Looking Into Indoor Air

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Cover: For 20 years air quality regulations have focused on the effluent levels found outdoors. The search for a total-exposure air quality model now directs us to look at the air indoors, where modern society spends most of its time.

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Getting the Inside Story

EPRI has always had a strong and active interest in the quality of the outdoor environment, especially air quality, which is one of the principal research areas of the Environmental Assessment Department. Another aspect of air quality is now gaining more and more attention at EPRI—indoor air quality, particularly in homes. This interest is largely based on the question of whether accumulations of pollutants indoors present a risk to human health. Federal and state air quality regulations designed to protect human health do exist, but such regulations are based on outdoor air quality. The problem is that people spend more than 75% of their time indoors; moreover, individuals with such pulmonary problems as asthma and bronchitis—the people the regulations are specifically designed to protect—spend nearly all their time indoors. One may ask, therefore, whether regulations based on outdoor concentrations of pollutants are realistic in terms of a person's total exposure to pollutants in the air.

Research managed by both EPRI and the federal government has shown that the air quality indoors may differ considerably from that outside a house. Some pollutants are at higher levels indoors, some are lower, and others are about the same. In some instances, a house acts as a shield against outdoor pollutants. In others, normal household activities or even the house itself can be a source of pollution. How serious is indoor air pollution in terms of human health? What is the effect of weather stripping, which reduces the exchange of air between the house and the outdoors? What is the total exposure of humans to airborne pollutants? These are some of the questions our research seeks to answer.

The overall EPRI research on indoor air quality focuses on three facets. The first involves the relationship between indoor and outdoor air quality; specifically, whether models can be developed that will allow us to estimate indoor concentrations of pollutants on the basis of outdoor measurements. This capability is important in developing so-called total exposure models—models that allow us to estimate total exposure to pollutants during overall daily activities. Successful development of total exposure models will allow us to pursue the second part of EPRI's research agenda—meaningful community epidemiologic studies on the relationship between air quality and pulmonary dysfunction. We feel that a correlation between human health and air quality will be of real value only if indoor exposure is included as part of air quality analysis. We also want to know the effect on indoor air quality of measures to increase energy efficiency in the home, including such approaches as insulation and passive solar heating.

An active EPRI research program that addresses these concerns is now under way, managed through both the Environmental Assessment Department and the Energy Utilization and Conservation Technology Department. Results expected in the next two years should put us well on our way to a better understanding of air quality and its effect on human health.

Ralph M. Perhac, Director
Environmental Assessment Department
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Authors and Articles

People might be inclined to stay indoors on a smoggy day to avoid the pollutants in the air outside. But concentrations of some regulated pollutants are often higher indoors, and many air constituents that originate there tend to linger, especially as we button up our houses to save energy. **Air Quality in the Home** (page 6) reviews some of the thinking and research now being done to prevent a collision between the criteria of indoor air quality and those of energy conservation.

For technical background, *Journal* feature editor Ralph Whitaker turned to EPRI's Energy Analysis and Environment Division and to Ralph Perhac, director of the Environmental Assessment Department since 1980. Perhac came to the department in May 1976, having been with the National Science Foundation for 2 years as director of a program on the environmental effects of energy. For 7 earlier years he was a professor of geochemistry at the University of Tennessee. Before 1967 Perhac worked for 14 years in geochemical research and geologic exploration for Exxon Production Research Co., American Overseas Petroleum, Ltd., and the Atomic Energy Commission. He holds BA, MA, and PhD degrees in geology and geochemistry from Columbia, Cornell, and Michigan universities.

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Whenever many structures are built from the same design, as is the case with utility transmission towers, excessive design conservatism means an ever-increasing cost burden because of the specified use of unnecessary material. **Redesigning Line Structures** (page 15) describes the scope of field tests that will better define just where excessive conservatism begins. Jenny Hopkinson, *Journal* feature writer, developed the article with the cooperation of Richard Kennon, manager of the Overhead Transmission Lines Program in EPRI's Electrical Systems Division since 1978. An EPRI staff member since 1975, Kennon previously worked for Westinghouse Electric Corp., successively in sales and engineering, eventually as manager of capacitor equipment engineering. He has a BS in electrical engineering from the California Institute of Technology and an MBA from Indiana University.

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A question frequently asked in technological circles these days is, What's the risk involved? The answer is not always clear. **Toward Better Methods of Risk Assessment** (page 22) discusses EPRI research designed to improve methods of risk assessment and to answer questions about risk in electric utility design and operating practices. The author, science writer John Douglas, conferred with Ronald Wyzga and Paolo Ricci, who plan and manage EPRI research in environmental risk assessment.

