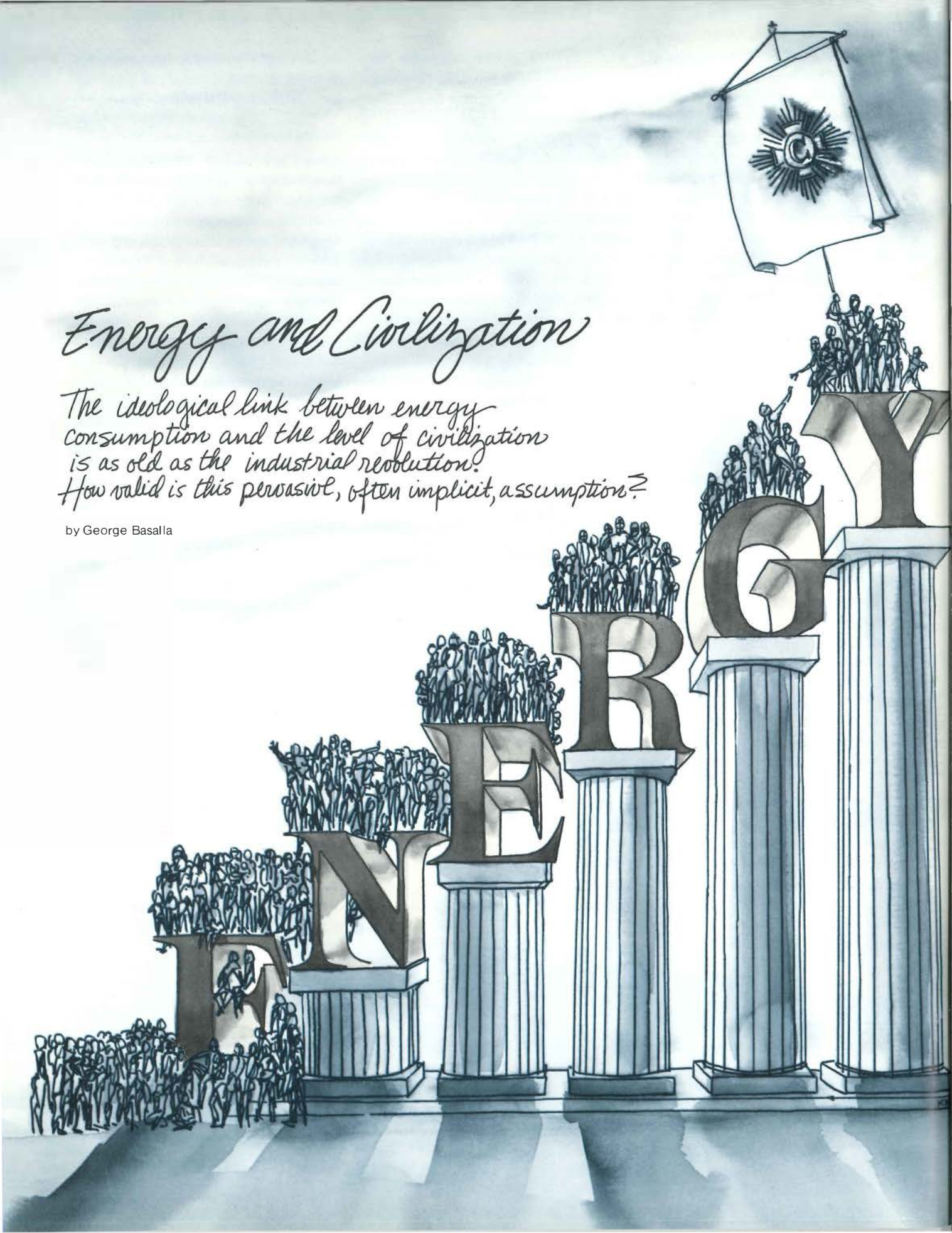
According to the manual, eight major sequential steps are necessary before a utility decides on a disposal system: the waste must be characterized; a disposal option (pond or landfill) selected; available disposal sites determined; the necessity of a liner determined; processing requirements assessed; transportation methods selected; systems and cost evaluated; and a disposal system chosen.

Sludge specifics

Subsequent manual chapters address sludge disposal specifics: current practice, waste composition and quantity, disposal alternatives, site selection, leachate, design of disposal areas, processing alternatives, forced oxidation, thickening/dewatering, fixation/stabilization, transportation, system costs, and utilization. When it comes to processing and disposal, the manual pays particular attention to new EPA regulations and possible future requirements of the Resource Conservation and Recovery Act of 1976 (RCRA). This law mandates environmentally acceptable disposal of solid wastes, including FGD sludge.

The manual, prepared by Michael Baker, Jr., Inc., Beaver, Pennsylvania, can be ordered from Research Reports Center, P.O. Box 50490, Palo Alto, California 94303, (415) 961-9043. This looseleaf manual will be updated as the state of the art advances and regulations bearing on sludge disposal evolve; a first revision is expected in May 1980. An ash disposal manual, companion to the *FGD Sludge Disposal Manual,* is scheduled for publication later this year. ■





Energy and Civilization

The ideological link between energy consumption and the level of civilization is as old as the industrial revolution. How valid is this pervasive, often implicit, assumption?

by George Basalla

The current approach to the energy problem ignores the fact that for almost two centuries energy consumption in the West has had an ideological component. High energy consumption has not only been associated with physical comfort, economic well-being, and military strength—it has also been identified with the idea of civilization itself.

The tendency of the western nations to equate energy use with level of civilization was accurately and satirically described by British author Aldous Huxley. Said Huxley, "Because we use a hundred and ten times as much coal as our ancestors, we naively think that we are a hundred and ten times better intellectually, morally, and spiritually" (*1*).

When energy consumption thus serves as a measure of the height of civilization reached by a nation, then changes in energy use will have wide implications. A retreat from rising energy consumption under those circumstances means far more than the minor discomfort of living in a warmer house in the summer and a cooler one in the winter, or driving a smaller car less frequently and more slowly. As less energy is available per capita, the nation is thought to lose its standing among the world's civilizations.

Those countries with high rates of energy consumption are ideologically committed to maintaining them, and those with lower rates are motivated to copy their energy-hungry, civilized superiors. This ideological commitment helps to explain why so many of the less industrialized nations felt it necessary to have their own nuclear reactors. It was not necessity that drove them to acquire them but the feeling that they might be left behind in this latest event in the energy-civilization race.

To simplify further discussion of these matters I will assume the existence of an energy-civilization equation. Although no one has ever formally written out such an equation, it has pervaded western thought for the past two centuries. It can be found in the physical, life, and social sciences, and in technology, philosophy, and popular culture.

The left side of the equation contains energy, a well-defined physical concept. On the opposite side appears civilization, which is a subjective evaluation of the intellectual, moral, and esthetic accomplishments of a society. The two sides of the equation are directly related so that high energy consumption results in high civilization and low energy consumption in a low level of civilization. If the use of energy is very low, then the society may be placed in the savage or barbarian state that precedes civilization.

Origins of the equation

Prior to the Industrial Revolution, new energy sources were not linked to the advancement of culture. Take the example of the Middle Ages, which witnessed a great power revolution. The waterwheel, windmill, and effective harnesses for draught animals were all first extensively used in the West during the medieval period (*2*). Although these new power sources transformed social and economic life, no medieval thinker was ever moved to claim that they were the ultimate sources of the cultural and spiritual achievements of the time. And conversely, medieval society never feared that dry streams, windless days, and bad harnesses would mark the end of its civilization.

The formulation of the energy-civilization equation was made possible by the scientific revolution of the seventeenth century. The emergence of modern science and the subsequent identification of scientific and technical advancement with human progress provided the kind of intellectual environment in which a newly introduced power source would be dealt with differently than it had been in the Middle Ages. The scientific revolution created a world view in which energy and civilization could be directly related.

By the early nineteenth century the steam engine had quickly become the symbol of industrialization and the social, economic, and cultural changes that accompanied it. In Great Britain, where it first appeared, it was admired as a contrivance that simultaneously brought wealth and civilization to the British people. The enthusiasm of those who commented upon steam-powered civilization went beyond simple praise. They felt it necessary to explain in detail how the energy of the coal in the steam engine could be transformed into civilization.

Their explanation may be summarized as follows. The burning of coal produces steam power that supplements and surpasses human power. This power is used to increase the productivity of labor and to create the additional wealth needed to maintain a nonproductive, leisured, educated class. The abundance of steam power also stimulates the growth of the middle class by supplying it with every sort of material goods and has the ability to raise the intellectual level of those at the bottom of the social scale. In an age when both education and material goods are being increased, the habits, manners, and feelings of even the lowliest laborer cannot help but be improved. Therefore, the steam engine not only weaves cotton, powers locomotives, shapes iron, and pumps water—it also influences the moral, esthetic, and intellectual life of the British people, and in that way, lifts the entire nation to a higher stage of civilization (*3*).

If this argument is too abstract for your taste, consider one put forth by a popular British author in 1868. According to this writer, just as man is the noblest work of God, so the steam engine is the noblest work of man. That is, man is to God as the steam engine is to man because it is responsible for the "physical, intellectual, and moral advancement of mankind" in the nineteenth-century (*4*).

The only note of regret to be found in this eulogy to the civilizing power of the steam engine occurred when the author

George Basalla is an associate professor of the history of science and technology at the University of Dela ware. This article is adapted from a speech presented at the Edison Centennial Symposium, April 1–4, San Francisco, California.

"The more historians and anthropologists learn about the early history of mankind the more they are convinced that science, religion, and art were always part of human existence and not refinements cultivated after reaching a certain stage of economic stability."

recalled the greatness of Greek civilization. "If only the Greeks had had the steam engine," he lamented, "just imagine how far even Greek civilization could have been advanced by it."

In 1876 our nation celebrated its centennial at an exhibition held in Philadelphia. The political freedom and growth of the American republic were being celebrated there with political oratory and lavish displays of agricultural and manufactured goods. Overshadowing all the speeches and goods was a huge, 1400-horsepower Corliss steam engine that stood over 40 feet above its platform and supplied power to all of the machinery on exhibit.

The centennial festivities began when President Grant opened the valve of the engine, and they halted when the engine's gigantic flywheel was stopped (5). Visitors to the exhibition looked upon this steam monster as both symbol and tangible proof of the progress America had made in the civilized world since the signing of the Declaration of Independence. To this day the Corliss engine remains the single best-known feature of an exhibition that was mounted to commemorate the first 100 years of American independence. A steam engine holds this distinction because it was the physical embodiment of the idea that a people who have access to large quantities of energy are progressive, civilized, and superior to those who use less energy.

One short, brilliant burst?

Up to this point I have been exploring the optimistic side of the equation, the side that correlates rising energy use with higher levels of civilization. There is a corresponding, pessimistic interpretation of the equation that emphasizes falling rates of energy use and the decay of civilization.

One such pessimist was the English economist and philosopher Stanley Jevons. In 1865 he wrote a book, *The Coal Question*, in which he warned his countrymen of a coming energy crisis that would threaten Britain's economy and civilization (6). Jevons's analysis of his nation's energy resources led him to conclude that its coal supplies were rapidly diminishing. Since he could not conceive of any alternative to coal, Jevons concluded that within a century Great Britain would be forced into moral and intellectual decline. He envisioned some time in the future when a New Zealander would visit the ruins of a coal-exhausted London in order to contemplate the remnants of British civilization, just as a nineteenth-century British tourist might visit Rome and mourn over its lost grandeur.

Since coal would no longer be available to energize the thrust of British civilization as it had in the past, the nation faced a melancholy choice. It could use up its remaining coal supply to fuel one short, brilliant burst of cultural activity, or it could ration the meager supply over a longer period of time and sink into an age of prolonged mediocrity.

Jevons's pessimistic forecast was widely debated in the press and in Parliament. The British prime minister argued that the national debt must be reduced in the light of Jevons's dire predictions. But then as now, the public was convinced that something would happen to prove Jevons wrong. It did. New coal supplies were discovered in England, and the petroleum industry was born during the very years of the debate over the coal question.

Theoretical justifications

The steam engine appeared to offer strong, tangible evidence that energy could be converted into civilization; however, it could not provide a proper theoretical basis for the equation. Only the sciences could supply such a foundation. During the nineteenth century, physics and chemistry, and then the biological, social, and behavioral sciences were called upon to offer theoretical justification for linking energy with civilization.

Early in the century, scientists had their first glimpse into the possibility of energy conversion. At that time they were interested in the conversion of heat to light, light to chemical action, chemical action to motion, motion to electricity,

electricity to magnetism, and so forth.

Some men of science were not satisfied to confine their conversion series to the boundaries of the physics and chemistry laboratory. Is it not possible, they argued, to convert physical forces or energies into biological ones? After all, it occurs naturally every time an animal assimilates its food. And cannot the series be extended from the biological to the nervous forces that energize the nervous system? And why stop here? Why not take the next step, the one that connects nervous forces to the mind and to the study of moral and intellectual energy?

One of those who was prepared to move from physics to culture was the American scientific journalist and publisher Edward L. Youmans. Youmans claimed that the transformation of water, steam, and electric power into social activities was the greatest accomplishment of the century. He went on to predict that in the future any question dealing with man and society would best be studied in terms of the physical principle of the conservation of energy (*7*).

Youmans's proposal to study social, economic, and political problems in terms of energy exchanges and conservation gained in popularity during the twentieth century. As proof, allow me to introduce three strikingly different figures who in the early twentieth century attempted to understand society in terms of energy: a distinguished German chemist; a well-known American literary personage; and a British chemist.

The German chemist was Wilhelm Ostwald, winner of the 1919 Nobel prize for his work in physical chemistry. Ostwald was part of an influential group of chemists and physicists, known as the energeticists, who were convinced that the atomic theory of matter should be replaced by an energetic theory of matter. At the same time that he was engaged in his chemical labors and philosophical speculations, Ostwald became fascinated with all aspects of the idea of energy and he announced the discovery of an energy-based moral principle that should henceforth govern all of man's actions. It was called Ostwald's energetic imperative, and its message was simple: Do not waste energy!

The energetic imperative had as its corollary our familiar energy-civilization equation. But Ostwald modified it somewhat. Not only did the civilized nations of the world have more energy available to them but they used their energy allotments more efficiently than did the uncivilized societies (*8*).

If one accepted the energetic imperative and its corollary, then war was immoral because it wasted energy and lowered the level of civilization of those who engaged in it. Ostwald firmly supported this interpretation until his country entered World War I. Then he pragmatically altered it by stating that the highest civilizations made the most effective use of energy even when fighting wars. Wartime Germany, in Ostwald's judgment, was using energy more efficiently than its enemies in the Allied camp. Therefore, Germany continued to retain its superior civilized status, while its foes were slipping toward savagery.

Among the American intellectuals influenced by Ostwald's ideas was the historian and writer Henry Adams. In his famous essay, "The Virgin and the Dynamo," Adams evaluated the effects of two great and different energies upon the course of Western civilization.

The religious energy generated by medieval Catholicism in its veneration of the Virgin Mary had caused magnificent cathedrals to be erected and inspired poets, philosophers, and theologians in their creation of the culture of the Middle Ages. Opposing the energy of the Virgin stood the dynamo, a secular generator of energy, values, and civilization in the twentieth century. The force of electricity emanating from the steam-driven dynamo was every bit as mysterious and powerful as the religious force produced by the veneration of Mary. Yet, the cultures that sprang from these two generating sources were radically different. One was religious and unified; the other was secular and fragmented.

Henry Adams added further refinements to his commentary upon energy and civilization when he included the phase rule recently discovered by chemist Josiah Willar Gibbs. Adams wrenched the phase rule from its scientific context and applied it to the energy-civilization equation.

The first phase in human history, according to Henry Adams, extended from the appearance of man on earth to the year 1600. During this initial phase, religious energy determined the nature and direction of civilization. The coming of the steam engine heralded the opening of the second age, that of mechanical energy, which was to last for three hundred years. The mechanical phase, in turn, was supplanted by the age of electricity that arrived in 1900 and would be extinguished within seventeen and one-half years. Each phase of human civilization became progressively and alarmingly shorter because the energy that drove them was limited. By 1917, said Adams, there would remain only one untapped source of energy—the ether that filled the entire universe. But ethereal civilization was doomed to perish within four short years and then the human mind would reach the ultimate limits of its possibility in the year 1921 (*9*).

The third twentieth-century figure in my account is the British chemist Frederick A. Soddy. Working with other prominent British scientists, Soddy developed the disintegration theory of radioactivity, confirmed the transmutation of the elements, and was the first to advance the idea of the isotope. For this work he won the Nobel prize in chemistry in 1921—the ominous year that Henry Adams had chosen to mark the end of civilization.

Not only was Soddy a pioneer in the study of the atom, he was also an early and enthusiastic proponent of atomic energy. If mankind was ever able to release the energy in the heart of the atom, wrote Soddy, he would have available to him a huge and inexhaustible supply of energy that would utterly transform society and lift civilization to heights hitherto undreamed of. An atomic-powered soci-

"During the nineteenth century, physics and chemistry, and then the biological, social, and behavioral sciences were called upon to offer theoretical justification for linking energy with civilization."

ety of the future would reach such a peak of perfection that it could only be compared with the paradise we know as the Garden of Eden.

Soddy recognized two serpents, two sources of evil, bent upon destroying his atomic-powered Garden of Eden. The first was war. Suppose the energy of the atom was used for warfare and not for the advancement of civilization? Science fiction writer H. G. Wells had already raised that possibility in a novel he wrote in 1914 and dedicated to Soddy. In the Wellsian version of the future, atomic energy was first released in bombs, and only after the world was reduced to ruins and misery did the surviving humans build a new and glittering civilization, using the energy of the atom for peace.

The other nemesis threatening future dwellers in Eden was the traditional economic system that hampered the equitable distribution of available goods and services. In attempting to solve this problem, Soddy turned from chemistry to economics. His economics, however, was to be truly scientific for it was based upon the laws of thermodynamics.

Wealth, Soddy claimed, was essentially the product of useful and available energy, and the entire body of economic thought must be revised accordingly. Once the economic system was placed upon an energetic basis, current inequities would vanish and a paradise would await mankind in the atomic future (*10*).

I have touched on but a few of the many attempts to give scientific credibility to the energy-civilization equation. I could have pursued its use by Sigmund Freud, who linked sexual energy, and its sublimation, to civilization. I could have introduced current anthropological and sociological thought based on a link between energy and cultural achievements. And I might have explored modern energy sources—coal, petroleum, the atom, the sun—noting that the disclosure of each was accompanied by exaggerated claims that it would be the basis for a new society and a higher civilization. Or, we might have looked more closely at a National Science Foundation course in which energy was described as follows: "Energy is the source and control of all things, all values, and all the actions of human beings and nature."

Validity of the equation

Given the origins and diffusion of the energy-civilization equation, we are still left wondering about its ultimate validity.

One of the first things to notice about this equation is that slight increases or decreases in energy use are presumed to cause large fluctuations in the level of civilization. If man uses less coal or electricity, then he is surely doomed to wear animal furs and gnaw on bones. On the other hand, if he adopts solar, fusion, or some other new energy source, then the Gates of Eden will be opened to him. We should be suspicious of such a formulation that places mankind so precariously between apocalypse and utopia. And we should be cautious in accepting an equation that does not reflect the fact that the vast increases in energy consumption over the past few decades have not necessarily enhanced our chances of reaching a new stage in civilization.

Perhaps one reason why our rapidly increasing energy consumption has not placed us upon a new plateau of civilization is the way in which we choose to use that excess energy. The crude formula linking civilization with energy has no place for questions of choice. It deals with energy expended per capita and does not ask if the energy was squandered on trivialities, wasted in destructive wars, or utilized to advance the social, moral, and cultural accomplishments we identify with civilization.

Another weakness of the equation grows out of the vague way energy is defined within its context. There is no quarrel when the term is limited to the physical domain. But what are we to make of the analogical reasoning that leads to the writing of serious essays on moral energy, sexual energy, or religious energy?

The culprits here are not only literary figures like Henry Adams but recognized contemporary scientists. For example,

the author of a currently popular anthropology textbook routinely examines the various fuels and the kinds of societies they might help to establish. Having completed this examination, he casually announces that his next topic will be spiritual energy and ways it is harnessed in prayer, sacrifice, ritual, and other religious practices (*11*).

If the energy-civilization formulation encouraged the loose definition of energy, what did it do to the definition of civilization? Immediately we are faced with an entirely different situation. Energy has its roots in the physical sciences, so no matter how it is misapplied, the original concept maintains its integrity. Civilization, on the contrary, never has had the kind of precise determination we associate with an accepted scientific concept. *Civilization* has always been a value-laden word that has changed over time, and it has been redefined again and again to meet current political, social, or cultural needs or desires. It is an ill-fated formula that would attempt to link closely two such disparate entities as energy and civilization.

Yet, even if we attempt to make the equation workable by focusing on one nation at a given time and assuming that its people will agree on what is meant by civilization, we find grave difficulties. When Stanley Jevons was predicting the imminent decline of British civilization in the 1860s, he supposed that coal, iron, and railroads had raised England to the pinnacle of culture. No so, responded contemporary literary critic Matthew Arnold. "Let us suppose," he said, "that two hundred years from now, England were to be swallowed up by the sea. When the rest of the world recalled England's greatness, they would undoubtedly remember the age of Shakespeare as her golden hour, rather than the time of Alfred, Lord Tennyson and Queen Victoria. The Elizabethans managed quite well without the steam engine to produce a culture that is admired throughout the world" (*12*).

Should a twentieth-century opponent choose to enter into debate with Matthew Arnold over this matter, he would probably draw upon statistics proving modern superiority in life expectancy, literacy, nutrition, public hygiene, speed of transportation, equality of opportunity, and so on. In short, he would shift the argument to the arenas of quality of life and economic growth. Matthew Arnold would reply to his modern critic, as he did to Jevons, that national greatness is that quality which excites love, interest, and admiration for a nation and its deeds.

There is a great danger in assuming that cultural attainments must wait upon the fulfillment of creature comforts, that man could not study the stars, think about gods, or ornament a piece of pottery until he had a full stomach, a roof over his head, and a wall around his city. The more historians and anthropologists learn about the early history of mankind the more they are convinced that science, religion, and art were always part of human existence and not refinements cultivated after reaching a certain stage of economic stability. Neither historical nor anthropological research supports the popular view that economic necessity is prior to, and prepares the way for, the moral, intellectual, and esthetic life (*13, 14*). Therefore I for one would reject the simple correlation of energy consumption, economic growth, and civilization.

In the final analysis, it is not crucial that you accept all my criticisms of the energy-civilization equation. It is much more important that you recognize the equation as a pervasive, if often implicit, element in both popular and sophisticated approaches to energy and society. If the equation is as worthless and potentially dangerous as I think it is, then it should be exposed and discarded because it supplies a supposedly scientific argument against our efforts to adopt a style of living based upon lower levels of energy consumption. If it is a generalization of great truth and intellectual worth, then it deserves a more refined handling than it has received from its supporters to date. ■

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At the Institute

Nuclear Valve Instrumentation

Instrumentation that can be installed on power plant relief valves to give control room operators a valid indication of whether a valve is open or shut has been demonstrated by EPRI in the aftermath of the Three Mile Island accident. Technology for Energy Corp. is carrying out the research for EPRI.

A major contributing factor to the TMI accident was that operators were unaware that a relief valve (designed to open when relieving excessively high steam pressures) had not shut automatically. This new instrumentation will automatically alert plant operators if a relief valve remains open so they can prevent the unintentional escape of steam from the reactor coolant system.

The technique used in the new instrumentation is acoustic, involving electronic monitoring of the noise levels in and around the valve. Sensitive acoustic sensors, similar to microphones, are attached to each valve and can be used to distinguish between the ordinary background noise present when the valve is tightly shut and the much higher noise level when steam passes through the valve. This difference in noise level has been verified in laboratory tests and in a nuclear power plant under construction and not yet fueled, according to Gordon Shugars, manager of the project for EPRI. The technique is so sensitive that a clear distinction can be made even when the valve is only slightly open.

Because the sensors are attached to the outside of the valve, they can be installed when the plant is shut down for maintenance or refueling, thereby avoiding loss of operating time. No modifications to the valve are required and the sensors, which are available commercially, can be installed on all types of valves without their having to be disconnected and dismantled.

Further research on the causes of the TMI accident and the lessons to be learned from it has been taken over by the Nuclear Safety and Analysis Center, which EPRI has established at the request of the electric utility industry.

Voltage Reductions Examined

Voltage reductions, some requested and others mandated, are increasingly being used by public utility commissions across the country in an effort to conserve energy. But do the cutbacks really save energy, and hence the customer's dollars, or waste it?

What effect do voltage cutbacks have on the life expectancy and efficiency of household appliances, motors, and other electric loads? Despite much debate, no one really knows. To find the answers, EPRI is sponsoring a three-year, $550,000 study at the University of Texas at Arlington.

Headed by Mo-shing Chen of the university and Herbert Songster, manager of the project for EPRI, the study is aimed at obtaining reliable data on exactly how voltage cutbacks affect the utilities and their customers.

Explaining why the EPRI study is being undertaken, Songster said there may not be a direct relationship between voltage cutbacks and energy conservation. "No one really knows what the net effect of the cutbacks will be," he said. Using air conditioning as an example, Songster said a reduction in the voltage operating the appliance might mean it must run longer to produce the same level of cooling. The increased operating time might, therefore, offset any savings produced by the lower operating voltage.

Songster noted that most appliances carry a voltage rating, usually in the area of 120 volts. "That's the design value," he said, "but it doesn't mean that the appliance cannot operate efficiently at voltage above and below design—within reasonable limits."