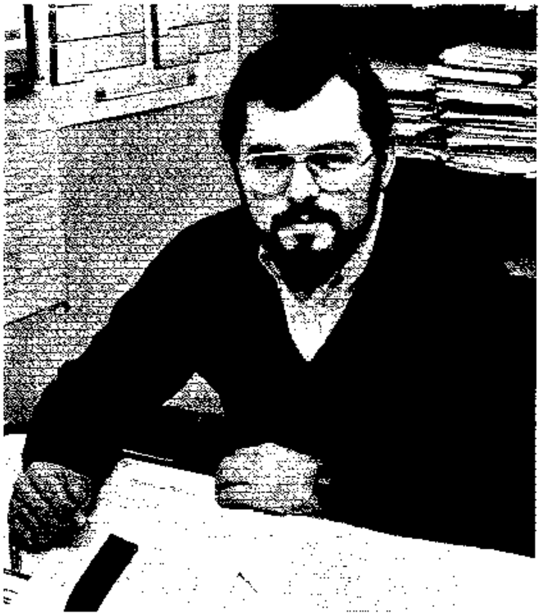
Wyzga was recently appointed Technical Manager of Environmental Integration for the Energy Analysis and Environment Division. He had been a program manager in the Environmental Assessment Department since 1978, having joined EPRI in 1975. Wyzga was formerly with the Organisation for Economic Co-operation and Development, working in Paris and serving as a professor of statistics in the American College there. From 1966 to 1971 he was an instructor at the Harvard School of Public Health, where he earned a PhD in biostatistics. Wyzga also has a BA in mathematics from Harvard College and an MS in statistics from Florida State University.

Paolo Ricci came to EPRI in 1979 as a project manager for risk assessment. During 1982 he is on loan to Italy's National Committee for Nuclear Energy. Ricci was formerly a research associate at Harvard University and before that was on the University of Ottawa faculty for three years. Between 1966 and 1972 he was an engineer successively with the consulting firms John D. Giannini Co. and Justin & Courtney Co. Ricci holds an MA in economics from Temple University, an MPA from Harvard University, an MS in environmental health from Drexel University, and a PhD in environmental engineering and science from Drexel.

Beginning this year, the *Journal* will publish the EPRI *Annual Report* in lieu of the regular April issue. In addition to statements on EPRI's operations and its financial position, the 1981 *Annual Report* will review last year's research.

Kennon

Perhac



Ricci

Wyzga

The average person breathes indoor air 75% or more of the day. Yet existing regulations are based solely on outdoor concentrations. Indoor levels of many contaminants are typically higher than outdoors, and common household items such as gas stoves, paint, cigarettes, bath towels, fireplaces, cleaning chemicals—even glued furniture joints and the walls themselves—can produce significant amounts of regulated substances. Efforts are now under way to create a total-exposure air quality model that will improve epidemiologic studies of human health.

Air Quality in the Home

Security and snugness. Nothing beats the image of the family home on a winter night, windows and doors tightly closed against wind and snow outside, a crackling fire for warmth and comfort inside. Of course, there must be family members: father with his pipe and slippers, mother with her sewing, children playing on the carpet and occasionally patting the shaggy head of their faithful dog.

The unexpected fact about this carefully constructed image is that it could represent worse air quality than the downwind side of an industrial city or one of its downtown street corners at rush hour. In an environment-conscious society, there goes security.

Or does it? This startling contradiction makes a point about the indoor environments where most of us spend most of our time. It also introduces important qualifications that stand in the way of tempting but premature conclusions.

How much exposure to what?

The point is that homes, offices, cars, and factories are the source of some air constituents that are not found outdoors; they are also the site of higher concentrations of other constituents. For example, as you briskly dry after a shower, your fluffy towel sheds enough lint to bring the particulate loading of the bathroom air to a much higher level than that present in the outdoor ambient air.

Of course, this high concentration of lint is only momentary. When you hang up your towel and leave the room, normal air exchange with the rest of the house and with the outdoors begins to dilute the concentration, substantially limiting your exposure. Still, the example brings out an important caveat that must be considered in comparing indoor and outdoor air quality: towel lint and many other constituents of indoor air, although acknowledged to be foreign matter, are not generally thought to be dangerous at the concentrations we normally encounter. Concentration levels are key to indoor air quality, whether the constituent is the aerosol from a spray deodorant or the dust from a floor mop.

Establishing a substance's health effects involves a great deal of careful research and testing. With the notable exception of cigarette smoke, indoor contaminants have not been evaluated extensively. For this reason, professionals today are cautious in discussions of indoor air quality. The intent is to deal only with what the air constituents are and in what concentrations they occur. Whether the substance is actually a health hazard is generally not dealt with at this stage.

Of course, air quality is subject to value judgment on esthetic grounds—appearance, visibility, odor—before any constituent concentration is high enough to be harmful rather than just unpleasant. *Pollution* and *contamination* are long-established descriptions for perceptible outdoor hazes and odors of any kind. And when the wind brings industrial smells into our neighborhoods, the terms are bound to be used in talking of indoor air quality. However, few airborne species are known pathogens, and still fewer appear in our usual living and working spaces.

The most significant fact is that indoor air is our prevailing environment—probably 90% of the time, according to an interagency federal research group, and even more for sensitive population fractions such as babies, the very old, and people who are sick or in institutions. Does all this mean that we have been barking up the wrong tree by regulating outdoor air quality, with maximum permissible ambient concentrations and emission rates for particulate matter, a number of gases, and several trace elements? Not necessarily, because air quality has relevance for many ecologic systems (forests, agriculture, rivers, and lakes among them). But the major concern is human health, and it is well established that human activities are churning out increasing quantities of an ever larger variety of particles and gases. It is time to learn what follows us indoors (or originates there), whether the concentrations are different, and if so, why.

Indoor levels, outdoor pollutants

Ralph Perhac has headed EPRI's Environmental Assessment Department since 1980. Research in the programs under his direction may deal with any environment, most obviously those of land, air, and water and the systems of plant and animal life and enterprise they support. EPRI is most interested in the influences of environmental agents and factors introduced by the generation and transmission of electricity (and to some extent the supply of utility fuels and materials and the end use of the electricity). But it is sometimes necessary to look beyond the phenomena and products of utility operations, especially when natural processes in the biosphere produce some of the same effects but to an unknown degree. This is especially true in the matter of air constituents.

When EPRI first began to investigate indoor air quality, it focused mainly on air constituents already being monitored (and many of them regulated) outdoors. The point was to compare indoor and outdoor concentrations and, where possible, define the relationships and find the reasons for differences. Because individuals spend so much time indoors, large and consistent differences would be important in the scientific study of the effects of air pollution. The information also could be useful to those involved in setting air quality standards.

The initial sponsored research dealt largely with pollutants produced in fossil fuel combustion. Sulfur dioxide, nitrogen oxides, ozone, carbon monoxide, carbon dioxide, and certain hydrocarbons were the gaseous species of interest. Particulates were sampled and analyzed to differentiate the fraction of respirable matter and quantities of trace metals and various compounds.

Geomet, Inc., conducted the measurement and analytic effort for EPRI over a two-year period, 1978–1980, during which ten single-family houses and two office buildings in and around Boston were successively instrumented and monitored for two-week periods. Gross characteristics of the houses and their occupancy were cataloged in advance. For example, four houses were all-electric, and six used natural gas for cooking and heating. Five houses had occupants who smoke, two had fireplaces, and one had a wood stove. Occupancy ranged from two to six people, and five houses had dogs or cats.

Air quality was monitored at three points indoors (typically, the kitchen, a bedroom, and the living room) and at one point outside, together with four items of weather data: temperature, humidity, wind direction, and wind speed.

Hourly rates of air turnover were also calculated. This is the volume of air exchanged between indoors and outdoors and the basis for changes in various concentrations. Air exchange was computed from measurements of building volume and the timed decline in the concentration of a tracer gas (sulfur hexafluoride) injected into the indoor air. The relative tightness of house construction is a major influence on air exchange. Other variables are the use of windows and heating and air conditioning systems to control temperature, patterns of entry and exit, and wind intensity against specific leaks.

Air exchange in the EPRI-tested houses was found to range from as little as 0.5 to as many as 1.3 complete turnovers in one hour. The average was about 1.0.

Oxides and particulates

Findings from the study are provocative rather than conclusive. Researchers accustomed to relatively ponderous, weather-related shifts in outdoor air quality were surprised by fast and marked changes—virtual spikes—in the indoor records of constituents traceable to specific human activities, such as the use of stoves or cleaning fluids.

The maximum concentrations named in ambient air quality standards are time-averaged values, the averaging periods being as short as one hour and as long as one year. Because the EPRI-sponsored measurement program allowed only two weeks at each test site, it was not possible to draw precise comparisons with all air quality standards.

Measured outdoor concentrations of regulated pollutants seldom exceeded federal standards. And for indoor concentrations traceable only to outdoor sources of those pollutants, the same was true. In fact, sulfur dioxide and ozone levels were typically lower indoors than out, although ozone was the subject of occasional spikes exceeding the one-hour outdoor standard of 120 ppb.

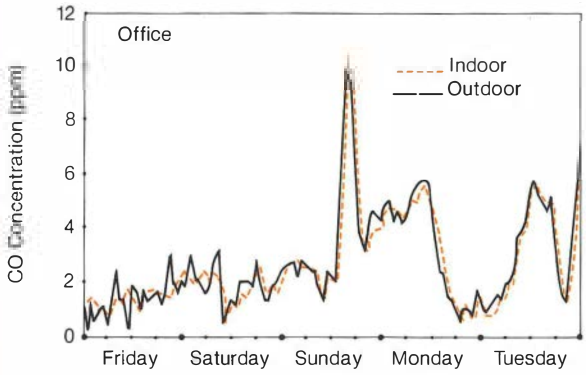
Offices and all-electric houses generally tracked the outdoor air quality, rising and falling at about the same rates and times of day. Houses with gas facilities understandably showed somewhat higher concentrations of carbon monoxide and nitrogen oxides. Values of both peaked when meals were being cooked. However, 24-hour indoor average values for nitrogen oxides were higher than outdoor averages for the same period in all-electric as well as gas houses. This suggests that indoor levels of nitrogen oxides are augmented from outdoors but do not then disperse or react so quickly to form other compounds.

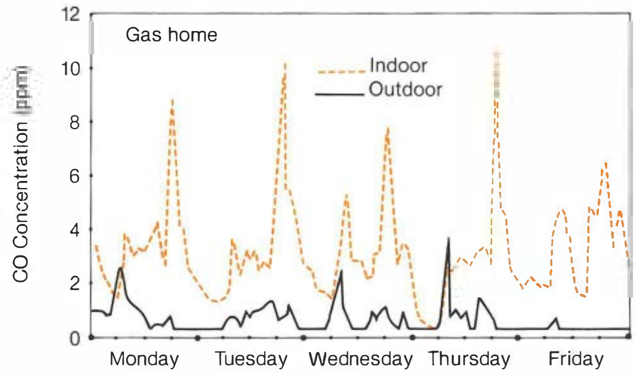
Nitrogen dioxide is a constituent for which comparisons of concentrations are awkward because no short-term averages are given in the federal standard; the federal standard of 50 ppb is an annual average. The only other basis, even for academic comparison, is California's one-hour average of 275 ppb. EPRI's test program in the Boston area never exceeded one-hour average values of 196 ppb outdoors or of 241 ppb indoors. The highest 24-hour averages were 70 ppb outdoors and 102 ppb indoors, not badly out of line with the one-year federal limits.