Noting that utilities often receive reports of motor damage when emergency conditions force cutbacks in power output, even though electric motors are designed to tolerate a 10% variation in voltage, Songster said the EPRI study will also "take a look to see if the age of the motor or some other factor is the reason."

The study will be conducted in two phases. Phase 1, to be completed by August 1980, will examine how voltage variations affect the energy consumption of heating and cooling equipment and a host of other appliances, both residential and commercial.

Phase 2, to be completed by March 1982, will use the facilities of Texas Electric Service Co. and another utility to be selected from a northern state to record energy consumption, voltage, temperature, and humidity on 10 different circuits with varying load characteristics.

In the end, Songster said, the effort will provide utilities with data on how voltage cutbacks affect operations and long-term efficiencies. At the same time, it will provide scientific conclusions about the advantages or penalties for utility customers.

Levenson Testifies on Nuclear Safety

Testifying on nuclear safety systems before the House Subcommittee on Energy Research and Development in Washington, D.C., Nuclear Power Division Director Milton Levenson argued against "massive new programs to explore the unlikely" as a result of the Three Mile Island accident.

"The maximum risk [of a nuclear accident] arises not from the maximum events but from the aggregate of the lesser events," he said. Levenson based his remarks on his recent experience as chairman of the TMI Ad Hoc Industry Advisory Group, as well as his background of 35 years in nuclear R&D.

Noting that the various investigations triggered by TMI are likely to lead to some changes in nuclear plant operations and systems, Levenson professed belief that these changes "will not require extensive new developments or research into entirely new areas," but rather that "we go back into more mundane areas we once explored thoroughly but in recent years have skimmed over in our search for larger and more serious hazards with which to terrify ourselves."

To do this, he explained, "We must review our designs and plants for lesser events—for example, to make sure that containment buildings isolate on lesser accidents so that another TMI sump pump-out doesn't occur automatically." Levenson also cautioned against oversimplification of the causes of TMI by those claiming that "we just need different management" or that "better operators or more training will solve it all." TMI was a system problem, involving a very complex chain of events whose succession was triggered by both men and machines. In commenting on the man-machine interface, he noted that both are essential parts of nuclear safety systems, and safety would be maximized by remembering "it isn't only the operator and the switch he throws, but also the designer and the lines he draws, the electrician and the wires he pulls, and the regulator and the changes he permits or induces or demands." Levenson maintained that checks and balances must exist for all.

Also testifying at the hearing chaired by Congressman Mike McCormack were representatives from Combustion Engineering, Inc.; Stone & Webster Engineering Corp.; and the Environmental Coalition on Nuclear Power.

EPRI Hosts International Groups

Arnold Fickett, manager of EPRI Fuel Cells and Chemical Energy Conservation Technology (second from right), explains various energy research projects sponsored by EPRI to (from left) M. Suzuki, Mitsui and Co.; T. Hirayama, manager R&D Planning, Tokyo Electric Power Co. Participating in the discussion were Sherman Feher, EPRI planning analyst, and Edward Gillis, EPRI fuel cell project manager.

Two representatives from the Instituto de Pesquisas Technologicas (IPT), São Paulo, Brazil, meet with EPRI staff to discuss the possibility of an information exchange agreement in the energy research areas of biomass and fluidized-bed technology. R. L. Rudman (left), director of the EPRI Planning Staff, and Sherman Feher, EPRI planning analyst, explain EPRI's efforts in biomass and fluidized-bed development to Nedo Eston De Eston, adviser to the IPT board of directors, and to Marcos de Mattos Pimenta, IPT consultant.

EPRI President Floyd Culler (left) receives a pair of lacquered vases from Ye Zhi-qing (far right), senior vice minister of the Ministry of Metallurgical Industry and chairman of the board of directors of the Chinese Society of Metals. Ye led a group of eight Chinese metallurgists on a month-long U.S. tour.

L. Becka (right), director of research and development for Servicios Eléctricos Del Gran Buenos Aires and Walt Esselman, EPRI director, R&D Planning and Assessment, discuss various research projects being sponsored by the electric utility industry.

Western Coal Production

A dramatic increase in western coal production may occur in the near future, according to a report by a national group of energy analysts and policymakers, the Energy Modeling Forum (EMF). If coal production triples by the year 2000, as some economists predict, western coal production in the United States could rise from a 1975 level of 112 million tons to about 1.5 billion tons by the end of the century. In that same period, eastern coal production could increase from 500 million tons to about 1 billion tons.

These projections were developed by using results from 10 mathematical models that cover several scenarios on future energy and economic conditions. The projections from the models were compared and interpreted by EMF, which is sponsored by EPRI and administered by the Stanford University Institute for Energy Studies.

"The rise in the price of oil has improved the competitiveness of coal in all applications and thereby increased the total coal demand," according to the report. "This increased demand, environmental standards that create a cost advantage for low-sulfur western coals, and the depletion of low-cost eastern coals produce a higher rate of growth in the demand for western coals than for eastern coals."

Another key conclusion of the report is that the increase in coal production is limited by demand rather than by supply. "None of the models envision serious depletion of the coal resource base and no constraints on coal production are triggered," states the report. Furthermore, the models showed that much more could be mined for a small additional cost.

A gradual increase in the price of electricity was also projected by the models. The report states that the increased cost of electricity follows the recent inflation in power plant construction costs and the gradual replacement of lower-cost old plants by higher-cost new plants. Coupled with higher fuel prices, these factors may produce a 42% increase in real (not including inflation) electricity prices by 1985 and a 74% increase by the year 2000.

The possible environmental impacts of fossil fuel emissions were not evaluated in this study. However, the scenarios fed into the 10 models did assume utilities were meeting environmental regulations as they now exist and would continue to do so at future levels.

EMF operates through ad hoc working groups of about 35 analysts and policy makers from universities, government, and industry. These groups analyze and compare the projections from the major energy models used by electric utilities and others involved in energy analysis and policy decisions.

The need for such an organization was brought to light as a result of the 1973–1974 OPEC oil embargo, which revealed a severe lack of available data on the interrelationships between energy and the economy. EMF was created to examine the quality of existing data on this subject and to help policymakers understand how energy supply and demand affect the economy and vice versa.

The report *Coal in Transition: 1980–2000,* EPRI EA-967, is available from the Research Report Center.

Coal Emissions and Western Ecology

Western coal reserves will probably play an important part in America's effort to meet rising energy demands in the next decade. But finding ways to efficiently burn the coal without harming the environment presents a challenge.

To help meet that challenge, EPRI contracted with researchers from Colorado State University to study the effects of sulfur dioxide and other pollutants on specific natural environments, or ecosystems, in the western states.

Of particular importance, according to Robert Goldstein, EPRI project manager, is the acquisition of reliable scientific data to aid in planning and licensing new coal plants.

"Increased understanding of how gases from burning coal affect grassland ecosystems should lead to more efficient development of electric generating capacity and energy resources in the Great Plains region," Goldstein said.

The two-year project will analyze existing data to determine what is known and what remains to be answered about such questions as: What impact do sulfur dioxide emissions from coal burning have on sensitive grasslands in the plains states, such as Montana and the Dakotas? Does the concentration of the emission, or pollutant, play a significant role in the impact it has on the environment? Is duration of exposure a key factor in determining the environmental impact of emissions from coal-burning power plants?

Calendar

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

SEPTEMBER

17–21
Solar Program Review and Workshop
San Diego, California
Contact: Frank DeWinter (408) 425-1211

19–21
International Symposium on Controlled Reactive Compensation
Varennes, Quebec
Contact: Narain Hingorani (415) 855-2309

OCTOBER

16–18
Second National Symposium on Environmental Concerns in Rights-of-Way Management
University of Michigan
Contact: John Huckabee (415) 855-2589

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

Nuclear Waste Disposal

"Proceed with caution, but proceed."

This is the message EPRI President Floyd L. Culler, Jr. recently presented to a congressional subcommittee on the subject of America's nuclear waste disposal program.

Culler said that despite questions raised by the recent TMI accident, he considers an acceptable plan for nuclear waste disposal the most important issue confronting nuclear energy.

"Whether the use of nuclear energy for production of electrical energy expands, remains constant, or even is discontinued altogether," Culler told the congressional panel, "this nation must develop and implement a nuclear waste management program."

The program is urgently needed, regardless of the future of nuclear energy, he said, for two reasons: An inventory of nuclear radioactive wastes produced by military programs conducted during the past 35 years requires disposal. Existing commercial reactors produce, and will continue to generate, fuel wastes that are radioactive.

Culler said a wealth of scientific data compiled in recent years has convinced him that the basic technology for a safe waste disposal program exists today. What remains to be demonstrated are large-scale plants and facilities to provide for construction and operating experience of "real equipment, at real sites, with actual material to obtain experimental and practical data."

It's time to progress beyond "a history of paper studies and long-range problems," he commented, into practical experiments that can help produce answers to specific questions. What disposal criteria and failure-mode analysis are to be used? What linings stand up best in furnaces for radioactive glass? What kinds of handling devices are most economic and reliable? What geologic formations, through careful engineering, can be used to store radioactive wastes in fail-safe arrays?

The body of technology developed over the past 30 years suggests the adequacy of nuclear waste disposal in salt repositories in the earth, he added, as well as several other techniques for safely disposing of radioactive wastes in geologic formations.

Predicting Pollution Levels

The first phase of a research study to predict air pollution levels from coal-fired power plants was recently announced by EPRI.

The Research Corporation of New England was awarded a $1.4 million contract to manage the technical aspects of the study. Researchers plan to test the validity of computer models that predict air pollution levels near coal-fired power plants that use tall chimneys.

The effort has been initiated in response to the Clean Air Act Amendments of 1977, which authorized the use of mathematical models to verify that coal-fired power plants comply with federal air quality standards. These models have been used previously for estimating purposes, but they have not had the official sanction now given.

Glenn R. Hilst, EPRI project manager for the study, says the use of models for regulatory decisions and permits will place a premium on their accuracy and reliability. However, most of the models have not been adequately tested, he states. The study is designed to measure the actual concentrations of pollutants near several power plants and then compare these measurements with pollutant levels predicted by models. The results should lead to the development of newer and better models, as well as help verify the accuracy of existing models.

"Inaccurate models can lead to either under- or overestimating the environmental impacts of power plants," according to Hilst. "This could mean, for example, that if the models are wrong and overpredict pollution concentrations, a proposed coal plant may be denied a construction permit or be required to install unnecessary and expensive pollution control systems. On the other hand, underestimating could result in expensive modifications after a new plant has been built. In either situation there would be a needless cost for the utility and its customers."

The coal plants for this effort have not yet been selected, although they will represent various geographic areas so that a national perspective can be developed. This study is one of several research projects under way at EPRI to examine the potential environmental impacts associated with the production and distribution of electric energy.

Nuclear Energy, a Responsible Option

If America fails to develop nuclear power, the result could be long-term consequences more harmful to worldwide human well-being than any of the risks related to making use of the nuclear option.

And that, Chauncey Starr recently told a special luncheon meeting of the American Nuclear Society (ANS) in Atlanta, means the United States and other industrialized countries have an obligation to Third World countries to reduce dependence on limited oil and gas supplies by developing all alternative energy sources, including nuclear.

Starr, former president and now vice chairman of EPRI, made the remarks in accepting the American Nuclear Society Power Division's Walter H. Zinn Award, presented for "outstanding contributions to the advancement of nuclear power." It was the fourth such award ever presented by the group.

Noting the growth of Third World populations and economies, Starr told the meeting, "We perceive the threat [of catastrophe] resulting directly from the pending unavailability of petroleum and natural gas at a reasonable cost. This unavailability could lead to global tensions and political instabilities, economic crises, and ultimately, military conflicts based on the need to obtain and control liquid fuel resources. We believe that history and current events substantiate the threat

inherent in the international struggle for raw materials."

If the industrialized nations of the world make use of available nuclear energy technology, according to Starr, it will free up rapidly depleting fossil fuels for use by the developing nations. Failure to make use of the nuclear option will increase world tensions as nations grope for a share of the oil, gas, and coal reserves.

"The catastrophe that could be avoided [by making use of nuclear energy] is at least as threatening as the one projected by those who oppose the use of nuclear power," Starr continued, "and, I would argue, more realistic."

In discussing alternatives to using oil and gas, Starr said, "As a nuclear proponent, I do not view the future as either solar or nuclear. In fact, nuclear power may well be a transition fuel to a solar future, if such a future develops. But the question remains: Will such a future develop?"

If the antinuclear groups are incorrect in their assessment of nonnuclear alternatives and nuclear development is halted, the potential for massive social and political upheaval is substantial.

Noting that the focus on catastrophic risk has made nuclear opposition appear to be socially responsible, Starr said nuclear proponents have failed to bring home to Americans the fact that a concern to avoid worldwide catastrophe is central to the broader case for nuclear power.

Centennial Exhibit Available

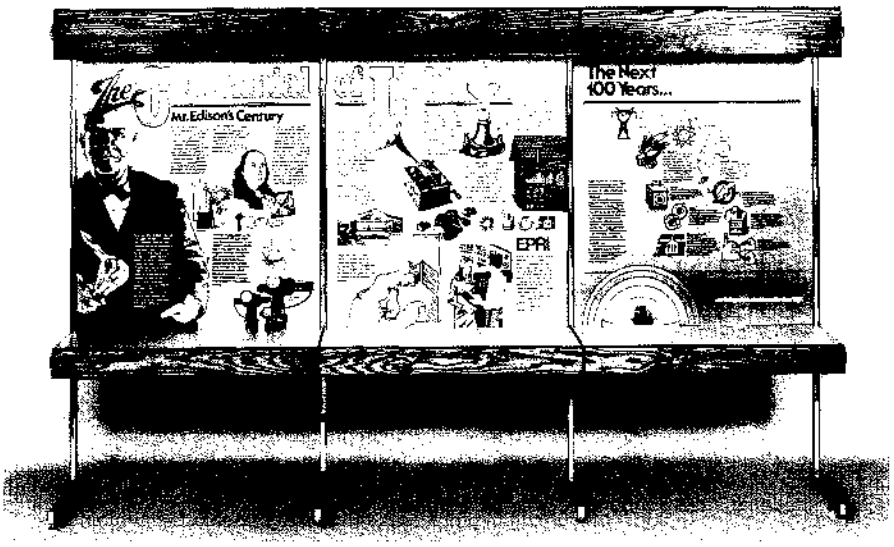
EPRI has developed a series of technical exhibits for nontechnical audiences in cooperation with design consultants Roger Tierney Associates. The purpose of the program is to inform the general public of the industry's efforts to meet the challenges posed by the shortage of oil and gas.

The exhibit structure has space for three interchangeable panels. One panel provides space for a message from the subscribing utility. Construction is of square chrome tubing, oak, and masonite. A permanent, fitted packing case is included with each exhibit structure. The header conceals a fluorescent light, and a shelf is provided for literature and distribution. Each exhibit is 12 feet wide, 8 feet high, and 22 inches deep. Two people can set up the exhibit in about 45 minutes.

Although EPRI is not involved in the production or sale of the exhibit hardware, all concepts, copy, and graphics are reviewed and approved by Institute staff.

For cost and delivery information, contact Roger Tierney Associates, Inc., 2955 McCall Street, San Diego, California 92106; (714) 222-9900.

The exhibit on technological progress highlights the Edison Centennial. A spectator-operated replica of an Edison lamp is part of the panel on the right. Other topics currently available focus on solar energy and on energy and the economy (the latter emphasizes equal opportunity). A story on coal has also been developed and will soon be available. Additional energy topics are being planned.



Washington Report

Many in Congress and DOE hope the electric vehicle will offer Americans a future transportation alternative that reduces the nation's reliance on imported oil.

Against a spring and summer backdrop of long gasoline lines, short tempers, and rising OPEC prices, Congress and the administration are accelerating efforts to develop technologies that will wean the United States from its overdependence on imported oil. One such technology receiving increasing emphasis today is the electric vehicle (EV).

Unlike conventional vehicles powered directly by petroleum, EVs are fueled by electricity stored in rechargeable batteries. Ideally, EV owners would recharge these batteries at night or during other periods of off-peak power when electric utilities have available coal, nuclear, or other forms of baseload generation. Thus, EVs would aid in diversifying energy sources used for transportation, a sector of the economy that is dependent on oil for about 50% of its needs.

Tempered enthusiasm

In Washington, D.C., enthusiasm is high for EV technology, but it is also tempered in many respects with a realistic assessment of the technology's limited potential to replace conventional vehicles.

"Electric vehicles will never be a substitute for the love affair Americans have with the internal combustion engine," admitted Congressman Mike McCormack in testimony before the Senate Transportation Appropriations Subcommittee on June 4. A sponsor of legislation enacted in 1976 that intensified the federal EV program, McCormack conceded that EVs will never be able to compete with conventional vehicles in terms of speed, range, and other characteristics. Indeed, many promoters emphasize that EVs will be used primarily for short commutes and shopping trips.

That realistic assessment of the limitations of EVs, however, is by no means tantamount to a waning of enthusiasm. McCormack, for example, urged in the Senate hearing that the country move forth "as aggressively as possible" toward the goal of commercializing EVs. He advised attendees to remember three things: EVs do work; they save oil; and they protect the environment.

"In trying to save energy in this country," McCormack observed, "the private transportation system is the most efficient way to do it."

Current legislation

The Senate hearing at which McCormack was testifying was called by Senator James McClure, also an EV promoter and sponsor of several pieces of current legislation designed to spur the technology on to commercialization. S. 624, for example, would amend the Motor Vehicle Information and Cost Savings Act to allow automobile manufacturers to include the gasoline mileage equivalent of EVs in the computation of their fleets' corporate average fuel economy (CAFE) standards, which require all vehicle manufacturers to attain a fleet average fuel economy of 27.5 miles per gallon by 1985. At the present time, only vehicles fueled by petroleum may be included in the computation of this average. McClure's bill, as well as a companion bill (H.R. 3718) introduced by Congressman Tom Corcoran, would remove this obstacle, providing an incentive to manufacturers to produce EVs.

DOE, the federal agency charged with administering the EV program, believes that such an incentive would work.

"It is our judgment that the inclusion of EVs in the CAFE standards would be a strong incentive for the major automobile manufacturers to develop and produce significant numbers of electric vehicles in the near future," stated Vincent J. Esposito, acting director of Transportation Programs in DOE's Office of Conservation and Solar Applications at the June 4 EV hearing. DOE now estimates that some 8.6 million vehicles may be in the nation's transportation fleet by the year 2000. The added CAFE incentive would increase that number to 12 million, according to Esposito.

In addition to S. 624, legislation has been introduced by Senator McClure to provide a 10% tax credit, up to $1000, for the purchase of an EV or retrofit of a conventional vehicle to EV technology. A similar bill has been introduced in the House by Congressman Charles E. Grassley.

Federal program

The federal EV program was established by the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976. (A hybrid vehicle combines features of conventional and electric vehicles.) The 1976 legislation authorized funding of $160 million over a five-year period for a comprehensive program geared toward commercialization. Among the activities authorized

were R&D to improve EV performance; procurement and demonstration of up to 7500 EVs; and incentives such as loan guarantees and planning grants for small businesses to produce EVs. The original legislation was amended by the DOE Act of 1978—Civilian Applications—to extend the demonstration schedule two years (from 1984 to 1986) and to increase the number of vehicles to be demonstrated from 7500 to 10,000.

The EV program includes demonstrations in the private sector, as well as in federal agencies, universities, and state and local governments. DOE shares the costs of the program, but the site operators in the various sectors own and maintain the EVs.

Demonstrations in the private sector were the first to get under way during 1978. Five organizations were selected by DOE to purchase and demonstrate a total of 165 EVs: American Telephone and Telegraph Co.; Consolidated Edison Co. of New York, Inc.; Long Island Lighting Co.; EHV Distributors (Penn Jersey Subaru Inc.); and Walt Disney World Co. Five federal agencies also participated in the first round of demonstrations in 1978 with a total of 35 vehicles.

In mid-April of this year, DOE announced the first participation of state and local government organizations. Nine agencies were selected to demonstrate a total of 200 EVs over the next four years, including cars, vans, and light trucks.

The direction of DOE's demonstration program was examined by the General Accounting Office (GAO) this spring. Its report made several key recommendations, primarily that future private-sector demonstrations be postponed "until commercially viable [electric] vehicles become available." Until then the report notes, "program emphasis should be placed on demonstrating EVs in the federal sector."

GAO notes that DOE has been emphasizing the private sector "because it believes the private sector will have the greatest effect on the commercialization process and that is where the success of the program will be determined." However, GAO maintains that it is too early to demonstrate the vehicles in the private sector and such premature demonstrations could adversely affect commercialization. Citing the limited performance of today's EVs and their high costs, the report notes that DOE "may be placing vehicles in uncontrolled situations where any such failures will be highly visible and could damage public acceptance of more advanced vehicles when they become available." The agency further stated the belief that the federal sector would constitute a more controlled environment for such demonstrations at the present time.

GAO's report also recommends that DOE's R&D program for EVs be strengthened. Noting, for example, that "improving battery performance is one of the most important steps toward developing an electric vehicle that is commercially viable," the report recommends that DOE redirect its battery R&D funding to emphasize advanced battery concepts as opposed to currently available lead-acid batteries. "For various reasons, we believe DOE's research on lead-acid batteries is an ineffective use of limited R&D funds," the report notes. "According to several studies, lead-acid batteries will not have the performance capabilities to achieve widespread EV commercialization." According to the GAO report, DOE plans to spend $7 million on lead-acid battery R&D over the next three years.

Milestones

This year DOE's EV program reached several milestones in technology improvements.

In early May the agency introduced four EVs designed and built specifically for the program, incorporating improvements available in existing, off-the-shelf technology and components. The vehicles were a pick-up truck designed by Battronic Truck Corp. of Bayertown, Pennsylvania, initial price $18,500; a four-passenger car designed by Electric Vehicles Associates, Inc., Cleveland, Ohio, initial price $15,500; a multipurpose van, designed by Jet Industries, Austin, Texas, initial price $12,500; and a two-passenger car designed by South Coast Technology Corp., Inc., Santa Barbara, California, initial price $15,500. (DOE notes that all initial prices quoted are for individual vehicles and that fleet prices could be considerably lower.)

In introducing the vehicles, Omi Walden, assistant secretary for Conservation and Solar Applications, pointed out that their performance improvements represent a step forward in terms of speed, acceleration, safety, and maintenance. The vehicles are designed to accelerate from 0 to 30 mph in 10–11 seconds, compared with 13–15 seconds for existing EVs, and their maximum range is 40–60 miles in stop-and-go driving, compared with about 30 miles for current EVs. The vehicles are now undergoing acceptance testing at the U.S. Army Mobility Equipment Research and Development Command in Ft. Belvoir, Virginia.

In late June DOE unveiled the first of two advanced, experimental electric test cars. Known as Electric Test Vehicle—One (ETV-1), the four-passenger, subcompact car was built by General Electric Co.; Chrysler Corp. provided some of the components and styling and Globe Union Inc., the high-energy batteries. According to DOE, the car was designed so it could be mass-produced for about $6500 (1979 dollars) by 1985. Advances include computerized control systems; lightweight body materials; low-cost, high-current power transistor modules to control motor speed; and batteries with 25% higher energy and longer life.

DOE notes that computer performance projections indicate ETV-1 has a 100-mile driving range at speeds up to 45 mph with two passengers. With a full load of four passengers, it has a range of 70 miles in stop-and-go driving and more than 115 miles when driven at a constant speed of 35 mph.

This fall DOE expects to receive delivery of the second advanced experimental test car, which is being designed by the Garrett Corp.

Research on Foundation Systems

by Phillip Landers

Current design techniques generally overcompensate for foundation movement and thus inflate construction costs.

Figure 1 Construction of a typical pier for transmission line towers consists of augering a hole, inserting an anchor bolt cage, and backfilling the hole with concrete. This particular cage is 14 ft long and weighs more than 5000 lb.

Tower foundations account for a significant portion of transmission line construction cost. Therefore, economies in this area should be sought, while avoiding any compromise in the strength and integrity of the transmission line itself.

A variety of foundation systems may be used, depending on the type of superstructure to be supported and the soil in which it is embedded. These systems may be as simple as a hole in the ground to accommodate the butt of a wood pole or as complex as an array of reinforced concrete piles to support a massive steel lattice structure. With the cost of constructing transmission lines ever increasing, it is imperative that electric utility engineers and designers are provided with the best possible design tools to ensure high reliability at minimum expense.

The design of foundations is not a new problem for structures such as bridges and buildings where all conditions of soil and load are fixed. But foundations for transmission line structures present some radically different problems. Unlike foundations for buildings and bridges that must support the enormous dead loads from concrete and steel superstructures, transmission line structures must resist sizable live loads (such as wind, ice, and broken conductors), and they receive relatively little help from the small dead loads involved.

Buildings can be designed for subsurface soil conditions encountered at one particular site. Transmission lines, however, often extend hundreds of miles and encounter numerous soil conditions along the route. As a result, the subsurface soil investigations for transmission lines make up a greater percentage of the overall cost than do those for other structures.

Techniques presently available for designing foundations capable of supporting structures subjected to high compressive loads are generally well understood, technically advanced, and well implemented in practice. This can be attributed primarily to the research conducted in other areas of the building and construction industry. However, techniques for designing foundations for high-moment and uplift loads unique to transmission structures are not as well advanced or understood.

High-moment foundations are generally associated with single-pole structures and longitudinally loaded H-frames. Uplift/compression foundations are generally associated with transversely loaded H-frames and multilegged lattice towers.