Particulate levels indoors were found to be higher than outdoors in almost all cases, regardless of what room concentration was considered. On average, living room concentrations were about 50% higher than outdoors. (In houses with smokers, the difference was 300%.) These differences are startling, so it must be emphasized that the outdoor concentrations never exceeded either the primary federal standard (260 $\mu g/m^3$) or the secondary standard (150 $\mu g/m^3$). Also, the two office buildings in the test program must be distinguished: their particulate concentrations were always slightly lower than outdoor levels, because of their air conditioning and filtering systems.

Analysis of air samples permitted separate measurement of respirable particles, defined for this study as particles in the range of 0.5–3.5 μm in diameter. Their occurrence was about the same as for particulate matter in general, being highest in houses with smokers and on occasions when fireplaces or (to a lesser extent) woodstoves were in use. Fireplaces are incontrovertibly serious

The high air exchange rate in office environments where mechanical air-handling systems are used cuts indoor carbon monoxide (CO) concentrations to about the same levels recorded outdoors (left graph); indoor CO concentrations in all-electric residences are slightly higher, although they still track the outdoor changes very closely. In contrast, the significantly higher CO levels in a residence with gas facilities (right graph) do not closely follow changes in outdoor concentrations, being more dependent on indoor activities, such as cooking and heating. Note the regular occurrence of sharp peaks around the dinner hour.





contributors to reduced indoor air quality, just as suggested by the vignette of the family living room. When wood was burned, concentrations of particulates increased four or five times; the 150-$\mu g/m^3$ secondary standard for total suspended particulate matter in the outdoor air was always topped in the indoor air by the smaller, respirable fraction alone.

Benzo-a-pyrene (BaP) is an organic particulate derived mainly from the combustion of coal, wood, and refuse and to a lesser extent from automobile engines. It is a carcinogen, so measurements of BaP were added to the Geomet test plan. For the most part, indoor BaP concentrations were about 2–3 ng/m^3, the same as or only slightly higher than outdoors and not influenced by the different characteristics of house type or occupancy. But when wood was burned in either fireplaces or stoves, indoor BaP levels were as much as 20 times the outdoor levels. Even when averaged over 24 hours (the fire having burned for less than 3 hours), the concentration in one instance was 4.7 ng/m^3. The urban outdoor average, on an annual basis, is only 0.9 ng/m^3. BaP exposure in woodburning homes may be significant to public health.

Other compounds and trace metals

Of the air pollutants generated in houses, particulates come first to mind because they are associated with the traditional fires of heating, cooking, and tobacco smoking. But other agents are reckoned in assessments of air quality today, and they were monitored in the EPRI project.

Nonmethane hydrocarbons (NMHC) are subject to regulation if ozone concentrations exceed statutory limits; the guidance NMHC concentration is then 0.25 ppm, as averaged over the three-hour period from 6:00 to 9:00 a.m. The standard is so defined because NMHC is a photochemical reactant in the formation of ozone and smog. In EPRI's Boston area investigation, three-hour outdoor NMHC levels topped the guidance standard by an order of magnitude (7.4 versus 0.25 ppm), and indoor levels topped the standard by two orders (24.2 versus 0.25 ppm). One-hour indoor concentrations were even higher, traceable to such activities as the use of paints and cleaning agents. Two other categories of potential pollutants were monitored: two compounds that evolve in part from the sulfur and nitrogen oxides of combustion emissions and six metals that may occur in trace amounts.

Sulfate concentrations ranged from 2.0 to 10.0 $\mu g/m^3$ indoors and outdoors, typically a little lower indoors. The exception (paralleling observations in other studies) was found in houses where matches were frequently used by smokers and in lighting stoves. Nitrates result from the combination of nitrogen oxides and water vapor, inevitable in the kitchens of houses with gas stoves. Maximum 24-hour averaged concentrations in such cases were 1.5–2.0 times the outdoor levels; in all-electric homes the indoor levels were generally less than found outdoors.

Manganese levels, though monitored for only two weeks, compared favorably with three-month nationwide figures compiled six years ago. Lead and vanadium concentrations were mostly lower indoors than outdoors; there were no significant indoor sources, not even paint and plumbing. Indoor levels of arsenic, cadmium, and iron were likewise lower, except in houses occupied by smokers. Elevated iron concentrations are not explained, but arsenic and cadmium are known to be in cigarettes, the arsenic believed to be a residue from insecticides used on tobacco plants. The levels noted were considered typical; the arsenic and cadmium measurements, respectively, were three and five orders of magnitude below occupational safety levels.

New air quality model needed

EPRI's Boston project findings are points at the end of a trend line, confirming prior knowledge and adding to it. On the one hand, if outdoor ambient air standards are the benchmark, few indoor levels of regulated pollutants were found to be often or consistently excessive. On the other hand, using outdoor measurements as the benchmark, several pollutants commonly occurred in higher concentrations indoors: carbon monoxide, nitrogen oxides, NMHC, and particulate matter, including BaP where wood fires burn.

At least as important as the specific data is the fact that indoor and outdoor air quality are often so different. This raises other issues that need to be probed.

□ Better definition of proportionate exposure to indoor and outdoor environments could aid the development of more accurate models to assess the consequences of air pollution on health in various population groups.

□ Lengthy indoor exposure calls attention to the factors that cause indoor concentrations to become and to remain higher than outdoor levels. The most obvious is the air exchange rate, always influenced by human traffic in and out of buildings but increasingly affected by actions being taken today to insulate and weatherize for energy conservation. New houses, in particular, are designed on a buttoned-up basis with features that collect solar energy for heat and minimize air exchange so as to conserve that heat.

□ Indoor exposure time also raises a point about the identities and sources of air pollutants. Because of its utility industry auspices, the EPRI project concentrated on indoor manifestations of outdoor pollutants, the ones associated with industrial combustion. But reviewing the measurements, not to mention following the daily news for any period of just a few months, shows the presence and occasionally troublesome effects of substances previously unsuspected of being air pollutants. If utilities are in good conscience to encourage the energy and money savings of conservation—acknowledged to be the cheapest energy "source"—the effort needs to be paralleled by new understanding of the implications for indoor air quality and health.

Recognizing indoor exposures

Outdoor ambient air quality standards have always been subject to question on many bases, especially the precision and realism of specific values—for example, the maximum concentration levels and exposure times set to protect human health. Questions have also been raised about the relative importance of the agents defined as air pollutants.

Many such questions stem from the wide uncertainty about how pollutants are formed and transformed in the atmosphere, how they move and disperse and recombine, and how they act on ecologic systems in general, not just on human health. The questions are important because compliance with air quality standards, especially the control of combustion emissions, is expensive for many affected companies and entire industries. (The cost flows through to consumers and is likewise expensive for them, but it is not separately evident in the cost of living as it is in the cost of doing business.)

Epidemiologic studies have been conducted to defend the numerical values used in air quality standards. A principal approach has been to compile records of outdoor air quality measurements in several areas and search out correlation with epidemiologic data for respiratory disease in the same areas. The task is enormously complicated by demographic influences on the disease data. In fact, using this aggregate approach, a direct link is difficult to establish between human exposure and the presence

or absence of disease in individuals. It is becoming recognized that the sole use of stationary outdoor monitoring data is a serious shortcoming, perhaps the major one, in assessing exposures for either individuals or populations.

The professional community in air quality and environmental assessment, including EPRI's Perhac and his colleagues, sees the need to develop a new model of population exposure to air pollutants, a model that gives weight to the preponderant time spent indoors and recognizes the different identities and concentrations of pollutants typically found there. Considered as one side of an equation, such a model could be set against appropriate epidemiologic evidence for the existence of an exposure-disease relationship. If the exposure patterns and epidemiologic data are reasonably correct, it should be possible to estimate the magnitude of hazard from air pollution in a given population.

Newly modeled estimates could put into perspective the part that industrial combustion plays in the health hazards posed by today's complex air environments indoors and out. Those estimates might also be the basis for a revised regulatory approach to air quality control.

Articulating composite indoor-outdoor air quality policy would be an interesting challenge. For outdoor air quality control, the action path is well established: initiation of regulatory procedures, establishment of emission limitations, and industrial response to those limitations through use of pollution control technologies or altered patterns of plant and process function. The prospects for dealing with indoor air quality issues do not have any such precedent for measurement or control strategy. How regulation or education regarding indoor pollution hazards could be accomplished can only be conjectured.

Clearly, though, the challenge is one that crosses conventional lines of technical disciplines, industries, government jurisdictions, and geographic regions. Immediately evident is the need for self-consistent, comparable data, in turn calling for uniform instrumentation and practices in collecting and analyzing indoor air quality data.

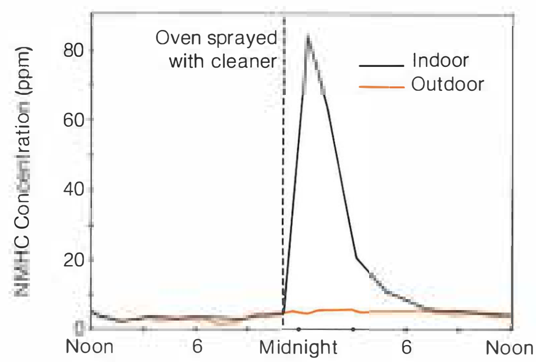
Assessing air exchange

The indoor-outdoor rate of air exchange has also come to be seen for its connection with energy use. Storm windows, caulking, plastic barriers, and weather stripping—the most obvious measures to conserve heat—have led to a widening range, but especially a downward trend, in the air exchange behavior of U.S. houses. The suburban Boston residences in EPRI's project ranged from 0.5 to 1.3 exchanges per hour. But building materials are becoming available and design research is afoot that will hold the exchange rate down to as little as 0.1 or 0.2.

Perhac and other air quality researchers who observe this trend are cautious. "If ambient air quality standards are true measures of safety, then we see little need for concern where air infiltration in a house produces at least 0.5 exchange per hour." But for tighter houses, there simply are not enough data to draw firm conclusions about health effects.

This implicit conflict between energy conservation and indoor air quality is a distinct disappointment for many electric utilities. The Bonneville Power Administration is a case in point. Urged by the times and ultimately required by congressional action to invest in energy conservation where that would cost less than the installation of new generating capacity, BPA developed a regionwide program to assist its utility customers in auditing houses and providing financial

Patterns of household activity can have extreme effects on air quality in the home. In a residence with a wood stove (left), average levels of benzo-a-pyrene (BaP) were significantly higher than those outdoors except on days 2, 6, and 11, when the stove was not in use. In another case (right), a commercial oven cleaner caused levels of nonmethane hydrocarbons (NMHC) recorded in a kitchen to increase 16-fold in less than 90 minutes.



assistance for energy conservation measures that would be cost-effective. Indoor air quality questions came to be a limiting factor when BPA, in its assessment of environmental consequences, could not flatly conclude that there would be "no significant adverse impact" on indoor air quality as a result of BPA's actions.