EPRI's emphasis is on improving design methods for high-moment foundations; subsequent projects will address the problems associated with uplift/compression foundations.

Drilled pier research

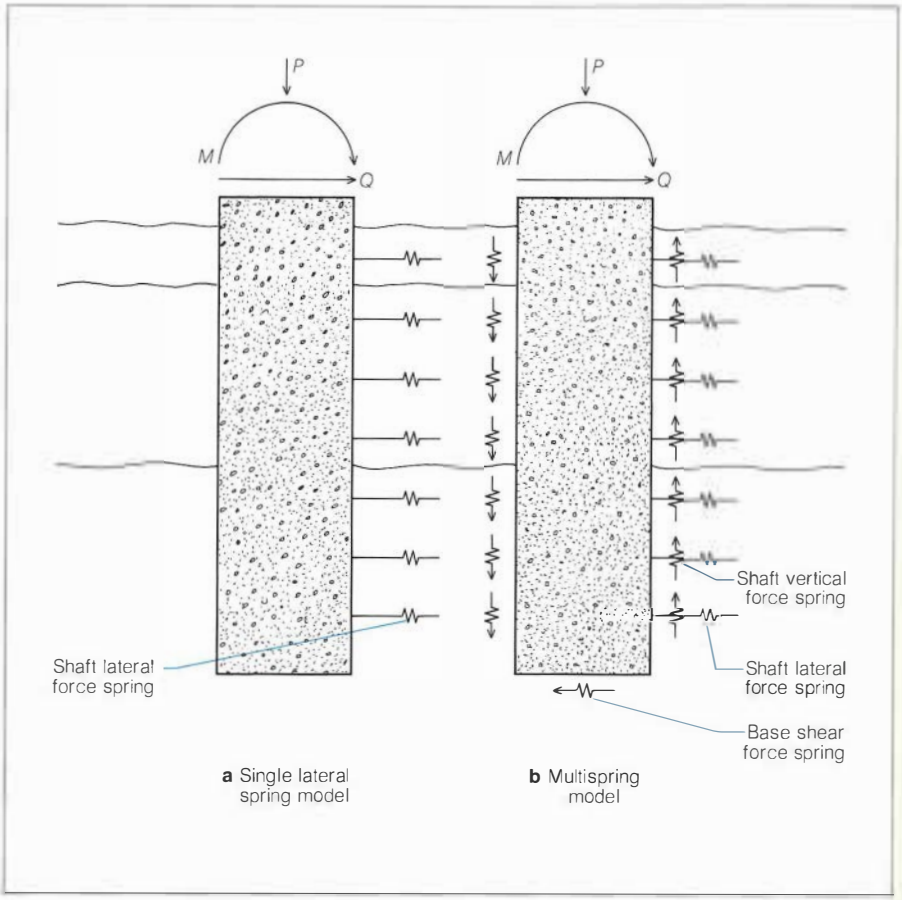
In recent years the drilled pier foundation (Figure 1) has become popular with electric utilities because of its simplicity of construction and its resistance to both high overturning moments and uplift/compression loads. This type of foundation is particularly well

Phillip Landers is a project manager in the Overhead Lines Program in EPRI's Electrical Systems Division.

suited to single-pole, H-frame, and lattice tower structures. To provide the utility industry the earliest benefit from this research, EPRI decided to direct its effort toward improving design methods for drilled piers that are subjected to high overturning moments. Thus RP1280 on laterally loaded drilled pier research with GAI Consultants, Inc., is intended to develop an improved analytic model for predicting the behavior of drilled piers subjected to high overturning moments and verify this model by performing full-scale, destructive field tests on drilled piers, fully instrumented and installed in a wide variety of subsurface soil conditions.

Many current methods for designing drilled pier foundations for high overturning moments use a simple model (Figure 2a) as a common starting point. This is a rigid shaft, embedded in an ideal, elastic soil, subjected to a relatively small vertical load *P*, a moderately high shear *Q*, and a very large moment *M*. As the drilled pier shaft begins to rotate under the load, its movement is restrained by the various levels of soil, which are modeled as elastic lateral springs. Present design techniques differ in the methods used to select the spring characteristics that best represent the way the soil will respond to this load. In selecting these soil characteristics, the designer must consider a number of variables: Is the soil granular or cohesive? Are the soil conditions uniform or are there many levels (which can vary from loose sand to hard rock)? Is the shaft of the drilled pier rigid or flexible? What model will incorporate all these variables?

Figure 2 The single-spring lateral model (**a**) is typically used to design drilled pier foundations for high overturning moments. These techniques have been found to overpredict foundation movement by a factor ranging from three to five. The multispring model (**b**) will allow better predictions of the behavior of drilled piers subjected to high moments in a wide variety of soils.



Design tool one: a practical model

Through the years many analytic models have been developed, each of which represented a different design approach. However, most of these analytic models were developed to represent ideal conditions and, in some cases, were verified only by laboratory-scale testing or by very limited full-scale testing. As a result, current design techniques generally overcompensate for foundation movement. (Designs may be overly conservative by a factor that ranges from three to five.)

If a method can be developed that will accurately predict this movement, it may be possible to reduce the size of the foundation required and thus reduce significantly the cost of the line.

In the present research, a three-dimensional model, is being used to develop an improved way of predicting load-displacement relationships for drilled pier foundations. A multispring model (Figure 2b) will be used to predict the behavior of drilled pier foundations in the wide variety of soil types. Before utilities can put this method into practice, it is imperative to verify the design by full-scale destructive testing in a wide range of soils. Twelve utilities across the country are participating in this full-scale testing: Allegheny Power System, Inc.; Arizona Public Service Co.; Baltimore Gas and Electric Co.; Bonneville Power Administration; Carolina Power & Light Co.; The Dayton Power and Light Co.; Jersey Central Power & Light Co.; Oklahoma Gas and Electric Co.; Southern California Edison Co.; Union Electric Co.; Utah Power & Light Co.; Virginia Electric and Power Co.

To ensure uniformity, a geotechnical engineer from GAI will work with each participating utility to monitor soil borings, classify soil and rock samples, conduct soil pressure meter tests, and design the drilled pier to be tested. A specially designed steel pole will be used to apply the load to the foundation. This method will ensure that the load transferred to the foundation during the test is similar to field conditions. Parameters that will be measured during each test include foundation movement at groundline, rotation of the foundation, internal loads in the foundation, and loads transferred to each soil level.

The initial shakedown test for this program was held on April 25 and 26, 1979, on a section of Duquesne Light Co. right-of-way in Pittsburgh, Pennsylvania. Engineers and designers, representing the participating utilities, took part in evaluating the test. With their help and field experience, future field-testing problems were minimized.

The field-testing program is scheduled to be completed by the summer of 1980, with eight tests in 1979 and four in 1980. This permits verification of this improved analytic method by fall 1980, after which the final report will be published. The results will be presented in a form directly usable by electric utility engineers and designers.

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

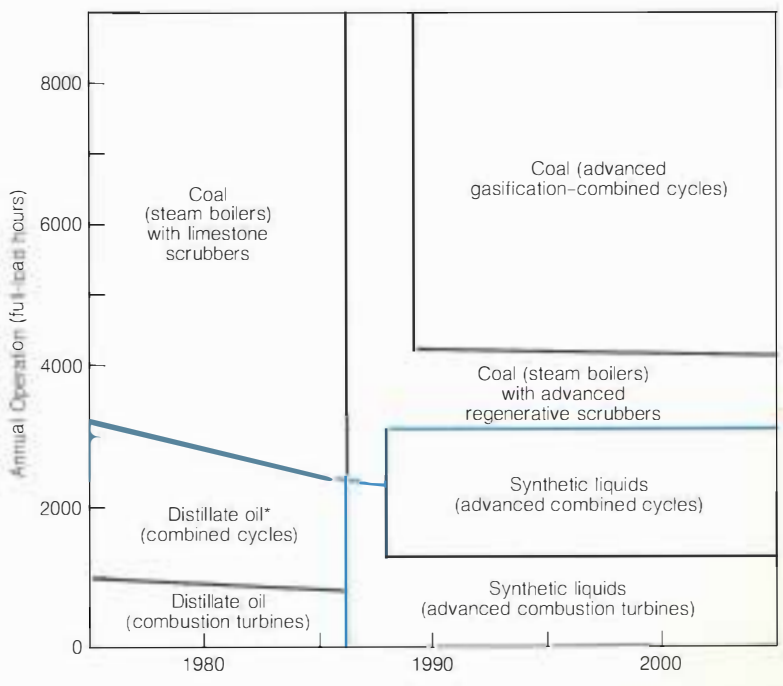
EVALUATION OF GENERATION ALTERNATIVES

More than a dozen new fossil fuel and advanced power-generating options are being funded by the Fossil Fuel and Advanced Systems Division. Many appear promising. To coordinate technical review, economic analysis, and consideration of intangibles, a division-level Program Integration and Evaluation office was established in 1977. This office has built on methods of assessment described in the May 1978 EPRI Journal *(pp. 19–26), "Market Potential for New Coal Technologies."*

Using utility system planning techniques for R&D assessment has been recognized as necessary since such work was started at EPRI in 1975. EPRI needs a view of generating options from the perspective of utilities if it is to responsively conduct R&D on their behalf. However, utility planning concentrates on selection of the next generating plant, while the problem of developing new alternatives spans the foreseeable future and requires definition of the role these new alternatives may play.

The fossil fuel generation additions that appear to promise reduced costs of electricity, according to data prepared for the June 1978 *Technical Assessment Guide* (PS-866-SR), are shown in Figure 1. The figure shows break-even capacity factors between economic alternatives as horizontal or sloped lines. All these plants are designed to meet 1976 New Source Performance Standards for sulfur emissions (1.2 lb $SO_2/10^6$ Btu). This diagram for the East Central United States updates a similar one shown in the May 1978 *Journal* article (p. 24).

Figure 1 The relative competitiveness of mature, fossil-fueled generating alternatives in the East Central United States. Initially, coal-fired units compete at capacity factors previously best served by oil-fired units. Synthetic fuel and advanced combustion turbines may stabilize the peak and intermediate load market. Similarly, scrubbers producing throwaway sludge may be displaced by advanced regenerative scrubbers. Finally, coal gasification–combined-cycle plants may take over the baseload fossil market. Other generating alternatives that appear close to being economically competitive include fuel cells, fluidized-bed combustion, and magnetohydrodynamics. Energy storage, solar, and nuclear options are not shown.



*The 1978 Fuel Use Act largely eliminates new oil-fired, intermediate load generation.

Two improvements have been incorporated in analyses conducted since then: estimates of plant costs have been increased to account for the effect of generating-unit reliability on utility requirements for reserve capacity; and escalation in fuel and operating expenses have been reflected in electricity costs by using 30-year levelization (life-cycle costing) rather than 10-year levelization. The reliability adjustments favor modular facilities, such as combined-cycle plants. The life-cycle costing penalizes technologies that are subject to high escalation rates, such as those using oil, which is expected to be priced very high in the future. In the

updated diagram, the same technologies emerge as economic as in the earlier diagram, and the relationships are similar.

The technologies that survive economic screening are then carried into generation expansion studies on six broadly representative, hypothetical utilities (EM-285). The expansion analysis determines an economically optimal plan of generation unit additions. This approach facilitates consideration of many tangible features of new and existing generation alternatives as they would interact in competition with each other, not just with respect to present commercial types of generation. Hence, the procedure can help estimate the incentives offered by each option and thus help determine EPRI's relative R&D emphasis.

Recently, a validation study for this method was completed by system planners from six utilities (RP991): American Electric Power Service Corp., Iowa-Illinois Gas and Electric Co., Middle South Services, Inc., Niagara Mohawk Power Corp., Pacific Power & Light Co., and Philadelphia Electric Co.

In March 1978 Power Technologies, Inc., was retained to identify utilities appropriate for the validation study, to develop a set of cases to be run, and to prepare a report consolidating and interpreting the results developed. EPRI solicited utilities to participate on the basis of similarity to one of the hypothetical utilities, difference from each other in planning methods, and geographic location. The six companies listed above accepted and the resulting report is now being completed. Each participant was charged with (1) implementing the corresponding hypothetical utility data on its planning computer programs; (2) screening technologies and performing expansion studies, using its own procedures and incorporating economic premises from the June 1978 *Technical Assessment Guide;* and (3) repeating these cases, using its own economic premises, including fuel costs and escalations.

In both sets of cases, the utilities used regionalized cost and performance data for generating technologies, as supplied by the EPRI Program Integration and Evaluation office. Two utilities used data from the same hypothetical utility, and two companies used the same set of regionalized technology data. Computations for Iowa-Illinois Gas and Electric Co. were performed by Black and Veatch Consulting Engineers, while Westinghouse Electric Corp. prepared material under the guidance of Pacific Power & Light Co. The utility studies came to several major conclusions that support EPRI evaluation techniques.

- The existing mix of generating units strongly affects the selection and timing of new types of generating plants.

- Considerable dollar savings result from the adoption of advanced, economic alternatives, but these savings represent only a few percent of a utility's future revenue requirements.

- Regionalization of plant costs has only a minor impact on new plant selection.

Existing and planned nuclear units help determine the window for coal gasification–combined-cycle plants because both systems compete for baseload duty. For utilities having nuclear capacity that exceeds their minimum annual load or having coal and nuclear units that together provide more than about 70% of the utility's capacity, the adoption of gasification–combined-cycle systems may be delayed. In the same way, existing hydroelectric generation in the West will affect selection of additions in that region for several more decades.

Using the more economic generation options through the study period (1985–2005) results in savings that considerably exceed the sums being spent to develop them. Customers, however, may see only a few cents' reduction in electricity bills during this period because most of the new technologies emerge in the expansion plans when they are just marginally less expensive than conventional technology. Greater benefits will accrue later, but not before technology introduction costs are underwritten. The motivation for research rests largely on environmental and resource availability issues. Research also represents a hedge against fuel cost escalations that are higher than anticipated.

Regionalization of power plant costs, such as those for labor rates and productivity and for enclosed construction, makes little difference in the comparison of alternatives.

A number of insights emerged as a result of the studies.

- Many combinations of the more economic generation alternatives lead to acceptable expansion plans. For utilities, this allows considerable latitude in the way facilities are expanded. For the developers of new types of generation, it means that market size may vary over a substantial range.

- The 1000-MW nominal unit size used in studies of many generating alternatives is too large. Such an addition to the EPRI synthetic utilities disrupts the objective of meeting a loss-of-load-probability criterion. Lower growth projections delay the need for large units. Increased costs require tighter adherence to annual growth increments. An expedient is to presume construction of generating units shared among several owning utilities. This approach enables use of currently available cost and performance estimates for large units until data are assembled for smaller units.

- Unit reliability estimates appropriate for utility evaluation of generating units are different from those needed for research evaluations. Utilities can use historical unit reliability data in their evaluations of the next generating unit, while EPRI needs to account for research to improve reliability of current technology when setting reliability targets for new technologies. Hence EPRI conducts its evaluations presuming ultimate unit reliabilities, while utilities use unit reliabilities based on current experience.

An evaluation of intangibles was included in the study. Not all characteristics of a technology fall within the framework of an economic analysis. Many environmental considerations, resource impacts, and siting factors can be considered as intangibles. To bring these considerations into perspective, 30 intangible characteristics of each technology were ranked relative to those of conventional generation by the Program Integration and Evaluation staff. Simultaneously, the participating utilities independently identified the relative importance to their purchase decisions of each of the 30 intangible characteristics by weighting them. Combining the technology rankings with the utility weights revealed the following.

- The preference order of the technologies with respect to intangibles was reasonably aligned with the order of economic attractiveness, implying that the same technologies may be favored whether quantitative or qualitative factors dominate the purchase decision.

- The preference order of technologies was almost identical for each utility, even though weights on individual characteristics varied.

- The evaluation of intangibles provided an effective means for communicating the good and bad features of each type of generation.

The similarity in the preferences of the participating utilities was not anticipated. It can be rationalized, however, by the premise that the objectives of each utility are very similar. The utilities differ mostly in terms of the proportion of generating types among their current facilities. These differences

reflect the fuels available in each utility's region of the country.

The participating utilities show strong interest in ranking technologies by intangibles as a way to address concerns that have become dominant over the last decade.

The project indicated that EPRI procedures provide results that are similar and comparable to those of the participating utilities. This validation has shown that many different planning procedures and perspectives tend to produce the same set of preferred new options. Also, the study provides utilities with generic information on the relative value of new technologies, which is useful for preparing license and permit applications for new generating facilities. *Project Manager: Oliver Gildersleeve*

THERMAL ENERGY STORAGE

A 1976 EPRI report (EM-264) identified thermal energy storage (TES) as one of a few technologies with near-term potential for use as a large, centralized utility energy storage device, putting TES in a league with pumped-hydro and compressed-air storage. In response to this preliminary finding, a more detailed evaluation of central station TES was initiated and has recently been completed. The results raise considerable doubt that utilities would be willing to accept the economic and operating limitations of a TES power plant when other alternatives are available.

The idea of storing heat for subsequent power generation was probably conceived long before the first U.S. patent on a steam accumulator was issued in 1873. But it was the invention of the steam accumulator that made practical use of the concept possible. By 1920 both variable- and constant-pressure steam accumulators had found applications in balancing the supply and demand for heat in industry, and an accumulator supplying peaking steam to a turbine-generator had been used in a German power station. However, with the rapid development of steam power plants to much higher pressures and very large unit sizes, the use of accumulators as storage devices for peaking duty quickly became difficult and prohibitively expensive. Next, pumped-hydro storage and gas turbines provided attractive solutions to the peaking-duty problem for many utilities. Then came the Arab oil embargo of 1973. The resultant shortage of gas turbine fuel and a steadily increasing resistance to the siting of aboveground pumped hydro reignited interest in other ways to store energy, including TES.

In recent years dozens of innovative schemes for using TES with steam power plants have been advanced in the technical literature. When cost and performance projections were included in such investigations, it was almost invariably concluded that the particular TES concept presented could be cost-effective in the production of peaking power. However, all these studies were very limited in engineering detail. None of them adequately considered the implications of modifying today's highly evolved power plant designs so as to be suitable for integrated operation with TES. Clearly, a more comprehensive engineering analysis was needed to develop practical designs for integrated TES–power plant operation and to provide the basis for a consistent economic evaluation of the many proposed TES concepts.

Technology assessment

Recognizing that need, General Electric Co. initiated a study in late 1977 to determine which of the TES concepts would offer the best prospect for utility acceptance and possible commercial use in the near term (RP1082-1). This $475,000 project was cosponsored by DOE and EPRI, with NASA's Lewis Research Center managing the DOE portion. Over 40 TES concepts were identified in the first phase of the 18-month study. An extensive screening process (EM-1037) reduced the field to four integrated TES–power plant system selections for further analysis:

- Storage of pressurized high-temperature water (HTW) in steel-lined underground spherical caverns (serving as a large accumulator), integrated with a coal-fired plant to supply peaking steam.
- Aboveground dual-media heat storage in atmospheric tankage (oil-rock or molten salt–rock), integrated with a coal-fired plant to provide peaking steam generation.
- Storage of preheated feedwater in prestressed cast-iron vessels to provide peaking capacity through reduction of peak period extraction of turbine steam in a nuclear plant.
- Dual-media heat storage for peak period feedwater heating in a nuclear plant.

In the second phase, fully developed conceptual designs, performance calculations, and detailed capital cost estimates were prepared for each of the four TES power plant concepts. All designs were based on an eight-hour, off-peak period for charging the TES system, and they included sufficient storage capacity to provide six hours of peaking generation.

With the designs developed for a 740-MW coal-fired plant, about 400 MW of additional peaking capacity was obtained through separate peaking turbines operating on steam produced from storage. In addition to the need for an added peaking turbine with its associated condenser and heat rejection equipment, the use of TES with the fossil plant required some major changes in the fossil plant design. The first was the elimination of the boiler steam reheater, a consequence of using large amounts of high-pressure turbine exhaust steam to charge the TES system. Without reheat, the 3600-rpm, tandem-compound main turbine had to be replaced with one of a 3600/1800-rpm, cross-compound design to cope with the much higher moisture content in the low-pressure turbine stages.

In the two 1100-MW nuclear plants, TES could provide an additional 150 MW of peaking capacity by taking over most of the peak period feedwater-heating duty. Although the nuclear reactor–steam generator design need not be modified with this TES concept, the turbine-generator rating and cooling capacity must be increased significantly, and the turbine itself must be completely redesigned to handle large variations in extraction steam flows.

In terms of both the added TES peaking capacity and the heat rate for the additional peak period energy produced, the fossil plant with underground HTW storage (the steam accumulator) clearly emerged as the preferred choice. The incremental cost for this TES peaking power, including necessary modifications to the original coal-fired plant design to permit TES integration, would be about $690/kW (1976 dollars), and it would deliver peaking energy to the grid at a heat rate of 12,150 Btu/kWh. The closest competitor to HTW TES was the coal-fired plant with dual-media (oil-rock) TES, at a cost of nearly $750/kW and a heat rate of 14,700 Btu/kWh. Both nuclear TES feedwater-heating options had higher heat rates and cost estimates exceeding $1000/kW.

Economic assessment

The possible benefit of using TES in a future utility generating mix was examined by comparing the annual revenue requirements for a system expansion that includes TES power plants with those for expansions that use alternatives to TES. This comparison was made for expansion of a utility system repre-

sentative of the northeastern United States and for two variations having different proportions of oil-fired gas turbines and coal-fired plants designed for daily cycling, these variations being available alternatives to TES. A review of the results leads to several interesting conclusions, all referenced to the underground HTW TES design.

- Economic competitiveness between TES and cycling coal plants is very sensitive to system generation mix.
- TES capital cost reductions of 10–40% would be required before TES could compete with cycling coal plants.
- TES cost reductions of 40–50% would be required for TES to compete with gas turbines at 1500 hours of annual operation.
- At the currently estimated capital cost, TES would become competitive with gas turbines only when the fuel price difference (gas turbine fuel versus coal) exceeded $\$3.6/10^6$ Btu (1976 dollars).

More than 50% of the estimated cost of the HTW TES concept is tied up in the rather conventional equipment needed for the transport of heat to and from storage (piping) and for the conversion of stored heat to electricity (the peaking turbine). The possibility of substantially reducing the total TES cost by reducing the cost of such equipment is very limited. Consequently, if TES is to compete with cycling coal plants, the element storing the heat (the accumulator, in this case) must be nearly cost-free; but the possibility of fulfilling this requirement is virtually nil.

The results of this engineering project indicate that TES is not an acceptable near-term option for large-scale utility energy storage. R&D in the Energy Storage Program will continue to focus primarily on pumped hydro and compressed air for centralized storage applications and on batteries for the equally important, smaller, dispersed applications. *Project Manager: William A. Stevens*

PLANT RECIRCULATING WATER CHEMISTRY

*An earlier report on EPRI's Water Quality Control Program alluded to several crucial water-related issues facing the electric utility industry (*EPRI Journal, *August 1977, p. 50). Water conservation and effluent discharge are two of the issues that have substantial effect on steam electric generating stations. Environmental Protection Agency (EPA) regulations directed at plant cooling-water circuits have necessitated changes in the design and operation of such systems. Consequently, these factors have prompted new water chemistry studies.*

Makeup water for the cooling-tower system represents by far the largest single demand for this resource in power plants, where approximately 10–15 gal/min (631–946 cm^3/s) of makeup condenser cooling water is required for each megawatt (electric) of net generating capacity. This amount represents roughly 80% of the total plant consumptive water demand. Depending on the specific quality and level of treatment for proper conditioning of the makeup water, volumetric blowdown rates from these towers may be significant.

Some of the constraints encountered in the design of cooling-tower recirculating systems are attributable to regulations on aqueous plant discharge, the high cost of blowdown treatment, and the uncertain performance of available water treatment methods. Designs of closed-cycle plant heat rejection systems are similarly restrained by these same parameters.

Under the Federal Water Pollution Control Act of 1972, EPA promulgated a set of effluent guidelines and standards for steam electric generating stations (October 1974) that stipulated discharge limits for specific chemical constituents in the various plant liquid effluent categories. Restrictions on the blowdown from closed-loop cooling waters provided the primary impetus for raising the concentration factor within the towers to minimize such emissions and, accordingly, the quantity of makeup required. The concentration factor is usually defined as the concentration of soluble salts in the process water relative to that in the makeup water. Specifically, the controlling chemical constituents for cooling-tower blowdown included chlorine, which is a biocide, and zinc, chromium, and phosphorus, which are components of compounds related to mitigation of scale deposition and corrosion.

New EPA regulations are being proposed this year for 129 selected toxic substances, commonly known as priority pollutants, and revised plant effluent limitation guidelines that will encourage the use of recirculating cooling-water system designs with yet higher salt retention levels.

Another design consideration pertains to the cost of processing the cooling-water blowdown for disposal. The total installed cost for the retention of plant waste water in suitably lined solar evaporation ponds is purported to average about $50,000 per acre of pond surface. Ostensibly, processing 100 gal/min (6309 cm^3/s) of wastewater at a site exhibiting a 1-gal/min (63.1 cm^3/s) per acre annual average evaporation rate would translate to an expenditure in the neighborhood of $5 million for the construction of ponds. An alternative is to employ vapor recompression distillation, but this is also a very costly solution.

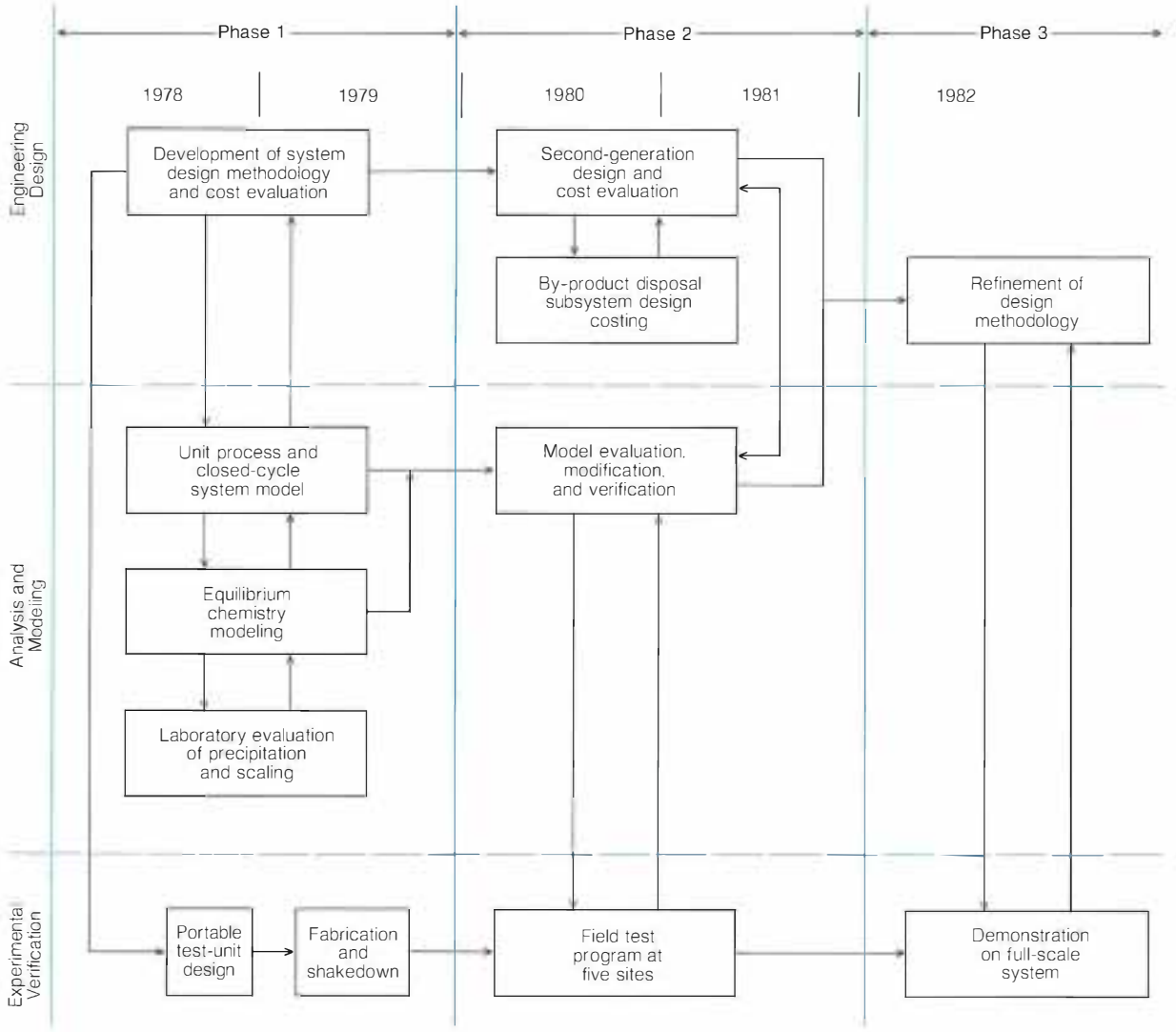
Finally, there are reliability and performance uncertainties regarding available treatment options. High salinity, the introduction of chemical additives, poor-quality source water, and other site-specific features may adversely affect the predictability of performance variables for suitable treatment processes.

Thus, cooling-water chemistry presents key problems in optimizing plant design. Curbing excessive water consumption, ameliorating the aqueous waste discharges to natural receiving waters, and maintaining plant cooling-water quality for maximum condenser heat transfer efficiency are the overall goals of EPRI's water management research. The results of a project conducted by Water Purification Associates to develop a comprehensive, integrated water management methodology for coal-fired power plants (RP909) stimulated new projects focused on individual areas critically affecting plant water management.

One of these new projects addresses the means by which closed-cycle cooling-water chemistry can be properly controlled (RP1261). In a power plant, simultaneous control of salt deposition, corrosion, and biofouling in circulating cooling loops is paramount for sustaining optimal condenser performance and avoiding costly maintenance shutdowns. Conventional means of control have relied on the use of high blowdown rates, chemical additives that alter the cooling-water characteristics, and/or treatment of makeup water. Because of the prohibitive cost of treating plant discharge in order to comply with current federal regulations, these conventional methods alone may be insufficient in an increasing number of cases.

Alternative approaches are available. Chemistry controls directed at the removal of adverse aqueous constituents in the loop would not only be desirable but also more effective than discharge treatment. Thus, the recirculating water is treated rather than merely conditioned chemically to achieve an acceptable quality. The fundamental objectives of this comprehensive project are to produce a verified treatment design procedure for water quality control in condenser

Figure 2 Major project elements for development of closed-cycle water chemistry control methodology.



cooling-tower circuits, a computer code that simulates circulating-water chemistry and its control, and operational guidelines for the operating utility to ensure its proper implementation of the design procedure.

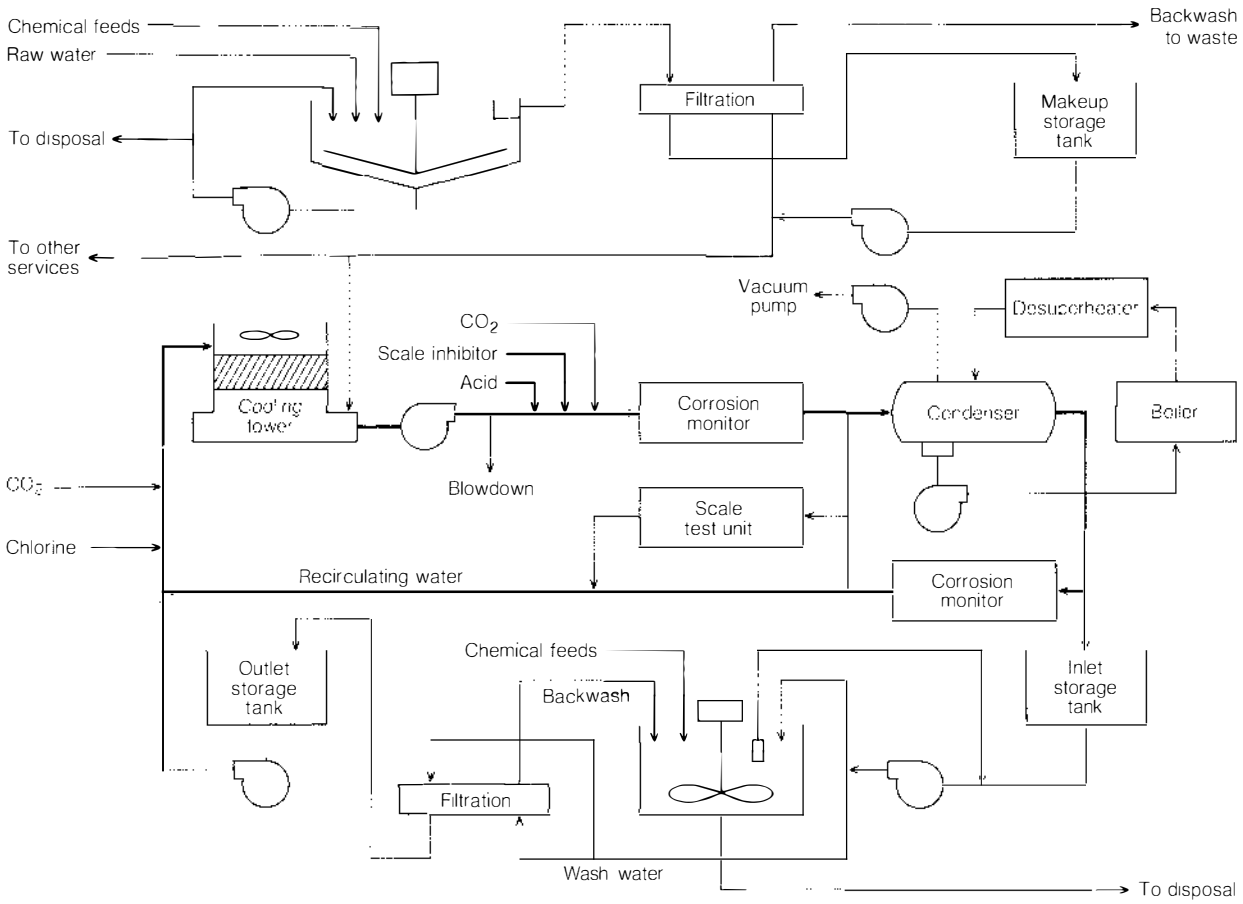
Several benefits are anticipated from this approach. While the alternative control methods selected will improve cooling-system performance, the results of this project will also serve to reduce the importance of water as a major siting constraint by attenuating makeup demand, permit the consideration of lower-quality water as a supply source, and minimize utility dependence on chemical additives.

RP1261-1 has been divided into three sequential phases of work: engineering design activities, analytic and modeling support, and experimental verification of the previous two phases (Figure 2).

Phase 1 is nearing completion. Stearns-Roger, Inc., the prime contractor, is coordinating and guiding the development of an engineering design methodology for cooling-tower recirculating water treatment. A number of system configurations will be compared on the basis of economic and technical performance. Only those representing the best composite evaluated results will be considered for field testing in the succeeding phase of the project.

To support this effort, Radian, Inc., will provide analytic and mathematical-modeling expertise for defining and describing the cooling-system equilibrium water chemistry, the heat and mass transport phenomena, the individual performances of treatment options, and the general effects of chemical additives. Codification of these detailed de-

Figure 3 Pilot-scale field-test facility for validating preliminary design methodology.



sign and performance computations into digital computer routines will offer the ultimate user, whether it be the technical designer or plant personnel, the capability and confidence to evaluate treatment and operation alternatives. The program will unequivocally improve and refine current design methods and enable prediction of adverse chemical and process conditions within the cooling loop.

Also as part of Phase 1, Resource Conservation Co. (RCC) will design, fabricate, and assemble a portable pilot-scale facility (Figure 3), which would duplicate, to the greatest possible extent, the design of an actual utility power plant circulating water system. The basic system will also incorporate the makeup and sidestream treatment units. This pilot plant facility is designed for a nominal circulating flow rate of 100 gal/min (6309 cm^3/s) and a system makeup flow rate of 1.5–3 gal/min (94.6–189.3 cm^3/s). Capability exists to vary the condenser inlet water temperature from 4.4°C to 33.5°C (40–92°F). The sidestream treatment test system will be a batch operation, designed with 1.08–3.8 gal/min (68.1–239.7 cm^3/s) capacity. With the flexibility to incorporate several additional options, such as reverse osmosis or electrodialysis, the facility can accommodate a range of typical inlet water chemistries for evaluating varying elevated cycles of concentration. Hence, this test unit will not only generate supplementary experimental data in support of the analytic modeling task but also help validate and qualify the predefined design methodology.

After the required tools and documentation have been generated, the obvious next step is to seek confirmation or refutation of the design methodology. Pilot-scale field testing of RCC's test unit at five different sites across the country has been proposed as part of Phase 2 to resolve this question of validity. The test sites selected will encompass a broad range of water qualities, meteorological characteristics, and plant-operating anomalies. This approach will alleviate, if not eliminate, design uncertainties and identify definite points and conditions of system failure, such as condenser scaling propensities, for the range of available makeup waters with and without treatment.

The Phase 2 on-site testing will span approximately 2½ years, commencing early next year at Public Service Co. of Colorado's Comanche Station, situated near Pueblo, Colorado.

Phase 3 of this project will consist of demonstrating the refined version of the documented design approaches and performance programs in a full-scale operating power plant station. Successful demonstration here will provide additional verification of the design methodology.

The need to consider residual chlorine discharge from condenser biofouling control treatment has become another constraint for a number of utilities. In addition to plants that use once-through cooling, closed-cycle plants are also facing these problems when they discharge into receiving streams or natural bodies of water. Although current federal effluent guidelines restrict chlorine emissions from cooling water to an average of 0.2 mg/l free available or total residual chlorine for a 2-h/day maximum, future regulations will undoubtedly be much more stringent. New limitations on utilities may range from demonstration of a program for chlorine use and emissions minimization to complete elimination of this constituent from plant liquid effluents. Alternatives to chlorine treatment are available, but their effectiveness as biocides and their ultimate impact on the environment are still being studied.

Concurrently, an adjunct project with the University of Miami involving controlled laboratory experiments on a bench-scale condenser system will determine the feasibility and effectiveness of using iron (VI) ferrate and sulfur dioxide as biocides (RP1261-3). These two novel means of condenser biofilm control have the potential for avoiding the undesirable side effects attributed to chlorine. If proven effective at the bench scale, they will be tested under simulated operating conditions in the field-test apparatus assembled for the closed-cycle cooling-water studies of RP1261-1. The objective of coordinating these pilot studies is to determine their compatibility with cooling-system materials and other treatment processes for control of scaling and corrosion.

Close coupling of the design methodology, pilot-scale field testing, and side-by-side comparison of pilot- and full-scale system performance will guarantee development of a fully verified design tool for the utility industry. Evolving from this project will be a comprehensive set of documents that will describe strategies to aid the designer and utility personnel in selecting the proper treatment schemes. These strategies will also serve to optimize the cooling-water circuit chemistries and to provide for proper management of plant water resources. Finally, these references will help the operating utility predict impending system problems and identify appropriate corrective actions. *Project Manager: Winston Chow*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

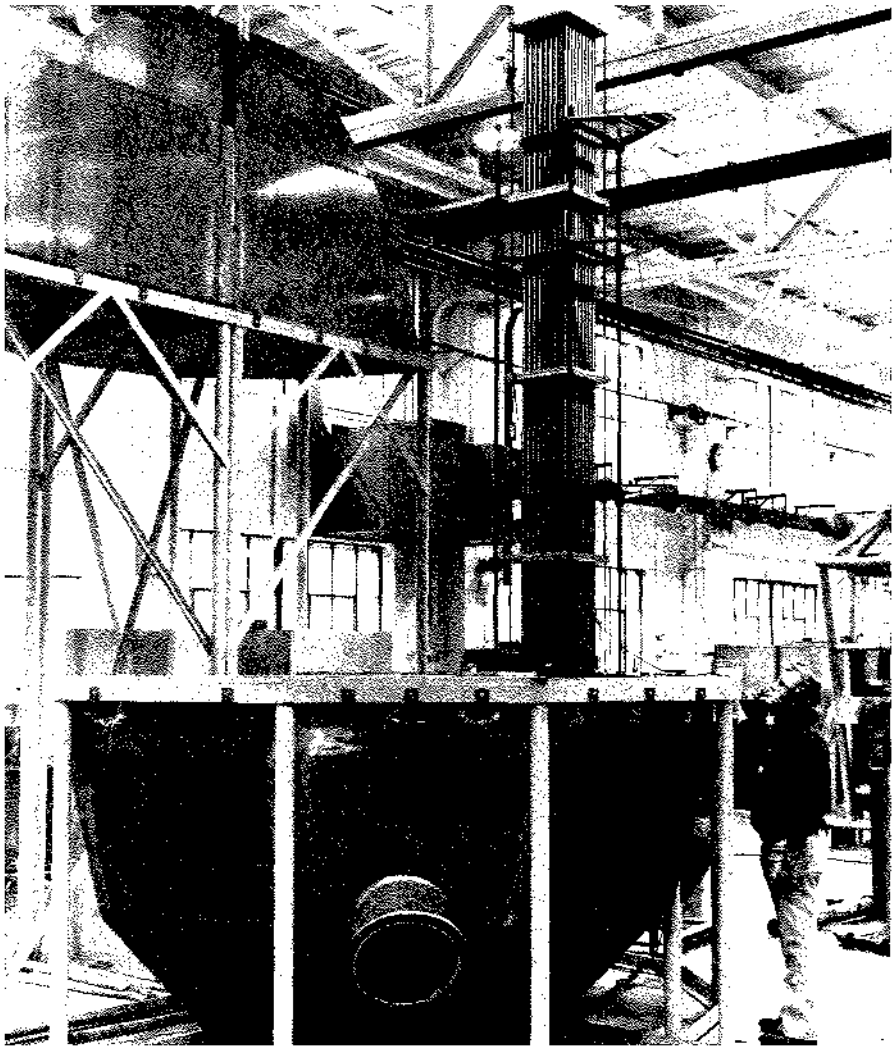
EVALUATION OF NONDESTRUCTIVE EXAMINATION METHODS

The in-service inspection of steam generator tubes is becoming more complex as new anomalies are discovered that affect inspection systems in ways not previously encountered. To increase inspection reliability, new and improved equipment and techniques have been developed. To evaluate these developments in a realistic and statistically conclusive manner, two facilities—a fixed-site mock-up and a portable test-bed tube module—have been developed that contain steam generator tubing with simulated field-type defects.

Steam generator (SG) tube degradation, particularly denting, has become increasingly severe in PWRs and is therefore of major concern to PWR-owning utilities. In response, the utilities are sponsoring a coordinated program via the EPRI Steam Generator Project Office (SGPO) to eliminate, or at least minimize, the causative factors and identify remedial measures. A part of this program is devoted to developing improved nondestructive examination (NDE) methods for SG tubing. To ensure that new NDE systems meet the needs of the utilities, it is necessary to provide test facilities that realistically simulate in-service inspection conditions and allow unbiased evaluations of the systems. The fixed-site steam generator mock-up (S126-1) and the portable test-bed module (RP1172-1) were constructed with these requirements in mind.

The fixed-site mock-up (Figure 1) consists of three sections, based on the SG designs of Westinghouse Electric Corp., Combustion Engineering, Inc. (C–E), and Babcock & Wilcox Co. (B&W). The Westinghouse and C–E sections are quarter-channel heads placed side by side at floor level, while the half-channel head B&W section is elevated to simulate access from the upper tubesheet. For each of these sections there are four stackable tube bundles, or modules, totaling 3.35 m (11 ft) in length when stacked. The modules contain support plates and approximately 85 tubes with manufactured defects designed to simulate as closely as possible the types of tubing defects found in the field

Figure 1 Steve Brown, eddy-current group leader at Battelle-Columbus, inspects the Westinghouse tube bundles after their positioning on the Westinghouse channel head, which is located immediately behind the C–E channel head (foreground). At upper left is the B&W channel head. Visible on the tube bundles are the tube module junction plates, support plates, and winglike supports for long tubes or U-bend sections.



in that type of steam generator. The tubes and support plate holes are arranged in the applicable vendor's pitch pattern. The tubes may be rearranged within the bundles or new ones added if desired. It is also possible to add individual tubes outside the modules to study U-bends or long, unbroken tube lengths.

The main purpose of the fixed-site mock-up is to allow statistically conclusive evaluations of an NDE system's ability to detect and characterize tube defects. This is accomplished by subjecting the mock-up to examination by the system and comparing the inspection results with a record of known defects in the mock-up tubes, using an approved statistical procedure. Such an evaluation will provide information on the system's capabilities to both the developer and the utilities. The mock-up also permits evaluation of an NDE system's compatibility with a simulated field environment (specifically, SG access geometry and interface with probe manipulation and positioning equipment) and provides a facility for training inspection personnel under simulated field conditions. This facility is located at Battelle, Columbus Laboratories and is available for use by developers of NDE systems.

Because an NDE system developer may wish to conduct preliminary evaluations of its system's capabilities in the laboratory before it is used in a major mock-up test, it is desirable that tube samples containing known simulated defects be available. To fill this need, a portable tube module has been constructed in which a variety of tube samples may be inserted. Two of these 0.9-m-long (3-ft) modules may be stacked (Figure 2). Each module weighs approximately 27 kg (60 lb), is air-transportable, and can accommodate up to 30 tube samples. The samples in each module are interchangeable with those in the fixed-site mock-up.

The portable test bed is expected to provide NDE equipment designers with information on the type and size of defects that will be encountered in the field and to provide feedback on an NDE system's capabilities during the early stages of its development. The use of this portable test bed is being coordinated by Battelle-Columbus. *Project Managers: Gary DeYoung and Gary Dau*

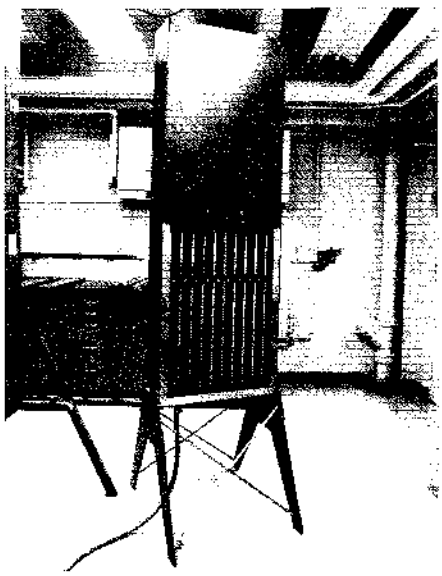


Figure 2 The portable test-bed modules may be used individually for bench tests or stacked on a stand, as shown. The carbon steel collars simulate the presence of a support plate, and the sleeve at the bottom simulates a tubesheet. Up to 30 tubes with simulated defects may be included.

EARTHQUAKE-INDUCED SOIL-STRUCTURE INTERACTION

Nuclear power plant containment buildings are typically massive, stiff structures embedded to various depths in local soil. In those instances where the buildings are not resting on bedrock, the surrounding soil may significantly influence the structural response of the plant during a strong earthquake. Soil-structure interaction is the process by which earthquake ground motions are transmitted to buildings.

In the seismic design of nuclear power plants, rocking of the structure is of principal interest, with vertical, horizontal, and torsional motions taken as secondary effects. During a strong earthquake, the surrounding soil, in its interaction with the structure, will be subjected to large compression and shear waves that lead to large strain, causing the soil properties to change. This change in soil property can have an appreciable effect on structural response, primarily by lowering the apparent fundamental rocking frequency of the structure.

EPRI's seismic studies began with a state-of-the-art assessment (EPRI 273) that led to a focus on nonlinear soil-structure interaction. A small study was initiated to define the scope of linear and nonlinear effects on earthquake-induced soil response (NP-865). These calculations showed substantial response reduction in the 1–5-Hz region with the nonlinear method. It was felt that if a more realistic, nonlinear approach leads to a reduction of the conservatism currently required to compensate for imperfect knowledge, there would be potential to ultimately improve on the floor-response spectra and component criteria.

The nonlinear soil-structure interaction program that finally evolved consisted primarily of experiments to establish a controlled three-dimensional data base and application of different numerical techniques to the EPRI tests for a better understanding of nonlinear methods.

Data base

Three explosive tests were conducted—SIMQUAKE IA, with 36.2 Mg (40 t) of ammonium nitrate and fuel oil explosives; SIMQUAKE IB, with 27.2 Mg (30 t) of explosives that were positioned closer to the structures ($1/12$, $1/24$, and $1/48$ scale) than in IA; and SIMQUAKE II, with an added $1/8$-scale structure and two arrays of explosives fired at a 1.2-s interval to produce a longer duration of excitation. Figure 3 shows a typical layout, with the explosives in the lined holes in the foreground and the models embedded to 25% of their height.

The most significant observation from these tests was that the rocking frequency was substantially reduced for each structure in all three tests after the excitation wave had passed and the structure began to "ring down." Field data and nonlinear numerical simulations suggested that the change in soil properties adjacent to the structure and the cavitation between the soil and the sides or bottom of the structure govern the decrease in the predominant rocking frequency. The tests indicated reductions of the rocking frequency to 20% of the value measured in low-amplitude vibration tests and calculated by linear, elastic methods.

Figure 3 Typical layout for SIMQUAKE IA and IB experiments. These are model structures at $1/12$, $1/24$, and $1/48$ scale, buried to one-fourth of their height. Lined holes in the foreground contain explosives for ground excitation.

Table 1
STRUCTURAL RESPONSE DURING SIMQUAKE TESTS

	Model Scale		
	1/8	1/12	1/24
Diameter, m (ft)	4.57 (15.0)	3.05 (10.0)	1.52 (5.0)
Height, m (ft)	6.86 (22.5)	4.57 (15.0)	2.29 (7.5)
Weight, Mg (t)	114.6 (126.4)	35.4 (39.0)	4.4 (4.9)
Pretest rocking frequency, Hz	11	15	30
Test IA	Not		
Ground motion, g	tested	1.0	1.25
Ring-down frequency, Hz		6.5	9.2
Test IB	Not		
Ground motion, g	tested	2.8	4.4
Ring-down frequency, Hz		3.5	5.0
Test II			
Ground motion, g			
From first array	0.8	0.8	0.6
From second array	2.3	2.3	1.7
Ring-down frequency, Hz			
After first array	3.0	*	*
After second array	2.0	4.9→7.4**	9.8

*Ring-down frequency from preliminary data reduction was not discernable after first-array excitation.
**Frequency shift.

Table 1 gives a summary of the structural response. If these observations are confirmed by future testing and analysis, one may contemplate that the ground motion amplification currently predicted to occur in the 3–5-Hz frequency range from resonance in rocking may occur instead at 0.5–1-Hz. This has implications for the potential reduction of design requirements for equipment having natural frequencies around 5 Hz. Data from these tests will be published in a multivolume EPRI report.