The BPA program is for the most part restricted to electrically heated dwellings. The uncertainty about indoor air quality meant a further restriction; BPA decided it would limit its aid to insulation in those houses that contain fireplaces or wood stoves, are built of masonry, have basements, or use well water supplies—factors that relate to the origin and dispersal of pollutants. For other houses, BPA would authorize complete weatherization. The distinction is important: insulation alone is a barrier only to heat exchange; weatherization also includes the weather stripping, caulking, and storm windows and doors that impede air exchange. The effect of this distinction has been to limit the most comprehensive conservation measures to only about 30% of the targeted houses. Because one-third or more of typical residential heat loss results from infiltration, it is evident that BPA and its utility customers have had to forgo significant energy savings, at least until a formal environmental impact statement and its risk analysis can be completed and evaluated.

BPA's caution is shared by other utilities. The caution at times becomes a dilemma where state regulatory bodies not only allow but encourage or require utilities to offer technical and financial aid in customer energy conservation.

Identifying true pollutants

One of the most difficult aspects of indoor air quality is the everyday advent of new pollutants, either the new presence or the recognition of a hazard. Singular episodes appear in the news, such as in June 1981, when trichloroethylene leaked at a small furniture factory in Tennessee, evolving vapors that sent 36 workers to the hospital with temporary dizziness and breathing difficulties.

More insidious are the recurrences, frequently in office buildings, that become virtually chronic for some groups of employees. In the Denver area, annoying respiratory symptoms—congestion, headaches, breathing problems—were ultimately traced to residues from a carpet shampoo that was being used periodically and without the recommended dilution.

Control or removal of trichloroethylene or carpet shampoo is one thing. Wholesale avoidance of an established building material is something else. Yet studies show that formaldehyde outgasses for long periods from particle board, some plywoods, and some foamed insulation. These materials are extensively used throughout the construction of mobile homes. Urea-formaldehyde foam has been considered for banning by the federal Consumer Product Safety Commission, but the matter remains unresolved.

Perhaps most vexing has been the rising awareness of radon gas and its implications. Radon, a product of radium decay, in turn decays to other radioactive elements. Alpha particles given off by those elements can constitute a dangerous dose of radioactivity if the elements are inhaled in sufficient quantity.

Radon is almost omnipresent in rock and soil, from which it out-gasses constantly and is dispersed. (For this reason, radon commonly occurs in well water but not in the water of rain- and snow-fed streams.) It also emanates from rock products, such as the brick, tile, block, and concrete used in construction. Where those materials are used inside buildings, the concentration of radon may go up, and so does the potential for inhaling its radioactive decay products, which may become attached to the fine respirable particulate matter that already abounds in indoor air.

Along with weatherization that bottles up indoor atmospheres and their heat

content, one of today's building design features is the concentrated use of stone and concrete as thermal mass to absorb, store, and then release solar energy for space heat. This so-called passive solar energy design is cheap and practical, but it is now being reevaluated because there is also some question about the lung cancer hazard from exposure to radon and its decay products.

Needs that point the way

Recognition of indoor air quality problems and responses to them date back only to the 1960s and probably include fewer than 100 research studies. Nationwide investigative scope began with work by EPA in 1975. Two recent efforts are truly comprehensive in consolidating the knowledge of indoor air quality and the research needed to extend that knowledge and solve the associated problems of air pollution.

Indoor Pollutants, published last year by the National Academy Press, is a National Research Council report by its Committee on Indoor Pollutants at the request of EPA. The project tallied indoor pollutant sources and characterizations, explored factors that influence exposure, discussed health and welfare effects, considered control measures, and presented recommendations on seven pollutant classes, ventilation and control strategies, education, and needed exposure studies.

The federal Interagency Research Group on Indoor Air Quality cataloged research needs late in 1980. This group brings together representatives of many federal agencies concerned with research on the indoor environment. Among the participants are the departments of Energy, Defense, and Housing and Urban Development; EPA; the Consumer Product Safety Commission; the Center for Disease Control; the National Institute for Occupational Safety and Health; the National Institute of Environmental Health Sciences; and the Occupational Safety and Health Administration.

An IRG workshop in December 1980 brought together more than 200 conferees to inventory current research efforts, review a strategy for proposed indoor air quality research, and outline specific research needs. The workshop called for a vast range of air quality monitoring and data collection, for adequate and standardized instruments and methods, for determinations of health effects, for research in control technology, and for work in risk analysis.

The National Research Council report and the IRG workshop report both constitute excellent agendas for indoor air quality research. Prospects for aggressive work under federal coordination are uncertain now, however, although one widely useful beginning has been made. Anticipating expansion of its energy conservation aid to utilities, BPA sought EPA assistance in developing a generally applicable methodology (known as a protocol) for conducting indoor air quality assessments. Geomet, Inc., under contract to EPA, has since furnished the protocol needed by BPA; and an expanded version for nationwide use is now in review before publication.