A large amount of structural and ground response data are also available from underground nuclear tests in Nevada. These data were examined for their value in providing applicable information for nuclear power plant design (NP-1091).

Numerical simulation

As an integral part of EPRI's research, the SIMQUAKE data were used to test different numerical simulation procedures that exist in today's technology. In particular, the focus was on the currently favored implicit techniques represented by linear methods such as FLUSH (*1*) and on explicit techniques such as TRANAL (*2*) and STEALTH (*3*).

The simulations with FLUSH were inconclusive (NP-1091), since this code accepts as standard input a vertically propagating seismic shear wave, which differs from the oblique waves generated by the experiment; also, the equivalent linear soil model does not correspond to the complex nonlinear behavior produced in the experiment. Although such linear methods as FLUSH adequately simulate low- to moderate-level earthquakes, a nonlinear capability is needed to handle simulations of strong earthquakes.

The explicit techniques, such as TRANAL and STEALTH, were developed from programs used in weapon applications to simulate the propagation of stress waves in nonlinear solids. These have not been generally adopted by the nuclear industry because they were considered to be relatively inefficient when compared with implicit techniques. The stability requirement governing the time step can lead to higher computer costs for such a technique in certain instances; but under highly nonlinear circumstances it may be the most reasonable method to use. An explicit finite element code, TRANAL, was used to simulate the SIMQUAKE experiments and achieved a reasonable degree of success (NP-945). In addition to being able to accept more-general input, this method can be reasonably efficient in three-dimensional simulations, provided the calculations can be performed entirely in-core. An interesting observation from these calculations was that the strong-motion rocking response of the three-dimensional model is significantly smaller than that of the two-dimensional model. This may be due to the restraint on the sides of the structure transverse to the direction of strong motion, which is not modeled in the two-dimensional model.

If the reduction in rocking response is confirmed by future research, the potential payoff from the insight gained in these projects will be significant. In EPRI's continuing effort to provide optional tools for the analyst, the STEALTH code will be modified to provide a production seismic code with capabilities to handle nonlinear three-dimensional situations (RP307). *Project Manager: Conway Chan*

References

1. J. Lysmer, T. Udaka, C-F Tsai, and H. B. Seed. *FLUSH—A Computer Program for Approximate 3-D Analysis of Soil-Structure Interaction Problems.* Berkeley, Calif.: College of Engineering, University of California, November 1975. EERC 75-30.

2. U.S. Defense Nuclear Agency. *TRANAL: A 3-D Finite Element Code for Transient Nonlinear Analysis.* Prepared by Weidlinger Associates. Washington, D.C.: GPO, June 1974. DNA 3501F.

3. *STEALTH: A Lagrange Explicit Finite-Difference Code for Solids, Structural, and Thermohydraulic Analysis.* Technical report No. 1 for RP307 prepared by Science Applications, Inc., June 1976. EPRI NP-176.

ON-LINE DIAGNOSTICS FOR POWER PLANT MACHINERY

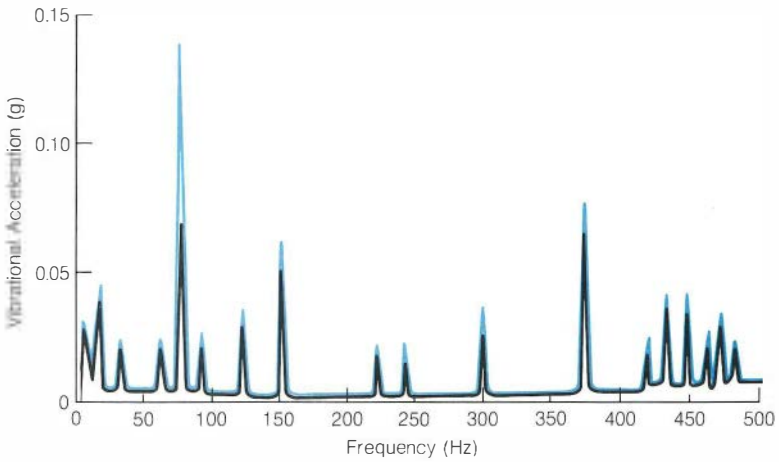
For many years industries that operate large rotating machinery have used vibration-monitoring systems to detect potentially damaging operating conditions and, in some cases, to automatically shut down the affected equipment. Although they protect machinery from catastrophic failures, these systems have not been designed to warn of incipient failures, nor have they provided diagnostic information that could be used to determine the machine's mechanical condition. Such information would give operators more time in which to compensate for the eventual equipment shutdown and plan for maintenance.

Vibration monitoring

Originally, vibration-monitoring systems detected the overall amplitude of vibration and warned operators when that amplitude exceeded certain limits. Later refinements included such techniques as bandpass filtering, which allowed the amplitudes of high-frequency and low-frequency components of vibration to be monitored separately. However, with the development of fast Fou-

Figure 4 The on-line vibration-monitoring system installed in Northeast Utilities' Millstone-2 nuclear power plant consists of vibration instruments (center right), a digital computer (lower right), an FFT analyzer (upper right), and terminals for operator interface (left).

Figure 5 Two spectra for a reactor coolant pump show a change in vibration at one frequency (74 Hz). Knowing the frequency of the change enables the system to determine what changes are taking place within the pump.



rier transform (FFT) instrumentation it became feasible to examine the entire vibration spectrum (continuous display of amplitude versus frequency) and thus gain additional insight into a machine's condition. The spectra serve as "frequency fingerprints," which skilled analysts use to identify such problems as rotor imbalance, seal and blade rubs, and alignment shifts. Even small changes in vibration, not reliably detectable by an amplitude monitor, can produce easily discernible changes in the vibration spectrum. Thus the FFT analyzer is not only very sensitive to changes in vibration but can also provide very good clues to their causes.

Presently, skilled analysts keep records of vibration spectra and analyze their changes over time. As long as the number of machines monitored remains small, this manual analysis is feasible. However, since utilities with nuclear plants are now implementing in-service inspection programs for rotating machinery, more data are being generated than can be handled manually without employing and training additional skilled analysts. Use of a digital computer to compare spectra and to determine machinery condition allows the expansion of machinery monitoring without increasing the number of skilled analysts.

If the computer is also used on-line for monitoring vibration, it can continuously check for spectra changes that indicate incipient failures. Early detection of failures gives operators more time to act before damage becomes extensive and gives maintenance personnel more time to prepare for their work so that downtime can be reduced. Shaker Research Corp., in cooperation with Northeast Utilities, is developing such a system as part of an EPRI program to increase plant availability (RP824).

On-line monitoring system

The monitoring system, which is presently installed in the Millstone-2 nuclear power plant in Waterford, Connecticut, consists of sensors mounted on five different pumps and drivers, instruments to monitor each sensor continuously and to warn operators if vibration exceeds a certain limit, an FFT analyzer, a digital computer with interfaces, a cathode ray tube (CRT) terminal to communicate with plant personnel, and a hard-copy unit to automatically record spectra under certain conditions. Figure 4 shows the system as it is presently installed.

The system operates in three modes: steady state, alarm, and start-stop. During steady-state operations the system obtains spectra for each pump and driver in sequence and compares the new spectra with previously stored information. The system analyzes any changes it detects and tells the operator what corrective action, if any, should be taken. For example, Figure 5 shows two reactor coolant pump spectra, which are essentially the same except at one frequency. As shown in Figure 6, the system analyzed the changes, decided the change was within normal limits, and informed the operator that no action was necessary. If an alarm occurs, indicating that a machine's vibration has reached a potentially damaging level, the system interrupts steady-state processing so that it can diagnose the problem with that machine. If the machine then appears to be failing, the system records additional data for a postfailure analysis. In the third mode, during starts and stops of machinery, the system takes data from which structural resonances and rotor critical speeds can be identified.

Operating experience

Two examples highlight experience with the system to date. The first example occurred during the plant heatup following a refueling.

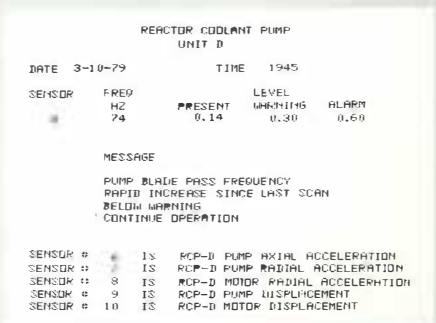


Figure 6 Hard-copy readout for vibration data in Figure 5. The system informed the operator that the change in vibration at the pump blade-pass frequency was within normal limits and recommended continued operation.

Operators received a high-vibration alarm from a vibration switch that was original equipment on the reactor coolant pumps. The alarm was intended to warn operators of excessive pump imbalance. Plant operating procedures required the pump to be shut down if the alarm did not clear within a certain length of time. Using the sensors installed as part of the monitoring project, Shaker Research recorded data for the affected pump, which operators then shut down. Using the system, which at that time was still going through software checkout, Shaker Research analyzed the data off-line. Results showed that the vibration switch was responding to high-frequency flow-related noise and that the pump was operating normally. This information, received promptly, enabled the plant to avoid a potential delay in returning to power.

The second example occurred during the most recent refueling outage. In some nuclear plants, vibration measurements on reactor coolant pumps are taken manually at the beginning of a refueling outage. Final maintenance planning must be deferred until the vibration analysis is complete. Moreover, personnel taking the measurements are exposed to radiation. At Millstone-2, however, the system had been operating on-line for about six months prior to the recent outage. In addition, vibration data had been recorded following the previous refueling. Analysis of the data indicated that no significant changes had occurred in the condition of the reactor coolant pumps. This analysis of continuous operating data, combined with the ability to monitor the pumps on-line to detect any subsequent changes at an early stage, led to the decision to perform no maintenance on the reactor coolant pumps. This decision not only saved time during the refueling outage, but also reduced personnel exposure to radiation.

Present plans are to continue the evaluation of the on-line system through September 1979, when the final report will be issued. *Project Manager: Gordon Shugars*

PARAMETERS CONTROLLING BWR PIPE CRACKING

The major factors contributing to intergranular stress corrosion cracking (IGSCC) in type-304 stainless steel subjected to oxidizing environments have been recognized for more than 20 years; however, the levels of and interaction between these variables in the high-purity BWR water environment have not been quantified. In the 5 years since bypass-line cracking was first observed, EPRI has sponsored several projects aimed at providing a quantitative measure of the variables that contribute to this phenomenon. These projects have led to an increased understanding of the problem and to the identification of fabrication processes that may substantially reduce the probability of cracking in the future.

It has been recognized for some time that IGSCC in BWR stainless steel requires the simultaneous presence of an oxidizing environment, a material condition that renders the metallurgical structure sensitive to that oxidizing environment, and a state of stress sufficient to cause cracking.

Prior to the current series of cracking incidents beginning in the fall of 1974, it was believed that metallurgical changes resulting from normal girth welding of type-304 stainless steel piping produced insufficient sensitization to cause IGSCC. Further, the residual stresses resulting from the welding process were not considered to be significant. Early study group reports from General Electric Co. and the Nuclear Regulatory Commission concluded that a weld-sensitized metallurgical condition (in combination with oxidizing environment) was one of the primary contributors to the IGSCC problem. The General Electric report further concluded that residual stresses produced in this same weld-heat-affected zone during the welding process were also primary contributors. Even with these major contributors identified, significant questions remained.

- How much weld sensitization could be tolerated?
- What levels of residual stress would be produced on welding for all pipe sizes?
- What influence could environmental changes exert?
- What could be accomplished to eliminate the problem practically?

It was assumed that a sufficient reduction in any of the three essential variables (stress, oxidizing environment, and material susceptibility) would eliminate the problem.

In the spring of 1975, EPRI established ini-

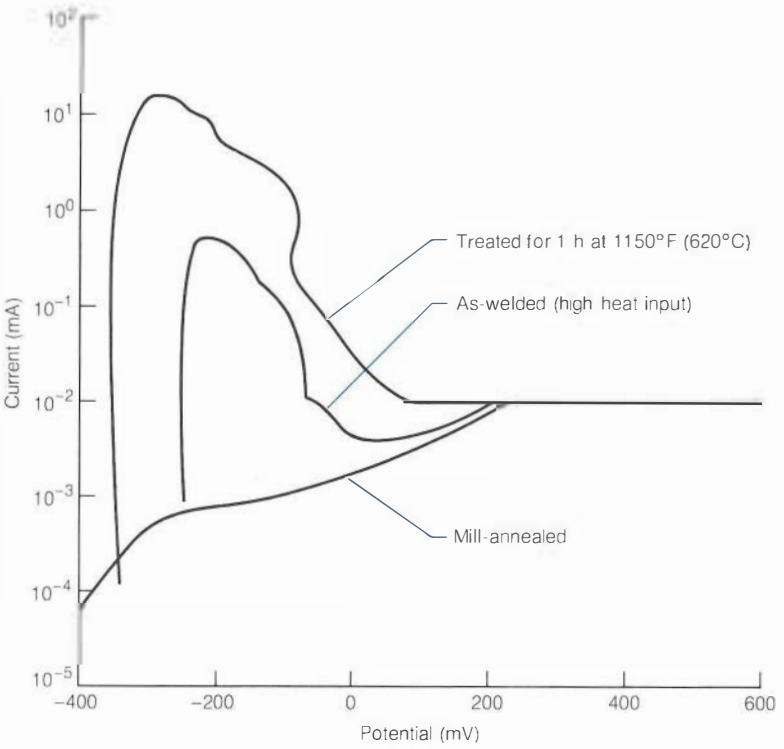


Figure 7 Effect of sensitization level on EPR measurements of type-304 stainless steel pipe.

tial research with Argonne National Laboratories (ANL) and General Electric to deal with the first two of these questions (RP449-1 and RP449-2, respectively). The primary objective was to identify the levels of sensitization and residual stress that could be expected to exist in the heat-affected zone of typical girth-welded pipe. Both small and large diameters were to be considered. A second objective was to determine the differences in levels of residual stress and degrees of sensitization that could lead to performance differences among the different piping systems. The performance evaluation made use of laboratory stress corrosion experiments on small testing coupons in a high-temperature water that approximated the BWR operating environment.

The principal tool used in the General Electric and ANL studies for quantitative determination of the degree of sensitization was the electrochemical potentiokinetic reactivation (EPR) technique. This measurement involves a reverse potential scan from the passive to the active region of the polarization curve in a specific electrolyte. The electrolyte is chosen so that sensitized grain boundaries will be preferentially attacked. A rapid current density increase during the scan through the active portion of the polarization curve will occur if the composition of the grain boundaries will not passivate. A nonsensitized structure will passivate and thus produce a proportionately lower current density. This procedure provides a quantitative measure of the material sensitization. Figure 7 presents typical polarization curves produced by the EPR technique for a series of thermally sensitized samples, demonstrating the discrimination capability of the technique.

EPR measurements were performed at both General Electric and ANL on welded coupons removed from a 4-in, 10-in, and 26-in schedule-80, type-304 stainless steel pipe. These measurements demonstrated that the degree of sensitization resulting from welding is significantly greater than that resulting from a sustained isothermal sensitization treatment of the same material for comparable times and temperatures. In addition it was observed that typical thermal treatments given to simulate weld effects were too severe. The EPR test was able to distinguish among the welded samples as to the degree of sensitization of each material. Subsequent stress corrosion tests demonstrated the excellent correlation between this test and IGSCC susceptibility of the various heats of type-304 stainless steel (Figure 8).

Residual stresses due to girth butt-welding, which have also been identified as major contributors to the IGSCC phenomenon, are the result of nonuniform expansion and contraction of pipe during the heating and cooling portions of the welding process. The magnitude of the stress can be on the order of the material yield strength or it can be higher if the material undergoes substantial strain-hardening during welding.

During the past several years, EPRI and DOE have supported theoretical work by Battelle, Columbus Laboratories that involves elastic-plastic finite element analysis in an attempt to model and thus predict the residual stress distributions as a function of welding parameters (RP1174). In addition to the modeling activity, residual stress measurements were performed on actual welded pipes at General Electric and ANL (RP449). Girth welds prepared in the laboratory and others removed from BWR service were examined.

Measurements were made by using both destructive (strain gage stress relief) and nondestructive (X-ray diffraction) techniques. In both of these techniques the amount of elastic strain resulting from the welding process is determined and then related to the stress level, using Hooke's Law. The residual stresses determined are combined with predicted operational stresses to quantify the total stress state existing on the pipe.

The residual stress measurements demonstrated that for both large- and small-diameter type-304 stainless steel girth welds, large tensile residual stresses can exist on the pipe's inside surface in the weld-heat-affected zone. The results suggest that the tensile stresses may be somewhat lower on the inside surface for the large-diameter (26-in) welded pipe than on the small-diameter (4-in) pipe and that these stresses become compressive in the large-diameter pipe at a small distance into the pipe thickness (less than one-fourth of the thickness). For the small-diameter pipe, the weld residual stresses remain tensile through most of the pipe thickness.

The information generated in these projects has been used to identify improved fabrication techniques and focus development of both the welding and the treatment of type-304 stainless steel pipe. Several new projects are now under way to develop and qualify several options. *Program Manager: Richard Smith*

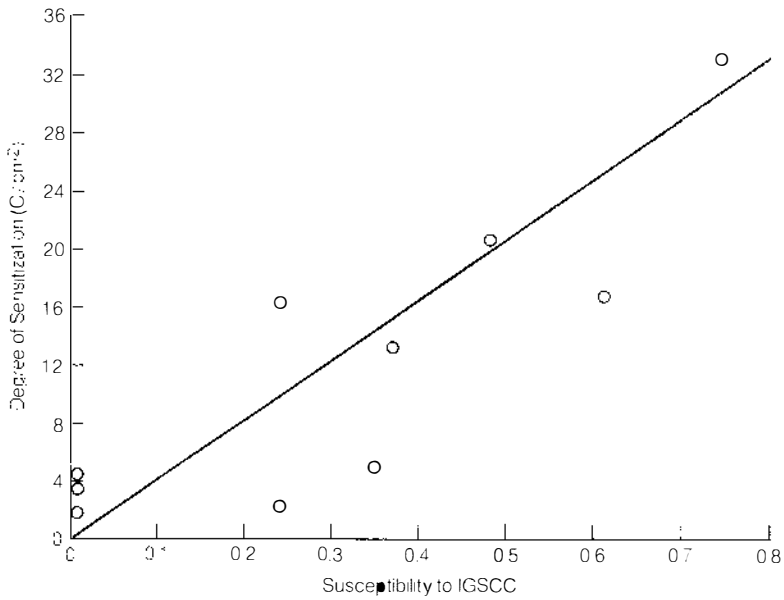


Figure 8 Correlation between degree of sensitization and IGSCC for 10 heats of type-304 stainless steel in as-welded condition. Sensitization was determined by EPR and susceptibility was determined by the constant extension rate test.

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

OVERHEAD TRANSMISSION

Utilization of overhead rights-of-way

An obvious strategy for getting better utilization of overhead rights-of-way is to put the conductors closer together on the transmission tower. Power Technologies, Inc. (PTI) has conducted a very thorough investigation of the effects of putting the conductors closer together and has found that the concept is not as simple as it first appears. The results of the bulk of this work are summarized in *Transmission Line Reference Book: 115–138-kV Compact Line Design.* The feasibility of closer spacing was established by this research, but a number of questions were left unanswered. Basically, the questions center on two considerations: what minimum spacing is possible and what special hardware is required.

Closer spacing of phase conductors has the effect of intensifying the electric field at the conductor. With spacings as close as 0.6–0.9 m (2–3 ft) for 138 kV, the maximum electric field gradients approach those of EHV and UHV lines. Therefore, extensive corona studies were conducted on a short test span at the PTI test site near Saratoga, New York. Data are now available to show that closely spaced 138-kV lines can be designed within acceptable corona limits.

With closer spacing, differential motion of conductors becomes very important. PTI has studied this motion under conditions of wind, ice dropping, galloping, and through-faults. All these data will be useful to the designer. The wind data are limited in scope but will be augmented by another project on transmission line wind loading (RP1277).

Closer spacing also leads to concern about the possibility of phase-to-phase switching-surge flashover. The contractor has attacked this on two fronts: transient network analysis (TNA) of typical 138-kV systems and actual flashover tests of three test spans. For each of these, a unique, efficient test procedure was developed. As the data were generated, they were digitized and stored on floppy disks. Later the data were transferred to a computer for analysis. In these experiments, the use of careful statistical design and high-speed data acquisition resulted in a ratio of useful information to unit of test cost that was nearly an order of magnitude higher than was achieved through previous methods.

The flashover tests determined the effects of spacing, hardware type, configuration, height above ground, line length, and ratio of voltages on the different conductors. The experiment design also allowed the effects of the concomitant variables of atmospheric pressure, temperature, and humidity on flashover to be quantified. The tests were conducted at Westinghouse Electric Corp.'s laboratory in Trafford, Pennsylvania.

The TNA study was conducted and analyzed in much the same way as the flashover experiments. The variables studied were line length, short-circuit capacity, line surge impedance, circuit breaker type, and circuit breaker reclosing. The TNA study was conducted at McGraw-Edison Co. in Canonsburg, Pennsylvania.

Most line hardware for 138 kV is not designed for high-level electric fields. Therefore, the need for special hardware was identified, but the designs were not developed. In order to achieve closer spacings, special insulator assemblies were developed. They are based mostly on the glass-reinforced polymer insulators recently introduced into the market, which permit use in special assemblies because they are easily adapted to different end hardware. Both pole-mounted and midspan sample assemblies were developed and tested.

One last strategy to allow closer spacing is the use of covered conductors. A relatively modest insulating cover will withstand an occasional conductor-to-conductor contact. Past experience at distribution voltages suggests that problems with covered conductors could be encountered at the support insulator. It was determined analytically and by test that certain attachment configurations will cause corona, which destroys the insulating cover. Support hardware designs that prevent this were developed.

The results of these two projects have gone a long way toward making it possible to design very compact high-voltage lines. The prospect of installing three circuits where there was one before is definitely feasible. *Program Manager: Richard E. Kennon*

AC SUBSTATIONS

Fundamental investigation of arc interruption in gas flow

As our power systems have grown in size, transmission voltages have increased, fault currents have become higher, and reduced fault-clearing time has become more desirable. Power circuit breaker manufacturers have responded to these needs with new, high-performance equipment, albeit piecemeal because of the early limited demand. The arc interruption technology has been developed largely by each manufacturer's doing some basic work and then gradually increasing interrupter performance according to data developed empirically. This approach has resulted in a considerable amount of basic design information, but all of it came from unrelated work. Until recently there was never a large, organized effort to focus attention on the interactions involved in the arc interruption process.

A project, now in its fourth year, undertaken with General Electric Co. was structured to study the interruption of an arc in a gas flow (RP246). The results of the study will provide information that may be used by the designers to develop more efficient arc interrupters for circuit breakers and thereby better meet user requirements.

The first phase of RP246, which was a two-year effort, was covered in an EPRI report (EL-284) issued in January 1977. The second phase of the project—another two-year effort—supplements and expands the initial investigation.

The primary effort in the project has been directed to the use of SF_6 gas as the interrupting medium (Figure 1). However, a number of gases and gas mixtures have been investigated, not only to permit evaluation of their relative interrupting performance but also to provide data to help identify those gas properties that determine arc interruption speed. The results to date have shown a good correlation between experimental and theoretical study in this area.

The nozzle and electrode geometry of the interrupter are controllable by the designer. The effects of changes in geometry are being investigated in a number of ways. Aerodynamic studies of cold gas flow are being made. The location of the upstream electrode in relation to the nozzle throat has been studied to show its effect on the interrupting performance. The effects of upstream gas pressure on gas flow and the interaction between the arc and the gas are being studied to provide information on their roles in the interrupting effort.

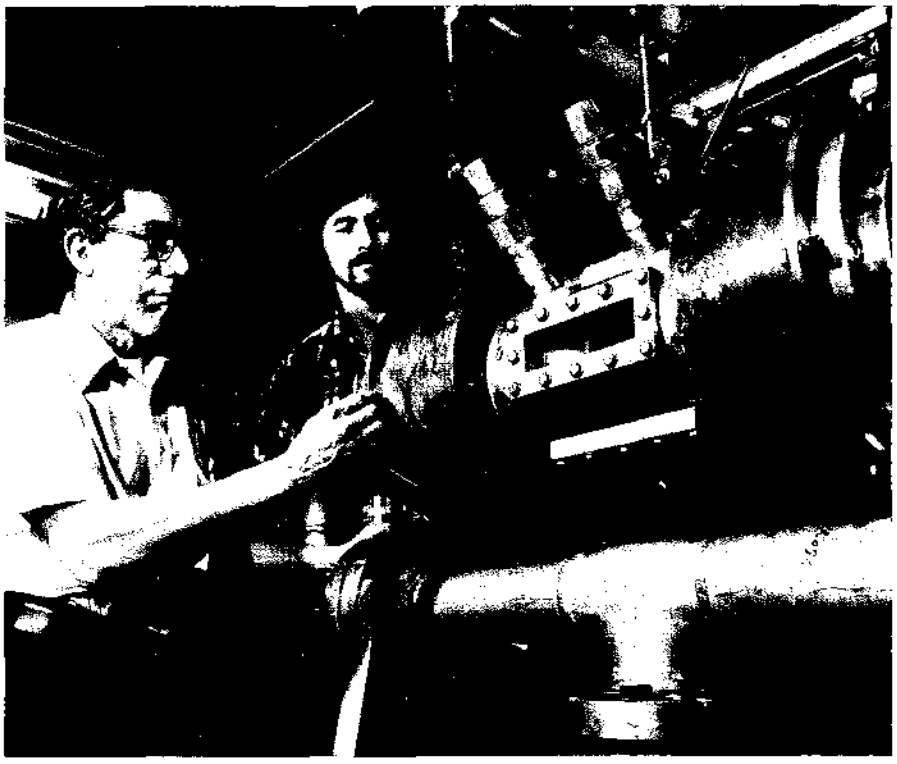
More information on the arc itself is being obtained by very high speed pictures taken at the rate of two million per second. These pictures are showing much greater detail on the arc behavior and its composition in the time period around current zero than previously available. Techniques have been developed for more precise arc measurements of postarc current, providing new and revealing information on arc energy values during the critical thermal interruption time period. Improved techniques for measuring arc temperature are also being developed. These more accurate temperature data are important in the determination of the arc plasma properties.

All these efforts are providing new and related data that will permit a much better understanding of the arc and gas flow interaction in the interruption process.

The report covering the second phase of this ongoing project will be available later this year.

The third phase of this effort, started in June of this year, will build on the knowledge gained in the first two phases to optimize nozzle designs for both single- and double-flow interrupters; these will then be applied in breakers having a puffer design that uses SF_6 gas. *Project Manager: Glenn Bates*

Figure 1 Test equipment being used at General Electric Co. to study the interrupting performance of single- and double-flow nozzles during investigation of arcs in gas flows.



Tuned sound enclosures to abate transformer noise

The objective of a project with Allis-Chalmers Corp. was to reduce the noise emitted from power transformers by developing a close-fitting, integrally mounted noise shell (RP995). The noise shell consists of a series of panels mounted to a framework, which is in turn supported and spaced from the tank by neoprene isolators. The development work was directed specifically toward retrofit application on existing transformers.

This project is a follow-on to work done under RP579, in which the theory was developed and applied experimentally to an existing transformer. The results were somewhat disappointing, however, with an 8-dBa reduction achieved where 15-dBa was expected. It is hoped that RP995 will result in an increase in this performance and will demonstrate the feasibility of a unit designed for commercial application.

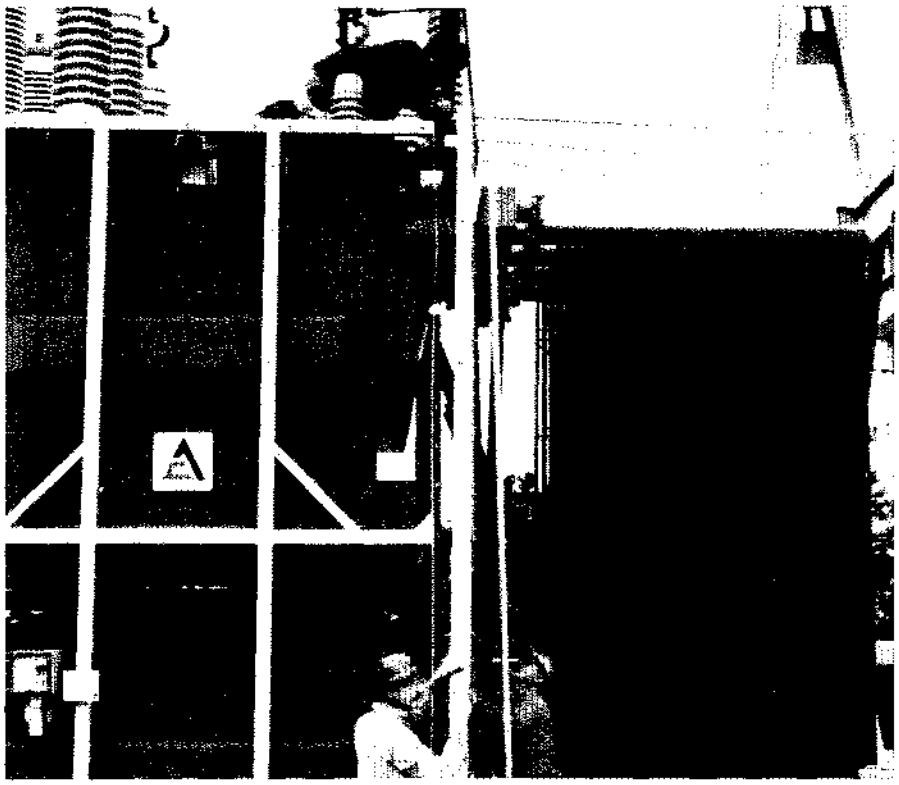
A complete noise shell enclosure was installed on a transformer for Consumers Power Co. in Jackson, Michigan (Figure 2). Costs projected on the basis of this installation and several business assumptions indicate an installed cost of 10–20% of a new (standard noise) transformer; this cost is lower than that of competitive noise control methods. It also has some features that should make it an even more attractive alternative.

Material loss factor (generally termed *damping*) of the enclosure material was found to be a critical parameter. Addition of a damping treatment to the experimental shell increased the performance up to the 15-dBa target reduction. Damping was also found to be critical on the demonstration unit. The plastic panels installed (loss factor of 0.05) resulted in a noise reduction of 8.5 dBa, which was increased to 11.6 dBa when acoustic foam was added inside the enclosure. Three panels were replaced with damped steel panels, and an overall 16.5-dBa reduction was achieved. A final report on this project can be expected later this year. *Project Manager: Ed Norton*

New insulating oils for electrical apparatus

Because of the declining supply of naphthenic-base petroleum crudes historically used for the manufacture of insulating oils,

Figure 2 Close-fitting, integrally mounted noise shell being installed on a transformer at Consumers Power Co. in Jackson, Michigan.



the oil companies have recommended that the more readily available paraffinic-base crudes be substituted to produce the insulating oil required by the electric industry.

The purpose of a project with Westinghouse Electric Corp. was to determine if an insulating oil manufactured from paraffinic-type crudes was interchangeable with the presently accepted insulating oil, and whether it would perform the same function without requiring major changes in design and without limiting operating conditions (RP577).

Paraffinic crude oils are known to contain significant amounts of wax; if this wax is not removed, insulating oil made from these crudes could have a pour point high enough to interfere with the low-temperature functioning of most electrical equipment. Because of the wax problem, it was necessary to study the behavior of the paraffinic-base insulating oil in representative production-size equipment, such as tap changers and power circuit breakers, to be sure that the equipment would operate when exposed to temperatures as low as −40°C.

Other studies, covering material compatibility, lubricity of the new oil, arc-formed gas, response to dielectric breakdown levels of large power transformers, and accelerated aging in distribution transformers, were important to ensure full acceptance of a replacement oil.

Tests showed that the paraffinic oil was at least as good as the naphthenic oil in terms of lubrication and should function satisfactorily in electrical equipment. A study of the arc-formed gas produced by very low arc current found that the gases produced were primarily hydrogen, with some acetylene and methane. The method used was a direct-current discharge between two needles immersed in oil. There appeared to be little difference between the types and amounts of combustible gases produced from either paraffinic or naphthenic oil. A study of performance in distribution transformers concluded that paraffinic oil could be approved for use in this type of equipment. *Project Manager: Ed Norton*

Miniature life testing

A unique alternative to the life testing of oils in full-size transformers is to age oils in miniature, capacitorlike cans containing both copper and insulating paper. A test of this type carried out by McGraw-Edison Co. had the advantage of taking much less time, yet yielded far more data because of the larger number of samples tested. Over 600 cans were filled with approximately 200 cm^3 of oil and were sealed with an insulating bushing in the cover to allow energizing of the copper-paper-wound pack. Some units were nitrogen-blanketed, while others were free breathers. In addition, the sampling units could be heated to simulate load cycling.

For the most part, standard ASTM tests were used to evaluate the oil and paper every two or three weeks until completion of the 14-month test. The results of this life testing showed paraffinic oil to be as good as or better than presently used naphthenic oil. This work also showed that minicapacitors can be used to evaluate any changes in unit performance that material modifications may produce.

Finally, a survey made of insulating oils used in other countries shows naphthenic oils to be very short in supply in many cases and paraffinic or mixtures of paraffinic and naphthenic oils to be in use. *Project Manager: Ed Norton*

Substation control and protection

EPRI is sponsoring a project for the development of a new substation control and protection system that will build on the newly developed microprocessor and optical communications technologies (RP1359). Utility engineers in general have come to accept digital computers for energy management and power plant control systems. There is now a consensus that the time is right for using digital computers, notably the new powerful microprocessors, in substations as well. This interest is fueled both by expectations of cost reductions through the use of these microprocessors in substation control and protection systems and by anticipated performance improvements of such systems.

Low-loss optical waveguide technology has also generated a lot of interest because optical waveguides are capable of high data rates at low cost. The optical fibers themselves are completely immune to noise, and this is highly desirable in high-voltage substation applications.

It is clearly not a simple task to build a system for substation control and protection that takes maximum advantage of these new technologies, but the development of such a

system is felt to be worthwhile. The diversity of requirements representative of typical substation control and protection functions illustrates this point. For instance, the required speed of response varies from minutes to milliseconds to fractions thereof; accuracy requirements vary from fractions of a percent to a few percent of the highest input signal; equipment and line protection needs high security and dependability; revenue meters need high data security, whereas a data-logging function is relatively noncritical, even if it is not unimportant. On the other hand, it is well known that computer systems become economical when the same hardware can be used for handling many different programs. Therefore, a proper compromise between the requirements for substation functions and the efficient use of hardware must be reached. It is clear that principles of systems engineering must be followed if all the conflicting requirements are to be given proper consideration in the design of a new, distributed, microprocessor-based substation control and protection system.

The EPRI-sponsored project for the development of a microprocessor-based system for substation control and protection involves four contractors at this time.

- Westinghouse Electric Corp. has been awarded a contract for the system development work (RP1359-1).

- Texas A&M Research Foundation is investigating electromagnetic interference (EMI) within substations (RP1359-2).

- Ohio University is studying revenue-metering algorithms suitable for implementation in a microprocessor (RP1359-3).

- Public Service Electric and Gas Co. of New Jersey is the selected host for the field demonstration of the new substation control and protection system that is anticipated to be developed in this project (RP1359-4).

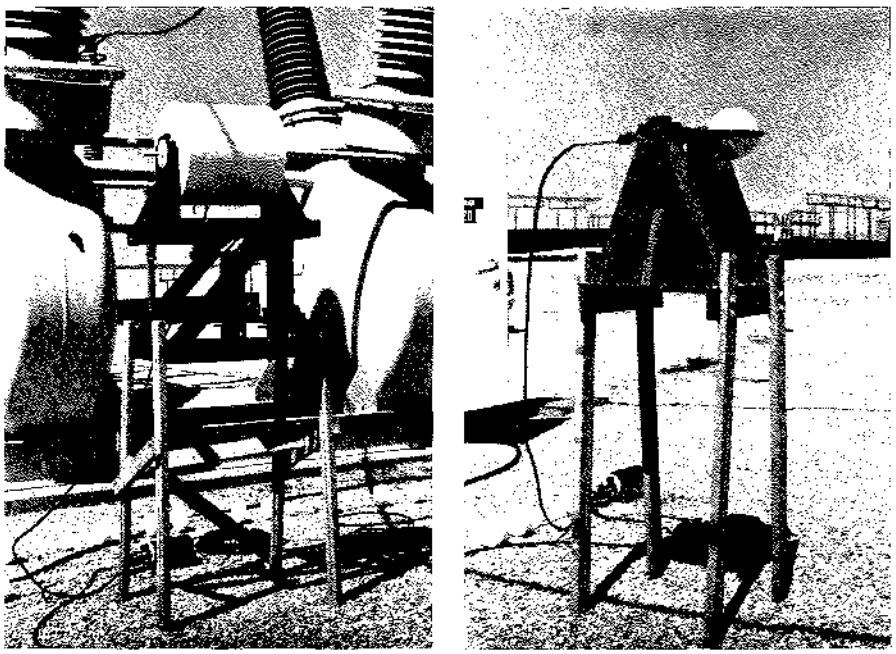
The major part of the project, the system development work conducted by Westinghouse, was started in October 1978. The first part of the project is a requirements analysis. This part is nearing completion and will be followed by various technology assessments and system concept developments that eventually will lead to a design specification. This is expected to be available in early 1980, prior to the start of the detailed design, building, and testing of the new substation control and protection system.

Work on the EMI study began in July 1978 and has progressed to measurements of EMI in transmission substations. The measuring system is capable of recording the electric and magnetic field components from power frequencies to 100 MHz or more. The electric and magnetic sensors for the measuring system are shown in Figure 3. The intent is to evaluate EMI in 115-kV–500-kV (and possibly 765-kV) substations and to develop test procedures that will ensure the survival of the new control and protection equipment in the substation even in the presence of short circuits. The data analyses needed for this are now in progress.

The study of revenue-metering algorithms was also started in July 1978, since it was felt that the metering function posed special problems that could have a significant impact on the overall system design. This seems to have been a correct assumption. It has been found that both a time skew between samples and the harmonic content within the current and voltages can cause large errors. On the other hand, it has been found that commercially available analog-to-digital converters are quite acceptable for the task. The testing of an algorithm employing Walsh functions is in its final phase.

Project Manager: Stig Nilsson

Figure 3 The magnetic (left) and electric (right) field sensors for the 100-MHz EMI measuring system built by Texas A&M Research Foundation as they were set up during measurements in a Public Service Co. of New Mexico 345-kV substation. The sensors are placed in wooden cradles that are put together without metal nails. The signals from the sensors are converted to an amplitude-modulated signal in a microwave transmitter located on the ground below the sensors. The 3-GHz carrier signal is brought through plastic waveguides to a recording van (not shown).



DC STATIONS AND EQUIPMENT

Advanced thyristor valve

A major factor in recent advancements in high-voltage direct current (HVDC) technology has been the development of solid-state thyristor valves. Such development has led to reliable, lower-cost HVDC converters. Further improvement of thyristor valves is the key to major advances and greater acceptance of HVDC and ac applications of thyristors, such as static VAR generators, both in the United States and elsewhere in the world.

Additional work is needed to decrease the cost of high-power thyristor valves, since they still account for approximately one-third the purchase price of an HVDC terminal. This constitutes the largest single fraction of the overall terminal price. Three factors that influence thyristor cost are the number of required series thyristors, which depends on individual thyristor voltage ratings; the number of required parallel thyristors, which depends primarily on the steady-state current rating of the HVDC application; and the total valve losses. Desirable operating features include increased rating of modules, while maintaining or reducing volume require-

ments, and new valve-firing methods that will allow valve firing without an amplifier/power supply at thyristor levels.

A project recently started by General Electric Co. has as its objective the development of an advanced thyristor valve for HVDC transmission systems that will exhibit improved performance, smaller size, and lower losses than existing thyristors, all at lower cost (RP1291). The immediate goal will be a light-fired, 77-mm (3-in) diameter cell with a 5000-V blocking voltage, a low thermal resistance package, and zinc oxide block protection for individual thyristors.

A related General Electric project is investigating forced-vapor cooling of thyristor valves (RP1207). EPRI projects on two-phase cooling of transformers, heat-pipe-cooled bushings, and vapor-cooled transformers have yielded encouraging results on the reliability and advantages of two-phase (liquid-vapor) cooling and of cooling thyristors by liquid flow through thyristor heat sinks and external heat exchangers, as in the valves for the prototype dc link (RP213); however, in RP1207 these principles are combined. The liquid coolant is pumped through the thyristor heat sink and actually boils. Most of the heat is removed by the latent heat of the boiling liquid, thus enhancing heat transfer. The project includes an investigation of the heat flow from the thyristor into the vapor-liquid mixture under steady-state and transient conditions and a study of the mixture's electrical insulation properties. A thermal mock-up of an HVDC valve module will be fabricated and tested.

The experimental work in RP1207 is in its initial phase. Computer models for both transient and steady-state cooling have been used to design and build a test facility for forced-vapor cooling. Experimental results show excellent correlation with both the transient and the steady-state computer models. Further extrapolation of these models indicates that an improved thyristor package may result in double the heat removal capability of existing package designs, thus permitting more efficient thyristor use and lower-cost design.

Dielectric tests of the cooling medium have been completed. They show that in all combinations of liquid and vapor fluorocarbons, either pure or with significant quantities of noncondensable gas impurities, the fluorocarbons have higher dielectric breakdown strength than the fiberglass-reinforced tubes used for piping the coolant between voltage levels.

The follow-on effort will consist of the final coordinated design, construction, testing, field installation, and field evaluation of a 150-kV, 2000-A prototype valve; it will incorporate the advanced power thyristor and cooling-system developments from both projects.

Plans will be made for installing a prototype valve in a host utility's operating HVDC system for field experience, evaluation, and performance characteristics.

A decision on the details of the equipment to be installed for field evaluation is scheduled for late 1979. At that time, the industry state of the art and General Electric's progress will be reviewed to determine the direction of future development. This will allow better technical control of the overall management and will provide an opportunity to examine advances by other developers of high-voltage thyristors. *Project Manager: Gilbert Addis*

POWER SYSTEM PLANNING AND OPERATIONS

Long-term power system dynamics

Long-term power system dynamic simulation capability has been a goal of the power industry for over a decade. General Electric conducted research in this area under RP90-7, which was started under contract to the Edison Electric Institute and was shifted to EPRI in May 1973.

Phase 1 of this work resulted in the development of an initial prototype digital computer program, LOTDYS (long-term dynamic simulation), which is capable of simulating power system performance for periods of up to 20 min following major system disturbances. Such accurate simulations enable planners to take preventive actions to avoid similar disturbances in the future. The program contains models of power-generating units, load, transmission system elements, and controls. To permit reasonable computer running times for studies, certain fast phenomena, such as the synchronizing-power and rotor-angle swings with periods less than 10 s, are ignored. The interconnection of models in LOTDYS is shown in Figure 4.

Phase 2 of the long-term dynamics research was conducted under RP764-1 during a one-year period ending in October 1976. In addition to expanding the capacity of the prototype program, additional prime mover and control models were included. Several modifications were made to simplify computations and thereby reduce simulation running times.

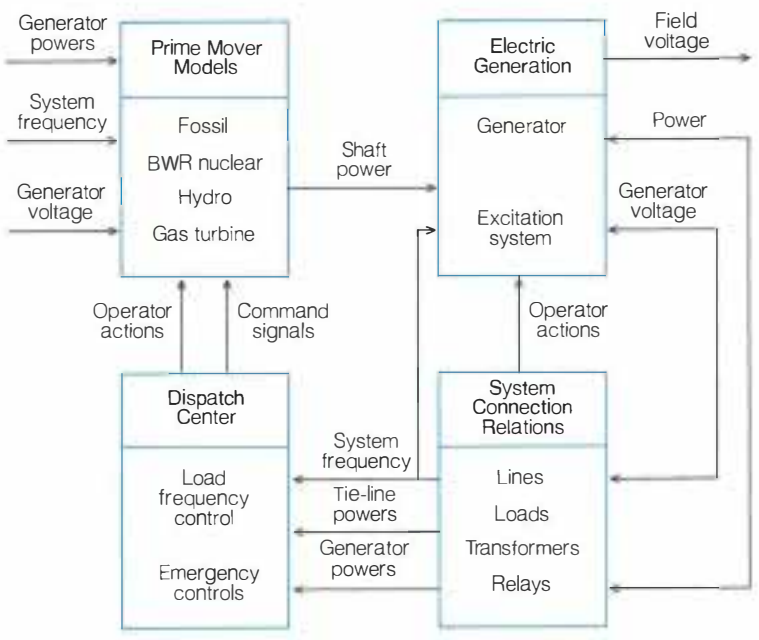


Figure 4 Interconnection of models in LOTDYS, showing transfer of information during computation.

Research in long-term dynamics has continued since 1976 under RP764-2. This third phase has among its goals the calibration of LOTDYS by using actual power system disturbance incidents and the development of guidelines for determining what data are needed and how to use them with the program. The disturbances were chosen to represent a broad field of possible disturbance modes. Four of the analyses are being made by General Electric with data and technical guidance from Consolidated Edison Co. of New York, Inc. (ConEd), Florida Power & Light Co. (FP&L), the New York Power Pool (NYPP), and Southern Company Services, Inc. (SCS). The fifth analysis is by Pacific Gas and Electric Co. (PG&E) of a recent incident that occurred on its utility system. A brief description of these incidents is included to illustrate the range of problems to which LOTDYS was initially applied. Not all these applications were successful.

A LOTDYS simulation study has been made of the last portion of the ConEd July 1977 blackout, following loss of the last ties and tracking the frequency decline during the 6 min before system shutdown. This blackout has been broadly documented in ConEd and government reports. The island response following the loss of the Linden-Goethals tie had both rapid and slow response modes, according to the utility's board of review. Immediately after the loss of the Linden-Goethals tie, frequency dropped at 1 Hz/s until it was arrested after four steps of load shedding. Frequency then rose to approximately 60 Hz until the loss of Ravenswood 3, about 7 s after the loss of the tie. Frequency then declined at rates between 0 and 3 Hz/s until final shutdown, about 6 min after the loss of Linden-Goethals. The LOTDYS study established the ability of this long-term simulation to follow both the rapid frequency changes at the beginning and the protracted operation at low and dropping frequencies.

An analysis of a power system incident with islanding of southern Florida and loss of customer load through underfrequency load shedding has been made with data and support by FP&L. This incident evolved rapidly, with load shedding completed in the first 5 s. It was chosen in order to examine the interface between short-term simulations and long-term simulations and to examine the ability of LOTDYS to follow rapid frequency excursions. The study started with short-term simulations of the line switching, unit trips, and swings following the fault. The short-term simulations were continued past the split-up (at about 1.3 s), through load shedding, to initial frequency recovery (at about 8 s). Long-term simulations were planned to follow the incident through frequency recovery to 60 Hz (at about 2 min) and possibly to resynchronization (at about 11 min). However, the LOTDYS studies could not be started, partly because the short-term simulations were unable to match incident voltage recordings and partly because the longer-duration incident recordings were insufficient to provide an evaluation benchmark for LOTDYS simulation.

A study of very low voltages that sometimes occur in EHV interconnections is being made with data and guidance from NYPP. The inability of a system to provide adequate voltage support has been identified by utility engineers as one of the long-term dynamics problems contributing to outages of power systems. Consequently, LOTDYS was prepared with a capability of representing the VAR flows and balances in the transmission network, as well as in some of the voltage control devices. The specific incident chosen represents a condition of declining EHV voltage caused by heavy summer loads, which were aggravated by increasingly heavy power transfers caused by forced generation outages. The study is being made to determine the degree to which the LOTDYS program can represent this type of disturbance, and if possible, to determine how the low-voltage condition occurred. If reasonable correlation with performance is established, it will be possible to determine the effects of other strategies and their effectiveness in returning a system in distress to a secure state. This study is in the final stages.

The LOTDYS simulation of the August 1973 Gulf Coast area power system disturbance has been completed, using only typical data and help from Southern Company Services. In this disturbance, a self-sufficient area was islanded, synchronism was lost and regained, and the area was reconnected, all in less than 8 min. A load of nearly 2000 MW was interrupted and restored in this action. The LOTDYS simulation that was assembled provided a near-perfect match of the first 2 min of records, which will enable operators to avoid a similar breakup in the future.

PG&E, with assistance from General Electric, is performing a LOTDYS study of a power system incident in the western states. The simulation program has been installed at General Electric on its MARK III time-share computer system, and PG&E is using it there. General Electric has provided consultation and has prepared a LOTDYS user's guide. The study has been set up in this format to make the simulation program available to utilities and, in turn, to obtain direct utility experience with long-term simulation and with the use of LOTDYS. A number of suggestions for improving LOTDYS have been made on the basis of PG&E experience.

General Electric's simulations are complete; results are being reviewed with the appropriate utility or pool. General Electric has also completed a set of guidelines for determining what power plant and power system data are required, where to find data not now routinely available, and how to translate the data into input for long-term and short-term system simulation programs. This third phase of long-term dynamic simulation research will be completed later in 1979, and both the guidelines and the simulation results will be reported.

The fourth phase of this research involves development of a production-type LOTDYS computer program. As a part of RP1469, contract negotiations are currently under way to develop the improved version, which should be completed early in 1981. *Project Manager: John Lamont*

DISTRIBUTION

Effect of voltage on energy conservation

Is it possible to conserve energy by reducing the operating voltage of electrical loads? What are the long-term energy input-output relationships of individual loads at supply voltages other than rated? What would be the impact on utility costs and operation if a permanent reduction in utilization voltage were implemented? In recent years, these questions have been studied and debated, but there is no general agreement on their answers. Interest in the subject has been increasing as more state regulatory agencies are either suggesting or requiring that utilities study or perform voltage reduction experiments.