For EPRI, the next research step combines concerns with indoor air quality and with energy conservation. Ralph Perhac's Environmental Assessment Department is cooperating with Thomas Schneider's Energy Conservation and Utilization Department in a two-year experimental and analytic investigation of residential air exchange rates, energy consumption, and concentrations of key indoor air pollutants.

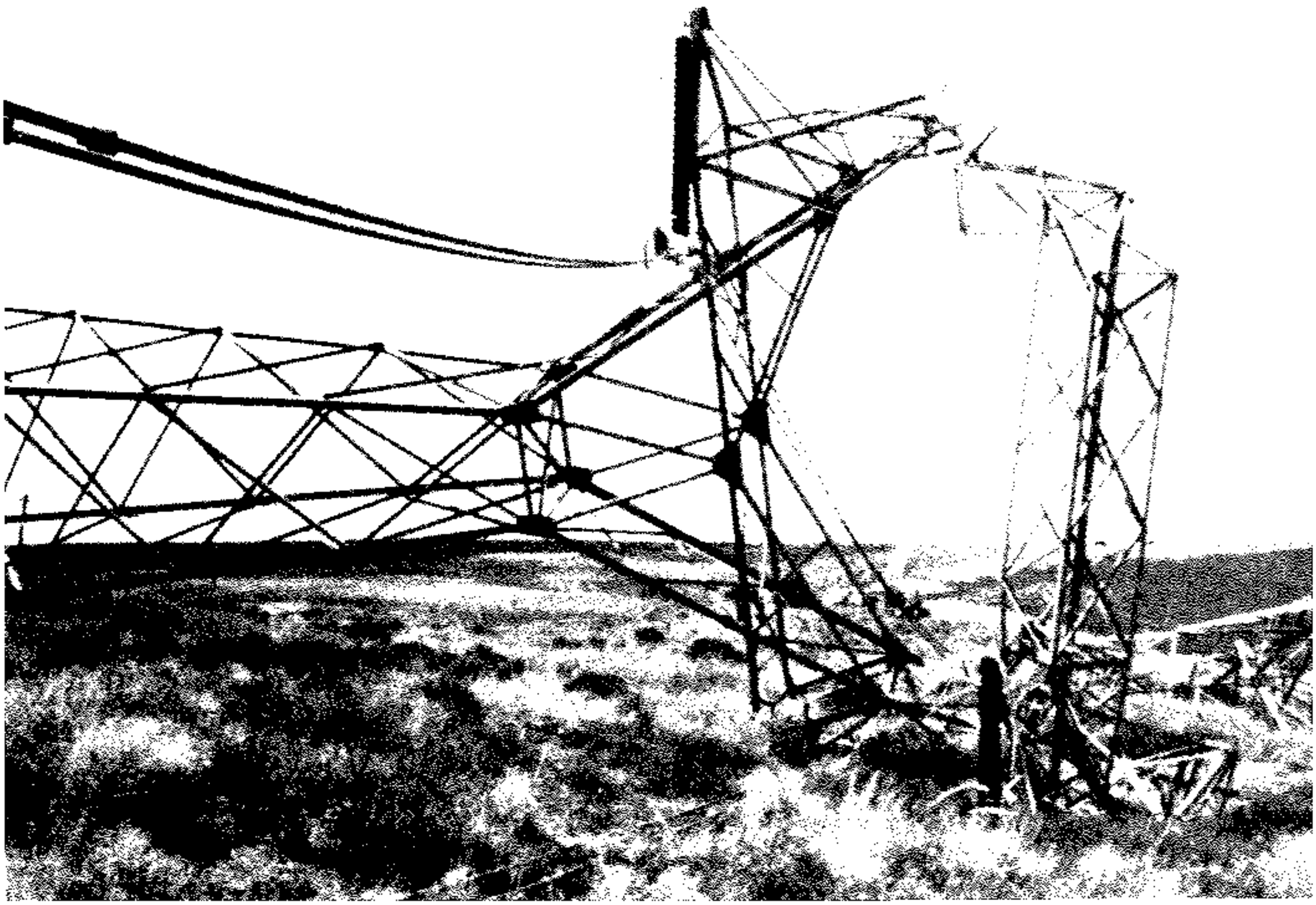
Correlation of air exchange and energy consumption was originally seen as an economic comparison alone; it would produce data and permit conclusions about the cost-effectiveness of various residential insulation and weatherization measures, including air-to-air heat exchangers that salvage indoor heat while permitting air exchange. Perhac saw the proposed research as an opportunity also to develop further information on the relationship of indoor air quality and air exchange rates. The work will therefore include measurements of radon, formaldehyde, respirable suspended particulate matter, carbon monoxide, nitrogen oxides, and other substances that may be designated.

It is clearly evident that there must be a balance between the value of energy saved by conservation measures (which result in reduced air exchange) and the value of indoor air quality lost by the same means. EPRI's research in the coming two years is planned to gain some better sense of where that balance point is or of how to locate it in specific situations. ■

This article was written by Ralph Whitaker. Technical background information was provided by Ralph Perhac, Energy Analysis and Environment Division.

Redesigning Line Structures

A new research facility that offers techniques for predicting how transmission towers, poles, and foundations fail will enable utilities to determine exactly where they can economize in their designs and where they cannot.



High winds gusting along a canyon in the state of Washington pitched seven transmission towers to the ground when their massive steel foundations pulled away from the soil. On another occasion in Wisconsin, a tower toppled, then another, and eventually more than 50 miles of transmission towers and cables cascaded to earth like dominoes.