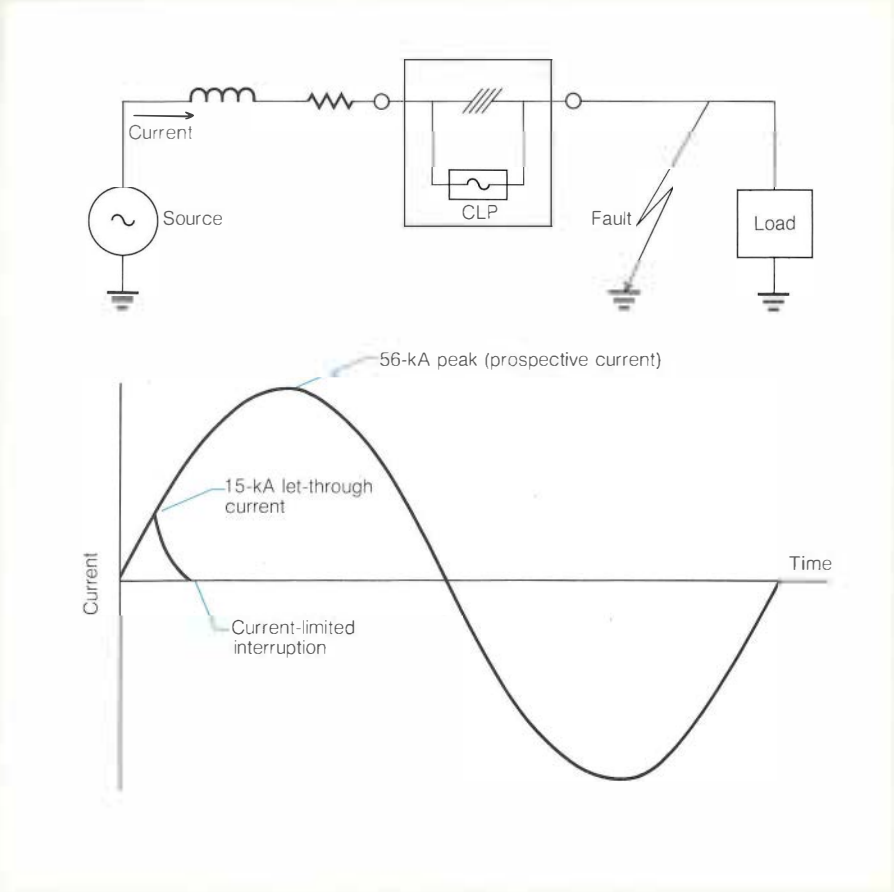
To shed light on these questions, a contract has been negotiated with the University of Texas at Arlington to make a quantitative study of the long-term effects of voltage reduction on the efficiency, operation, and economy of electric distribution systems and customer loads (RP1419). In addition, a new analytic tool will be provided that will enable utilities to study the effect of variables peculiar to their own systems on total energy efficiency.

Phase 1 will assess the long-term energy efficiency of typical loads above and below rated voltage. Among the loads to be tested are heating and air conditioning equipment (both domestic and commercial types), a full range of domestic appliances, various types of lighting sources, various types of induction motors, and distribution transformers. This phase, expected to be completed by August 1980, will be fully reported at that time so that the data will be available to the industry.

Phase 2, which is expected to be completed by March 1982, will be devoted to field experiments and the development of the analytic tool. Voltage reduction experiments will be designed and implemented on the systems of two cooperating utilities, one northern utility and one southern, for one year. Ten circuits with various load characteristics will be employed at each utility. The load composition of each will be accurately determined, and the energy consumption, voltage, temperature, and humidity will be recorded. The data thus gathered will be used as a base to verify the analytic tool—a load aggregation digital computer program that will enable the distribution engineer to correlate changes in energy consumption with changes in voltage. This program will be capable of representing typical distribution circuits and will incorporate load models constructed from the test data generated in Phase 1. After the load composition of a specific circuit is entered in the program, the energy consumption is determined as a function of voltage. It will also be possible to study the economic effect of voltage on a distribution system.

To conclude this phase, an assessment will be made of the impact of reduced voltage on the utility and on the customer. For the utility, implementation of system voltage reduction, operating problems, and system efficiency over the long term will be considered. For the customer, equipment life, economic advantages or penalties, maintenance of lifestyle, and the possible purchase of uprated replacement equipment will be considered. *Project Manager: Herbert Songster*

Figure 5 Circuit diagram and current-limited interruption by a CLP.



Gas-insulated vapor-cooled transformer

A status report in the October 1977 *EPRI Journal* announced the start of a project to develop a gas-insulated, vapor-cooled transformer (RP930). Briefly, the objectives of this project were to develop a safe, oilless, fire- and explosion-resistant transformer that utilities could buy at a cost comparable with that of oil-insulated transformers. The design was to maintain other specific transformer characteristics (physical dimensions, weight, and losses, for example) at levels equivalent to or better than those of oil-filled designs. Utility and industrial users require transformers of these specifications for application in confined locations. Until polychlorinated biphenyls (PCBs) were banned, PCB-filled transformers satisfied the technical requirements. Silicone-insulated transformers now meet the requirements, although they are more costly.

Encouraged by the successful two-phase cooling investigations in this project, the AC Substation Program is now reviewing proposals for a similar effort for larger, higher-voltage transformers rated 138 kV, 50 MVA.

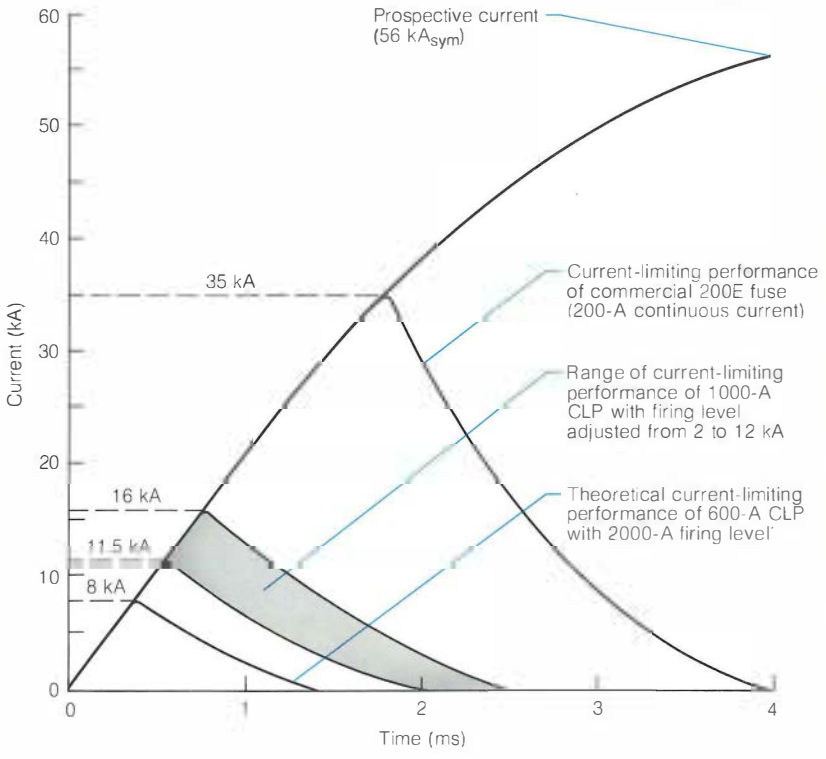
The work in RP930 developed two design adaptations of the vapor-cooling concept. Three prototype units were built and tested and will be placed in service by utilities to monitor and evaluate prototype performance.

In the first design, a pump circulates a fluorocarbon liquid coolant over the core and coil. Vapors that form when the coolant contacts the core and coil circulate through the coolers, condense, and are returned to the low-volume sump for recirculation. However, ambient temperatures are not high enough to provide the necessary vapor insulation at startup. A noncondensable gas (SF_6) adds the insulation required at ambient temperatures. The prototype of this design is a 15-kV, 2500-kVA substation transformer.

In the second design variation, the core and coil assembly is totally immersed in a mixture of perchloroethylene and oil. Vapors form as bubbles at hot spots but condense again within the liquid. This cooling system is more efficient than the first design because no noncondensable gas or pump is required. Two prototype transformers are based on this variation—a 34.5-kV, 1000-kVA network transformer and a 34.5-kV, 5000-kVA substation transformer.

The contractor did not meet all the objec-

Figure 6 Prospective current and interrupting performance of a 200-A fuse and of a CLP.



tives with either of the selected designs. However, successfully achieved objectives predominated over those narrowly missed. Both designs are far more fire resistant than their oil-filled equivalents. Each is more explosion resistant, the gas-vapor design more so than the liquid-filled design. Neither design met the cost objectives; but at 110% of the objective for the gas-vapor design and 103% for the liquid-filled design, the cost improvement over silicon-filled transformers (140%) is substantial. Operation at lower temperatures, possible because of the lower boiling point of the coolant, is expected to extend the life of the transformers. The field test program will yield further information on the transformer life and overload capability of these designs.

Throughout the project the contractor pursued a vigorous and extensive testing program on all candidate materials. Initial screening tests of these materials established compatibility. Designated amounts of solid insulation, conductor material, electric and structural steel, turn and layer insulation, and liquid or gas representing major components of the transformer insulation system were placed in stainless steel or glass containers and aged at elevated temperatures. Model dielectric tests on several major and minor insulation configurations established design clearances. Life tests on transformer models verified the recommended insulation systems for the prototypes. Transformer models also passed short-circuit tests before prototype construction.

The final report with more detailed information on this project will be available later this year. *Project Manager: R. S. Tackaberry*

Vacuum fault current limiter

A project by Gould Inc. and the State University of New York at Buffalo recently investigated a triggered, vacuum-arc commutating switch for use as a component in a resistive fault current limiter for transmission voltages (RP993).

During the course of this one-year project, analytic and experimental work was conducted to optimize the operation of a magnetically modulated, vacuum-arc, fault-commutating switch and to determine the feasibility of using this fast-acting switch in a particular application. In this application it would be triggered into conduction to divert the fault current from a fast-acting, parallel bypass switch. After a short period of time, it would be magnetically switched off to insert a current-limiting resistor, thereby allowing the bypass switch to deionize.

Reliable turnon was demonstrated, and reliable interruption in the 5–6.5-kA range was obtained, with maximum values ranging up to 9 kA. Transient recovery voltage capability was demonstrated up to 20 kV. However, with the performance levels currently foreseen, other methods being investigated in related studies appear to be less complex for application at transmission voltages. *Project Manager: Joseph Porter*

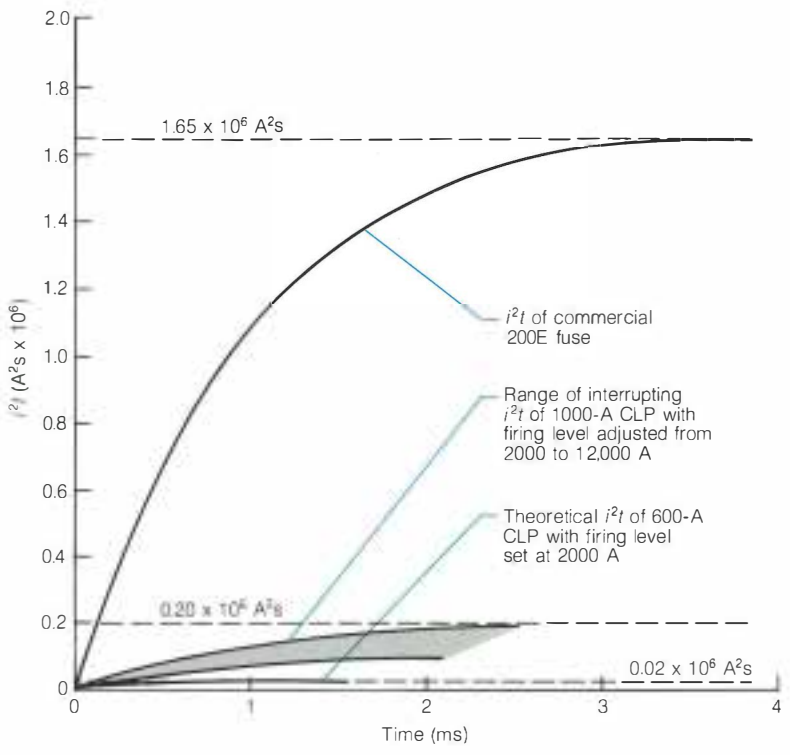
Current-limiting protector

Present current-limiting fuses are designed to limit let-through current. They also interrupt the circuit, thus acting as effective isolating links. The thermal duty and electrodynamic forces on the system are minimized because of the current-limiting action of these fuses and the rapid circuit interruption. Unfortunately, present current-limiting fuses cannot handle higher continuous currents (above 100 A) and still provide low let-through current characteristics.

A fuse that could predictably limit the magnitude of short-circuit currents and interrupt current within the first loop of fault current would permit utilities to indefinitely postpone replacement of existing equipment that can no longer handle today's fault currents. In addition, the device would permit reduction of fault current withstand requirements for new equipment, which would reduce cost.

A project with Phoenix Electric Corp. (RP1142) involves the design, construction, and testing of a current-limiting protector (CLP), which is a combination of elements that can handle high, continuous currents in the range of 1000–2000 A and yet limit the let-through currents under short-circuit conditions to less than 15,000 A (Figures 5 and 6). This is accomplished by shunting a conventional current-limiting fuse with a parallel copper conductor, which carries the continuous current. When a fault occurs, a

Figure 7 Total interrupting i^2t of 200E current-limiting fuse compared with that of CLP devices.



current-level sensor triggers strategically located chemical charges that pyrotechnically cut gaps in the copper conductor, thus diverting the fault current into the fuse, where it is interrupted in the normal manner. Since the current is sensed independently, its level is adjustable and is independent of the continuous-current rating. The device can also be triggered to open from an external signal, which offers a wide range of applications in which conventional current-limiting fuses could not be used.

The CLP will also substantially reduce the fault energy let-through. As an example, the CLP has been shown capable of reducing the let-through i^2t of a system fault to less than $1/60$ the value obtained with a high-power fuse on an identical application (Figure 7). The CLP thus offers the prospect of protecting transformers and capacitors from tank failures caused by internal faults.

Full-scale power tests have been conducted on prototype 1200-A continuous-current-rated devices. The voltages tested were 4, 7.2, and 15 kV, with available short-circuit currents ranging from 15 to 40 kV rms. These tests proved the feasibility of this concept and showed its ability to effectively limit the short-circuit current to very low values. In addition to the short-circuit tests, heat run and dielectric tests have also been performed with satisfactory results.

Work is continuing to refine the device and apply it to distribution systems. *Project Manager: Joseph Porter*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

PHYSICAL FACTORS

The basic objective of the Physical Factors Program is to define the distribution of pollutants and to assess the utility industry's contribution to that distribution. The program operates principally through two subprograms, one covering identification, characterization, and monitoring, and the other studying fate and transport. The first subprogram supports monitoring projects as well as research on developing new analytic tools and on identifying specific pollutants that may be associated with a specific process. The emphasis of the second subprogram is on studies of chemical reaction in the environment and on transport phenomena; such studies provide the information needed to evaluate the effect of the utility industry on local and regional air quality.

The Physical Factors Program is currently funding about $11 million in research, with projects undertaken by universities, private research organizations, and government research groups. The major program emphasis is on air quality related to the burning of coal. Increasingly, however, support is going to research on solid-waste disposal and on assessing the environmental effects of coal conversion processes—particularly gasification.

Air quality

Emphasis on air quality and related atmospheric chemistry remains high. The $7 million Sulfate Regional Experiment (SURE) is nearing an end. Despite the cessation of the data-gathering segment of SURE, 9 of the ground stations have continued to operate as part of developing regional air quality studies (RP1630). The eastern regional air quality study (ERAQS) comprises 13 stations east of the Mississippi that will gather air quality data through June 1980. As in SURE, a variety of air quality parameters will be monitored, but in the new study, the ground stations will put considerable emphasis on visibility and acid precipitation measurements. The full data-gathering program should be under way by fall of 1979. The western regional air quality study (WRAQS) is in the design stage; like ERAQS, it will involve a dozen or more ground stations' monitoring air quality and (to a lesser extent) acid precipitation. In the West, very strong emphasis will be given to visibility. In fact, 5 of the WRAQS stations will serve as part of the Environmental Protection Agency's (EPA's) 19-station VIEW network, a network that focuses on developing a solid base of visibility data. The full EPRI network for the West will not be in place until 1980; it will operate through 1982. The total cost for ERAQS and WRAQS will amount to about $12 million. These regional studies are not intended to be simply monitoring programs. Rather, the intent is to use the stations for generating high-quality data on air quality that can serve as a base around which specific scientific research projects can be developed.

EPRI is developing a second major project on air quality—the $10 million, 3-year plume model validation study (RP1616). The project comprises four components—management, field operations, data management and analysis, and independent auditing. The management contract has been awarded to The Research Corporation of New England, and requests for proposal have been issued for the other three segments. The basic goal of the project is to generate an incontrovertible set of data (ensured by the independent audit) against which plume models can be validated. The utility industry is faced with the necessity of having to use models as a means of demonstrating compliance with air quality regulations; thus there is a pressing need for data to validate models that the industry may be required to use. The plume model validation study involves an extensive field program of data gathering at three types of sites—coastal, plains, and complex terrain. The field program is designed so that individual components of a model can be tested (such as diffusion, transport, and deposition), as well as the model as a whole. Gathering field data for the plume model validation study will begin in the second half of 1979.

A number of different air quality and atmospheric chemistry projects are being supported by the Physical Factors Program. Those mentioned above are examples of the type of pollution identification and monitoring studies that are under way. All this work is closely coordinated with government programs. For example, during SURE the EPRI aircraft flew joint patterns with DOE's MAP3S program, and much of the equipment used in SURE stations is on loan from EPA. As mentioned earlier, EPRI's western visibility studies are tied in directly with EPA's VIEW project.

Solid waste

Over the past year the problem of solid-waste disposal has taken on new importance to the utility industry because proposed regulations (under the Resource Conservation and Recovery Act) may have a bearing on whether or not utility ash and sludge are considered hazardous. If it is, the disposal problem becomes severe because of the added cost (up to $50/t) of handling over 60 Mt/yr of waste. In addition to two small projects on the physicochemical characteristics of ash (RP1060 and RP1371), EPRI is supporting two major studies. One is aimed at evaluating the reproducibility of the proposed chemical test that EPA may use to define whether or not a solid waste is a hazard (RP1487). Further, the sensitivity of the EPA test to changes in procedures is being studied. The proposed EPA test involves extracting a waste with acetic acid and analyzing the extract for a group of potentially toxic elements. EPA has not yet been able to evaluate the reproducibility or sensitivity of the extraction procedure. Therefore, EPRI has taken on that responsibility, using both industry and EPA personnel in an advisory capacity.

A second solid-waste project is aimed at defining the statistical variation in ash composition so that a sampling program can be established that will yield representative material (RP1620). The reproducibility project is now under way and should be completed shortly. The compositional variation project will be under way in the fall of 1979, to be completed about six months later.

Organic pollutants

EPRI has always supported research on organic pollutants, but such research has typically been focused on analytic techniques or survey-type studies. The environmental effect of organic emissions is poorly known; hence work is being started on evaluating the nature of organic emissions. When coupled with biological and ecological studies, data on the nature of these emissions can be used to assess environmental effects. During 1979 a major project is evaluating the nature and biological activity of organic emissions from a coal-conversion facility, specifically a gasification plant (RP1617). Plans call for similar studies to be initiated in 1980 on emissions from cooling towers, especially on stack emissions from conventional coal-burning plants. *Program Manager: Ralph Perhac*

FORECASTING REGIONAL AND NATIONAL ENERGY CONSUMPTION

Much of the work of the Demand and Conservation Program has been oriented toward forecasting national energy consumption for the use of EPRI's Planning Staff and for use as general background information in the formation of energy policy. Increasingly, however, the need for regional (multistate) forecasts has grown because different R&D strategies and different policies have impacts that vary from region to region. Also, electric utility companies are showing more and more interest in increasing the availability and understanding of forecasting methods. Consequently, Demand and Conservation Program research is placing increasing emphasis on regional forecasts and service area forecasting methodologies.

Forecasting at the service area level

During the past two years, the Demand and Conservation Program has been exploring ways in which it could assist the electric utility industry in developing and disseminating information on service area forecasting methods. Since it is unlikely that any single method will ever prove to be universally preferred, the emphasis of this work has been to increase the number of forecasting options available to utilities so that it will be increasingly easy for a utility to find an approach that is particularly suited to its own needs.

While the program's first effort in this area, a model of energy consumption and economic growth for a metropolitan area, was completed some time ago (ES-187), this area of research began in earnest with the Load Forecasting Symposium held in December 1977. In this symposium a number of electric utility forecasters exchanged views on how to address particular forecasting problems (EA-1035-SR). A second symposium addressing different problems was held June 25–27, 1979, in Denver. The proceedings of this symposium will also be published.

One area that has long plagued utilities has been the quality of data used in constructing forecasting models. In most cases, utility forecasters are simply too busy to be able to carefully probe the underlying assumptions and methods used in developing the socioeconomic and other data used in their forecasting models. RP1478 is an assessment of the kinds of data that are used by electric utilities in forecasting. It investigates how data are developed, suggests alternative data series that may be used, and makes recommendations for future data development. This assessment is being done with primary reference to engineering end-use models and econometric models in use at Puget Sound Power and Light Co. (the cosponsor). The generality of the findings will be checked with four other utilities that represent different customer characteristics, ownership, and regions. This project will provide a readily accessible reference document for utility forecasters who are in the process of constructing or updating the models and have questions about where relevant data sources may be found and about the reliability of the data available.

A companion project seeks to determine whether models that have been developed by EPRI on state and national data can be applied at the service area level, in view of the constraints on data availability and quality that often exist (RP1477). This project takes three EPRI-developed models and three models developed by non-EPRI sources—two each for the residential, commercial, and industrial sectors—and investigates whether satisfactory data are available to estimate the models. If it appears that such models can be estimated, several participating utilities will attempt to apply the models to their own service areas. The contractor will assess whether the models are likely to be feasible candidates for forecasting purposes for utilities in general, as well as for the participating utilities. If the answers are promising, several new modeling options, heretofore not available at the service area level, will be candidates for implementation by utilities that wish to enhance or overhaul their forecasting systems.

Forecasting for multistate regions

An important issue for EPRI Planning Staff purposes and informed public policy debate is where economic growth, and consequently growth in the demand for electricity, will take place. Thus, a study has been undertaken to investigate the growth of electricity consumption in 15 multistate regions covering the conterminous United States (RP1293). The regions, which are aggregates of states (no region containing less than two), may be combined to correspond roughly to National Electric Reliability Council regions. The electricity consumption and economic growth models are being estimated by econometric techniques and will be sensitive to energy prices, prices of other factors of production, public policy, and other influences on energy consumption and regional economic growth. The project will provide forecasts of electricity consumption by consuming sector for each of the regions. It will be tied to results from another project (RP1008) to provide forecasts of load shapes as well as kilowatthour sales. In addition, the completed model will investigate the extent of the feedback relationship between energy prices and regional economic growth, an issue that is already becoming important for many public policy purposes and, depending on the size of the impact, may be important for R&D planning as well.

Forecasting national energy consumption

Forecasts of national energy consumption for all forms of energy are important for EPRI's internal R&D planning as well as for informed public debate on energy policy in general and on policy affecting electricity in particular. The Demand and Conservation Program's major effort in this area to date has been an in-house effort to synthesize the results of previous work on modeling energy consumption into a larger, more comprehensive model (*Demand 77;* EA-621-SR). The econometric models from this effort were assembled and run with alternative sets of assumptions concerning energy prices, economic growth, and government policy. Currently, work is proceeding on the demand 79 version of the model, which embodies the results of RP1098 for the residential sector, RP662 for the commercial sector, the in-house work of Larry J. Williams for the industrial sector, and RP757 for transportation.

A second study, RP1476, investigates the relationship between energy prices, inflation, economic growth, and energy consumption. This work is being done with a small, econometrically estimated, general equilibrium model of economic growth and inflation, coupled with an energy demand model that investigates the consumption of all forms of energy. *Program Manager: Robert Crow*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor / EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP411-4	Engineering Evaluation of a Conceptual Coal Conversion Plant Using the H-Coal Liquefaction Process	4 months	85.0	Fluor Engineers and Constructors, Inc. *N. Herskovits*
RP1179-8	Comprehensive Analysis of 6′ × 6′ Atmospheric Fluidized-Bed Combustion Facility Emissions	2 months	30.0	Battelle, Columbus Laboratories *C. Aulisio*
RP1199-5	Simplified Methodology for Economic Screening of Potential Low-Head, Small-Capacity, Hydroelectric Sites	6 months	41.2	Tudor Engineering *A Ferreria*
RP1260-14	Review of Surface Coal Mining and Reclamation Regulations	4 months	46.6	Environmental Research & Technology, Inc. *D. Golden*
RP1276-3	Evaluation of Dual Energy Use Systems, District Heating Survey	6 months	93.9	Energy Utilization Systems, Inc. *R. Mauro*
RP1412-5	Combustion and Emissions Characteristics of Coal-Derived Liquid Fuels	1 year	139.0	KVB, Inc. *W. Rovesti*
RP1457-1	Leachate Control and Monitoring Systems for Solid Waste	3 years	434.2	Matrecon, Inc. *D. Golden*
RP1651-1	Air-Gas System Dynamics of Fossil Fuel Power Plants—Analysis and Control Optimization	2 years	201.2	Westinghouse Electric Corp. *I. Diaz-Tous*
RP1655-1	Fundamental Studies in the Conversion of Coals to Fuels of Increased Hydrogen Content	2 years	723.0	Mobil Research and Development Corp. *L. Atherton*
RP1656-1	Methanol Synthesis Catalyst Preparation	13 months	100.0	United Catalysts Inc. *C. Kulik*

Number	Title	Duration	Funding ($000)	Contractor / EPRI Project Manager
Nuclear Power Division				
RP620-28	Study of Application of Electromagnetic Pump to 1000-MW (e) Pool-Type LMFBR	5 months	45.4	General Electric Co. *J. Duffy*
RP620-32	Conceptual Design of a 1000-MW (e) Heterogeneous Oxide LMFBR	9 months	221.7	Science Applications, Inc. *E. Fuller*
RP961-5	Validation of Real-Time Software Used in Nuclear Plant Safety Applications	8 months	94.3	GRC *A. Long*
RP1284-1	Electric Power Software Center	8 months	756.3	Technology Development Corp. *B. Zolotar*
RP1390-3	Refueling—Underwater Viewing Improvements	6 months	190.9	UNC Nuclear Industries, Inc. *T. Libs*
RP1446-1	Power Plant Availability Engineering Program	10 months	124.3	Pickard, Lowe and Garrick Inc. *R. Pack*
RP1451-1	Analysis of Nuclear Reactor Pressure Boundary Components Removed From Service	1 month	30.0	Southwest Research Institute *R. Smith*
RP1554-1	Growth and Stability of Stress Corrosion Cracks in Large-Diameter BWR Piping	2 years	1063.7	General Electric Co. *R. Jones*
RP1554-2	Instability Predictions for Circumferentially Cracked, Large-Diameter, Type-304 Stainless Steel Pipes Under Dynamic Loading (Phases I and II)	2 years	675.9	Battelle, Columbus Laboratories *R. Jones*
RP1576-1	Heat Sink Welding	1 month	30.0	Battelle, Columbus Laboratories *M. Povich*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Electrical Systems Division				
RP1427-1	Carrier Frequency Noise From High-Voltage Direct Current Converters	24 months	410.3	General Electric Co. *G. Addis*
RP1471-1	Detecting and Controlling Early Decay in Pressure-Treated Southern Pine Poles	36 months	106.1	The Research Foundation of State University of New York at Albany *R. Tackaberry*
RP1472-1	Integrated Control and Protection of Distribution Substations and Systems	4 years	3428.9	General Electric Co. *T. Kendrew*
RP1496-1	Development of Bulk-Graded, Filled Polymer Insulators	16 months	130.9	General Electric Co. *B. Bernstein*
RP7875-1	Fault Location Equipment for Gas-Insulated Transmission Lines	2 years	220.7	Ontario Hydro *T. Rodenbaugh*
Energy Analysis and Environment Division				
RP434-32	Electric Utility Rate Design Study	6 months	19.7	Resource Planning Associates, Inc. *R. Malko*
RP862-14	Development and Evaluation of an Automated Telephotometer System	9 months	97.7	SRI International *G. Hilst*
RP1303-2	Utility Modeling Forum	1 year	24.9	Terra Advanced Services Corp. *D. Geraghty*
RP1478-1	Assessment of Quality of Data Used in Utility Consumption Forecasting Models	11 months	54.9	Mathematical Sciences Northwest, Inc. *R. Crow*
RP1479-1	Geostatistical Estimation of Coal Seam Characteristics and Coal Reserves	18 months	95.0	Southern Illinois University *J. Platt*
RP1482-1	Supply Projections for Non-EPRI Technologies	11 months	253.9	Booz, Allen & Hamilton, Inc. *R. Urbanek*
RP1489-1	Expansion of Cooling-System Data Base to Include Environmental Descriptors	21 months	337.4	Ecological Analysts, Inc. *J. Reynolds*
RP1490-1	Immunotoxic Effects of Fossil Fuel Combustion Products	3 years	576.8	Battelle, Columbus Laboratories *L. Sagan*

New Technical Reports

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

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

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

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

ENERGY ANALYSIS AND ENVIRONMENT

Computer Software to Calculate and Map Geologic Parameters Required in Estimating Coal Production Costs

EA-674 Final Report (RP804)

This report documents methodologies and computer software developed at Oak Ridge National Laboratory to quantify and automatically map geologic and other cost-related parameters required to estimate coal mining costs. The software complements the detailed coal production cost models for both underground and surface mines, which have been developed for EPRI by NUS Corp. A detailed user's guide for implementing the software is included as an appendix. Also included is a brief review of studies on coal production, recovery, and resource calculation. This software system will be useful to utilities and coal mine operators in estimating costs through comprehensive assessment before mining takes place. Unlike most software of this type, which is developed privately, the ORNL–EPRI software is available to any potential user. *EPRI Project Manager: T. E. Browne*

Methodology for Assessing Ecosystem Effects Related to Intake of Cooling Waters

EA-1038 Interim Report (RP876)

Potential entrainment effects have been major factors in the evaluation of cooling-system alternatives. A critical review of the literature and data related to the entrainment of phytoplankton and zooplankton in power plant cooling water was undertaken by Lawler, Matusky & Skelly Engineers. The objective of the study was to develop a definitive documentation and assessment of the ecosystem effects of entrainment at the intake of thermal power stations located in lacustrine, riverine, estuarine, and marine systems. This report provides a broader analysis of the entrainment literature, focusing on the different approaches to assessment and commenting on their validity and problems. *EPRI Project Manager: J. Z. Reynolds*

Entrainment: An Annotated Bibliography

EA-1049 Interim Report (RP877)

The 604 annotated references in this bibliography on the entrainment of aquatic organisms at intake structures of thermal power plant cooling systems were compiled from published and unpublished literature for the period 1947 through 1977. This is one of a series of bibliographies on the assessment of cooling-system effects on the environment compiled by Oak Ridge National Laboratory and the Atomic Industrial Forum, Inc. The data base is being expanded to include all ecological effects associated with cooling systems. *EPRI Project Manager: J. Z. Reynolds*

Impingement: An Annotated Bibliography

EA-1050 Interim Report (RP877)

Oak Ridge National Laboratory and the Atomic Industrial Forum, Inc., compiled this bibliography of 655 annotated references on impingement of aquatic organisms at intake structures of thermal power plant cooling systems. The bibliography includes material published between 1928 and 1978 on impingement monitoring programs; impingement impact assessment; applicable law; location and design of intake structures, screens, louvers, and other barriers; fish behavior and swim speed as related to impingement susceptibility; and the effects of light, sound, bubbles, currents, and temperature on fish behavior. *EPRI Project Manager: J. Z. Reynolds*

Synthesis and Analysis of Ecological Information From Cooling Impoundments

EA-1054 Final Report, Vols. 1 and 2 (RP880)

Battelle, Pacific Northwest Laboratories undertook a literature review and assessment program to examine the effects of a once-through cooling mode of power plant operations on small, essentially closed aquatic ecosystems. The objectives were (1) to synthesize existing ecological information and data for cooling impoundments; (2) to analyze the information and data and derive technically sound conclusions concerning cooling-system effects on impoundments; and (3) to identify and to explain important effects that cannot be assessed with existing data. Ecological information related to plant effects was collected and evaluated for 14 sites selected on the basis of physical criteria and the availability of references. *EPRI Project Manager: J. Z. Reynolds*

Modeling Future Power Plant Location Patterns

EA-1063 Final Report (RP953)

A computer model was developed by Johns Hopkins University to generate probable locations for the facilities needed to meet postulated future energy requirements. The model uses linear programming to select the most probable locations within a region on the basis of physical and political factors. The linear program has four objective functions, based on transmission, coal supply, population proximity, and water supply considerations. This Applied Physics Laboratory location model is designed to be the link between large energy-economic models and cumulative environmental input models. *EPRI Project Manager: Richard Richels*

Chemical Effects of Power Plant Cooling Waters: An Annotated Bibliography

EA-1072 Interim Report (RP877)

The chemical effects of power plant cooling waters is the focus of an annotated bibliography produced by Oak Ridge National Laboratory and the Atomic Industrial Forum, Inc. The 950 references were extracted from the open literature (to the fall of 1979) and from environmental reports and impact statements prepared for or by the electric utility industry. Arrangement is by subject category, and indexes are provided. The topics covered are biofouling control methods; environmental effects of metals, corrosion inhibitors, and special-use compounds released in cooling waters; and site-specific effects of chemical discharges on water quality and aquatic communities. The intent of this project is to prepare and maintain a computer-searchable annotated data base on the assessment of cooling-system effects on the environment. *EPRI Project Manager: J. Z. Reynolds*

Proceedings: Advisory Workshop to Identify Research Needs on the Formation of Acid Precipitation

EA-1074 Workshop Report (WS-78-98)

This report documents the proceedings of a workshop sponsored by EPRI in August 1978 at Alta, Utah. The participants reviewed current knowledge on the formation of acid precipitation (rain and snow) and developed a set of specific recommendations for additional research deemed crucial to understanding the phenomenon and its causes. Six papers prepared for this workshop cover instrumentation and sampling, atmospheric chemistry, cloud processes, meteorological transport, and mathematical modeling related to acid precipitation. Thirty-eight research projects on instrumentation, field studies, modeling, laboratory studies, and data analysis and interpretation

are described, along with a discussion of rationale and resources required. *EPRI Project Manager: Charles Hakkarinen*

Electric Load Forecasting: Probing the Issues With Models

EA-1075 Final Report (RP875)

Changes in energy markets over the last decade have made capacity planning by electric utilities increasingly difficult but also increasingly important to producers and users of energy. This Energy Modeling Forum working group consisted of participants from utilities, research institutes, government agencies, universities, and consulting firms. The group focused on various approaches to the modeling of regional electricity consumption and investigated the new complexities and uncertainties that utility planners must confront in forecasting consumption. Eight scenarios were designed that assess the effects on electricity use of energy price changes, imposition of efficiency standards, movement to time-of-day pricing, and technical change. The working group also carried out comparative experiments with 10 electricity-forecasting models currently used by utilities or government agencies to investigate these scenarios. Results indicate the relative strengths of the various methods employed by these models and the potential importance of the impact on electricity use of the issues investigated in the scenarios. *EPRI Project Manager: Stephen Peck*

FOSSIL FUEL AND ADVANCED SYSTEMS

Preliminary Design of an Axial-Flow Hydrocarbon Turbine-Generator Set for Geothermal Applications

ER-513 Final Report (RP928-1)

The design of a 65-MW (e) turbine-generator set in which a hydrocarbon gas mixture is used as the motive fluid is outlined in this report by Elliot Co.; the set was designed for the power plant proposed for the Heber site in the Imperial Valley, California. Aerodynamic design considerations and estimated unit performance for three hydrocarbon gas mixtures are presented. The project determined that no advances in the state of the art are required to scale up turbine designs from present commercial practice and to construct a commercial-size axial-flow hydrocarbon turbine for geothermal applications. This information will be beneficial in selecting turbine configuration and assessing whether to proceed with geothermal development based on the binary cycle. *EPRI Project Manager: D. A. LeZotte*

Sludge Dewatering for FGD Products

FP-937 Final Report (RP786-3)

Six full-scale flue gas desulfurization (FGD) systems, including three lime-scrubbing and three limestone-scrubbing facilities, were evaluated to determine dewatering characteristics of the waste sludge produced. Pilot-scale centrifugation and bench-scale thickening and filtration tests were performed to determine equipment design and sizing criteria. Envirotech Corp. initiated this project to provide an understanding of dewatering technology for flue gas cleaning by-products and of the relationship between wet scrubber system parameters and sludge dewatering properties. Cost estimates for dewatering the six types of sludge are presented. This report provides a useful background to the various approaches available to utilities for dewatering by-product sludge from fly ash collection and FGD systems. *EPRI Project Manager: Richard Rhudy*

Coal Structure and Coal Liquefaction

AF-960 Final Report (RP779-16)

The amenability of a coal to liquefaction has been thought to be related to the chemical structure of the coal. The development of a good method to obtain information on the kinds and relative amounts of the aliphatic entities that make up much of this structure was the basis of a nine-month study conducted by Pennsylvania State University and being continued in a DOE project. A substantial cost saving could be achieved in the preliminary screening of a variety of coals if the amenability factor could be determined without a special test in a process unit. Significant progress in the development of an analytic method to provide detailed information on the aliphatic structure of coal and its liquefaction products was achieved during this study. Further work will determine the chemical structure of a wider range of coals and their relative liquefaction products to obtain a more universal correlation between various coals and their ease of liquefaction. *EPRI Project Manager: W. C. Rovesti*

Requirements Assessment of Wind Power Plants in Electric Utility Systems

ER-978 Final Report, Vol. 1 (RP740-1)

For this study, General Electric Co. first developed a rational approach to the consideration of wind power plants applied to electric utility systems, then performed a requirements assessment and a preliminary analysis of impact and penetration by studying wind generation in three actual utility systems. Conventional utility loss-of-load probability and production simulation methods were used, together with a wind turbine–generator performance model developed for the study. Evaluations were based on comparison of total utility generation system costs with and without wind plants and were expressed in terms of wind power plant value and cost. This project has verified that generation from intermittent resources like wind can be assessed by using standard utility-industry planning tools, such as system reliability and production-costing models. *EPRI Project Manager: Edgar A. DeMeo*

Combustion Demonstration of SRC–II Fuel Oil in a Tangentially Fired Boiler

FP-1029 Final Report
(RP1235-5 and RP1412-2)

KVB, Inc., reports on a combustion demonstration using a distillate fuel oil, SRC-II, produced by the solvent-refined coal process. The demonstration was conducted on a utility boiler located at the 74th Street Generating Station of the Consolidated Edison Co. of New York, Inc. The overall program was sponsored by EPRI, Consolidated Edison, and the New York State Energy Research and Development Authority in cooperation with DOE, which supplied the SRC-II fuel. Emissions and boiler performance were investigated at full load, half load, and three-quarter load for baseline and low NO_x (staged combustion) conditions. Results demonstrated that it is possible to substitute this higher-nitrogen-content SRC-II fuel for petroleum-derived fuel oil in a tangentially fired utility boiler over a range of normal operating loads without sacrificing boiler efficiency, while meeting all the current emission standards for conventional petroleum fuel oil. *EPRI Project Manager: William Rovesti*

Development of a Methodology to Incorporate Uncertainty Into Cost and Performance Data for Electric Power Generation Techniques

FFAS-1048 Final Report (TPS78-797)

This final report by Decision Focus, Inc., provides two case studies of uncertainty analysis applied to the economic comparison of alternatives to electric power generation. Uncertainty analysis helps to overcome the knife-edged characteristic of many economic evaluations where small, often insignificant, differences can control results. The analytic tools of decision analysis were applied. Quantitative models and sensitivity analyses identified the cost and performance variables that contribute most to overall cost uncertainty. Uncertainty in these variables was then expressed through subjective probability distributions, which were encoded during formal interviews with designated experts. *EPRI Project Manager: O. D. Gildersleeve, Jr.*

Development of the Zinc-Chlorine Battery for Utility Applications

EM-1051 Interim Report, 2 vols. (RP226-3)

The zinc-chlorine battery system is presently under development as a peak-shaving, energy storage device for the electric utility industry. Energy Development Associates reports on research to develop the necessary technology base for battery energy storage systems. The two principal objectives of this follow-on program were the preparation and analysis of a new 100-MWh plant design; and the design, fabrication, and initial testing of a 45-Wh battery module—the basic unit of the new 100-MWh plant design. Development programs on electrode research, electrolyte optimization, cell design, battery-performance verification, and low-cost materials and processes were conducted in support of these objectives. The report is published in two volumes, the first containing Parts 1–3 and the second containing Parts 4 and 5 and the three appendixes. *EPRI Project Manager: James Birk*

Substructure and Properties of Sodium Beta Alumina Solid Electrolytes

FR-1058 Final Report (RP252-2)

A study was conducted at Cornell University to determine the relationship between the impurities and microstructure of sodium beta alumina solid electrolytes because of the important economic benefits that could result from the use of long-life, high-energy-density batteries in load leveling. Part of this study involved an investigation of certain aspects of the electrolyte fabrication because the sintering process by which the electrolyte is made determines to a large extent the microstructure and impurity distribution. Specifically, this project demonstrated the effectiveness of transient liquid-phase sintering as a technique for more effective control of fine-grained beta alumina. The effects on ionic conductivity of the presence of silicon (as silicates), calcium (as calcium aluminates), and zinc (in solid solution) were quantified. The importance of the microstructure, particularly the role of the grain boundaries in the sodium ion conduction process, was explained. *EPRI Project Manager: K. R. Kinsman*

Assessment of Technical and Economic Feasibility of Zinc-Bromine Batteries for Utility Load Leveling

EM-1059 Final Report (RP635-1)

Gould Inc. was both a program-sharing partner and the contractor in this feasibility study undertaken to determine the viability of an advanced battery that uses an aqueous zinc bromide electrolyte for utility load-leveling applications. Gould's preliminary comparisons of bromine and chlorine as positive reactants in flowing-electrolyte cells led to promising proposals for storing bromine, minimizing self-discharge, controlling zinc dendrites, and developing a cost-effective cell design. The technical feasibility of Gould's design approach was demonstrated in several successive scale-ups of experimental cells under laboratory test conditions. *EPRI Project Manager: William Spindler*

Fatigue and Creep Behavior of Si_3N_4 and SiC for Gas Turbine Applications

FP-1060 Final Report (RP271)

Columbia University reports on the mechanical response of two important silicon ceramics at the extremes of strain rate application. The materials studied were representative of ceramics currently being considered for use in such advanced power system components as gas turbines and heat exchangers, where the advantages in performance are designed to be realized at temperatures that exceed the capability of uncooled metal alloys. This stands as one of the first studies to inspect two important material characteristics—response to cyclic loading (fatigue) and time-dependent deformation and fracture (creep). Objectives were to characterize the fatigue and high-temperature creep behavior of SiC and Si_3N_4, prepared by hot pressing, and to correlate the measured properties with microstructure, impurities, and thermal and mechanical history. Creep characteristics were assessed in uniaxial tensile lading, and fatigue properties were determined at ultrasonic frequencies. *EPRI Project Manager: K. R. Kinsman*

High-Strength Austenitic Alloys for Generator Retaining Rings

FP-1061 Interim Report (RP636-2)

Generator retaining rings are large, one-piece steel components placed at either end of a generator rotor to hold the field windings in place. The objective of this project by the University of California at Berkeley was to develop a nonmagnetic, strong, tough, hydrogen-resistant alloy, with these desirable properties achieved by heat treatment alone. Such an alloy would have properties superior to the state-of-the-art materials and could be produced by processing techniques that are more attractive than current manufacturing methods. The manipulation of alloy compositions and implementation of new processing techniques have resulted in the development of a series of alloys, some of which show high potential for application in generator retaining-ring manufacture. *EPRI Project Manager: K. R. Kinsman*

Development of a Standard Methodology for the Correlation and Extrapolation of Elevated Temperature

FP-1062 Final Report, Vol. 1 (RP638-1)

Techniques of extending creep rupture data to times and temperatures that are of interest in utility application are provided in this report by the Metal Properties Council, Inc. This in-depth evaluation is assembled in two volumes. Volume 1 provides a state-of-the-art critique of methodologies for the correlation and extrapolation of elevated-temperature creep and rupture data and a summary of a workshop on that topic. The report concludes that the attempt to standardize the technology of creep rupture data evaluation will help focus research activities on a common goal. *EPRI Project Manager: K. R. Kinsman*

Alloy Design for Long-Time Stability

FP-1068 Final Report (RP253-1)

If in the future an increasing number of fossil-fired power plants will be more highly stressed because they must operate in a load-following mode, it is important to produce improved methods for avoiding embrittlement and/or knowing when embrittlement is imminent. Columbia University undertook research to evaluate the potential for precipitation of a brittle phase—the sigma phase—in stainless steels and in superalloys during the expected life of these materials in steam electricity-generating stations, nuclear power plants, and gas-turbine power generators. For a modest cost, a new, significantly more powerful tool for assessing the risk of sigma-phase embrittlement was developed. The conflicts between the existing risk assessment procedure, PHACOMP, and the method developed in this research, SIGMA-SAFE, were resolved in favor of SIGMA-SAFE by measurements on power-plant alloys. *EPRI Project Manager: R. H. Richman*

NUCLEAR POWER

Large-Pool LMFBR Design

NP-1016-SY Summary Report (RP620-26 and RP620-27)

The design effort reported here and performed by Westinghouse Electric Corp., Advanced Reactors Division, and by Stone & Webster Engineering Corp. is an extension of past design effort and continuous concentration on those parts of the nuclear island unique to a commercial-size, pool-type LMFBR. In particular, the work covers the reactor vessel, deck, rotating plugs, upper and lower internals, internal plenum separator system, pumps, cold traps, intermediate system layout, containment/confinement system, plot plan, and residual heat removal systems. Preliminary thermal, hydraulic, stress, and system analyses are also presented. Goals for this period were achieved, namely, to refine the design status of components conceptually designed in a prior phase and to complete the conceptualization of the remainder of the nuclear island unique to the pool-type systems. *EPRI Project Manager: G. D. Baston*

Acoustic Techniques for Measuring Stress Regions in Materials

NP-1043 Interim Report (RP609-1)

Considerable savings are possible if surveillance techniques can be developed to replace some of the periodic inspection requirements of nuclear power plants. The primary objective of this project undertaken by Stanford University was to develop methods for the precise measurement of residual stress, to use these methods to make measurements on specific metallic samples, and to compare the results with calculated values. A computer-controlled system that produces quantitative two-dimensional images of stress contours in planar metal samples has been constructed and used to study stress distributions from both residual and externally applied stresses in aluminum, steel, and copper specimens. *EPRI Project Manager: G. J. Dau*

Application of Statistical Evaluation Methodology to the RELAP Code

NP-1053 Final Report (RP768)

This report covers a segment of work to develop methodology for the probabilistic quantification of uncertainties and the identification of conservatisms in nuclear power plant safety analyses. The developed procedure would be a computation substitute for complicated nuclear safety analysis computer codes. Westinghouse Electric Corp. studied a process that involves the use of best-estimate codes to determine the output distribution induced by input uncertainties. Westinghouse concluded that the developed procedure provides a reasonable approach to studying the effect of uncertainties in a complex thermal-hydraulic code, such as RELAP. *EPRI Project Manager: Boyer Chu*

Multireactor, Nonequilibrium, Fuel-Cycle Cost Minimization Program With Applications to Plutonium Recycle and Limited Separative Work

NP-1055 Final Report (RP300-1)

The primary objective of the EPRI plutonium recycle program has been the development of a technical base for the safe and effective use of plutonium in LWRs. Consistent with that objective is the investigation of utilization strategies to quantify the potential operating cost savings and to assess the impact of regulatory positions on the use of plutonium fuels. Stanford University has developed a program for the calculation of fueling requirements and fuel costs of a system of PWRs. The computer-based methodology used in this project is significant because it takes account of current thinking about the equilibrium fuel cycle and deals with the complexities of present-day nuclear fuel management. *EPRI Project Manager: R. N. Whitesel*

Measurement and Analysis of Gamma-Ray-Induced Contamination of Neutron Dosimetry Procedures Used for Reactor Pressure Vessel Applications

NP-1056 Final Report (RP827-1)

To obtain neutron flux and spectrum information below 1 MeV, fission foils are often employed. This study was conducted to qualitatively establish that photofissions do contribute to the activity produced in the foils, which if not corrected, could erroneously overpredict the neutron flux incident on the pressure vessel. Using the pool-type reactor at the University of Virginia at Charlottesville, Science Applications, Inc., performed measurements and calculations to assess the effect of photon-induced activity in neutron spectra measurements for pressure vessel dosimetry. Results indicate that photofission effects can be significant. Overestimates of the neutron flux can cause an overprediction in the radiation damage to the pressure vessel, which may, in turn, lead to underestimates of safety margins of pressure vessels or discrepancies between experimental and calculation benchmarks. *EPRI Project Manager: Henry Till*

Analysis of Utility Industry Data Systems

NP-1064 Final Report (RP771-1)

This 20-month project evaluated three data systems on their ability to supply data necessary to perform basic reliability and availability analyses applicable to power plants and their equipment. These systems are the Equipment Availability System (Edison Electric Institute), Operating Units Status Reports—Gray Books (U.S. Nuclear Regulatory Commission), and the Nuclear Plant Reliability Data System—NPRDS (American National Standards Institute). Stone & Webster Engineering Corp.'s aim was to determine what useful information on power plant performance could be gained from the data and to identify specific limitations and deficiencies in the data systems. This report provides a first attempt at documenting inadequacies of the data systems—inadequacies that have to be addressed if the industry is to have responsive performance data systems in the future. *EPRI Project Manager: William Lavallee*

Evaluation and Testing of Actinide Cross Sections

NP-1067 Final Report (RP707-2)

The recently released version 5 of the National Reference Nuclear Data File (ENDF/B) actinide library is based on the data produced (in the energy range below 10 keV) under this project conducted by E. I. du Pont de Nemours & Co., Inc. The extensive heavy actinide cross-section library at Savannah River Laboratory (SRL) was converted into the ENDF/B format and tested against SRL's heavy isotope experience. The objectives of this project were the preparation, review, and testing of the new data file; the reevaluation of the cross section of nuclides for which new experimental data are available; and the testing of the new evaluations against SRL actinide production experience. These new data offer the possibility of making significant improvements in the actinide library, particularly in the low-energy resolved-resonance regions of interest to thermal and near-thermal systems. *EPRI Project Manager: Odelli Ozer*

RETRAN Analysis of the Turbine Trip Tests at Peach Bottom Atomic Power Station, Unit 2, at the End of Cycle 2

NP-1076-SR Special Report

EPRI and Oregon State University used an analytic model based on and implemented by the RETRAN code in its present version (RETRAN-01-RET12D) to analyze turbine trip tests performed at the Peach Bottom Atomic Power Station, Unit 2, BWR during April 1977. Results obtained from this analysis and from an extensive set of associate sensitivity studies lead to a deeper understanding of the phenomena and mechanisms relevant to this type of transient. For the purpose indicated, the present version of the RETRAN code contains all the elements and flexibility needed for the formulation of a unique model. Characteristics exhibited by this model are in very good qualitative agreement with those observed during the tests and provide important evidence of the code's ability to model BWR turbine trips and similar transients. *EPRI Project Manager: Joseph Naser*

ELECTRIC POWER RESEARCH INSTITUTE
Post Office Box 10412, Palo Alto, California 94303

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