These are rare and extreme cases. Failures on transmission lines are much more likely to involve the bending of steel struts in a tower or the deflection of the top of a tower. Such structural damage can be caused by the sudden strains of dynamic loads—the uneven gusting of wind, the release of thawing ice from conductors, a tree falling across a conductor, or the initial process of stringing the line. The even pull of static loads is also a factor—a steady wind, a gradual buildup of ice, or the dead weight of the conductors or the towers themselves. A transmission system must endure both static and dynamic loads over a 30–40-year lifetime.

Utilities have remedied structural problems as needed, but up to now little utility-related structural research has taken place. The most relevant recent research in other fields has been that undertaken on structures like bridges, buildings, and off-shore drilling rigs. However, a new research facility dedicated to testing transmission structures will soon provide utilities with the opportunity to participate in exhaustive tests of the strength of towers, poles, foundations, and conductors. This testing is particularly necessary as utilities try to solve the problems of scarce capital, expensive rights-of-way, and diminishing public acceptance of transmission lines.

With new tools and techniques, researchers at the facility will determine how best to achieve optimal system reliability and yet avoid excessive redundancy and conservatism in the design and manufacture of structural components. Existing designs may be seen as too conservative; present design criteria, such as steel thickness and number of redundant steel struts, could translate into prohibitively high fabrication costs. Financial constraints compel utilities to lower these costs by investing in detailed research to quantify structural loads and the way different designs of transmission structures respond to the loads.

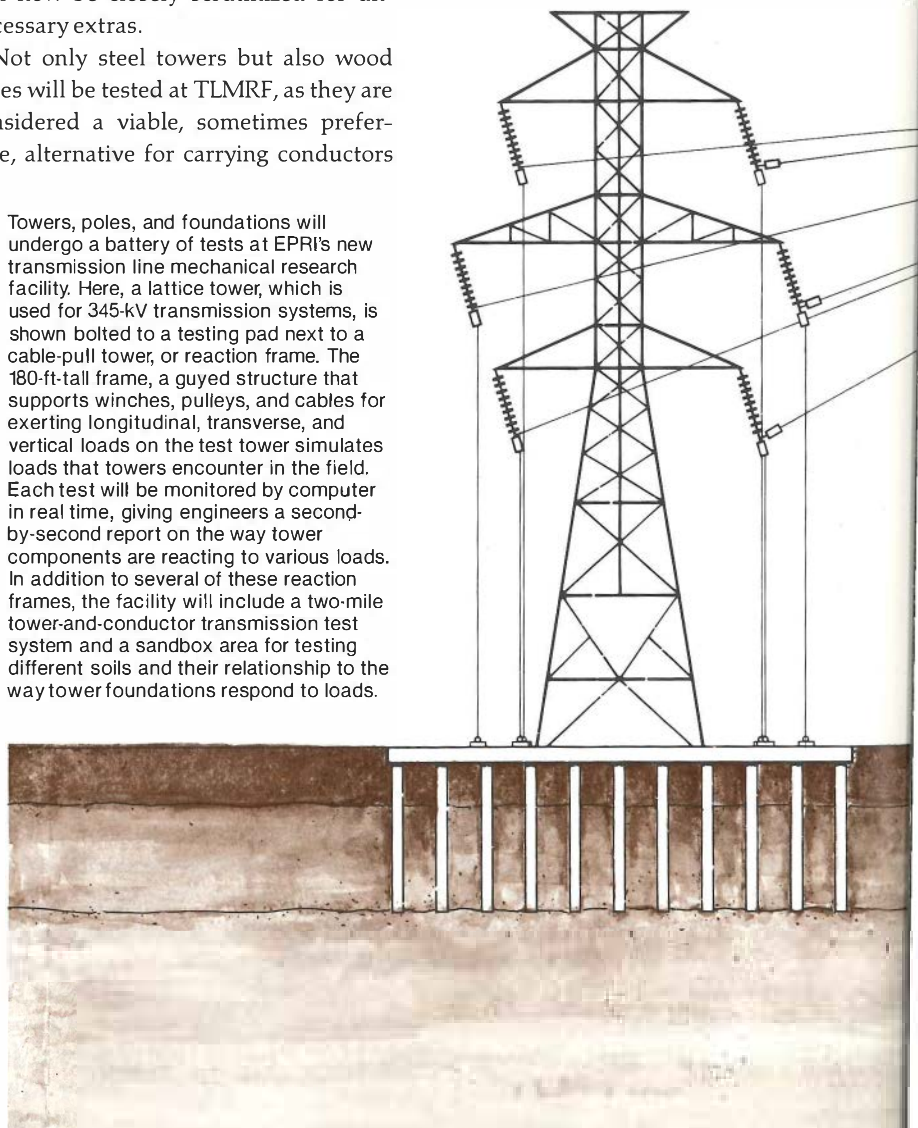
New testing program

The transmission line mechanical research facility (TLMRF) is being built under EPRI contract at Haslet, near Fort Worth, Texas, and is due for completion in mid-1982. It will include a two-mile tower-and-conductor transmission test system, an area for testing tower foundations, and a group of cable-pull towers (reaction frames) for measuring the response of tower components and conductors to static and dynamic loads. EPRI expects that it may take up to 10 years and $20–$30 million to complete the research needed, which will involve all aspects of system design from soil testing and conductor stringing to lifetime maintenance.

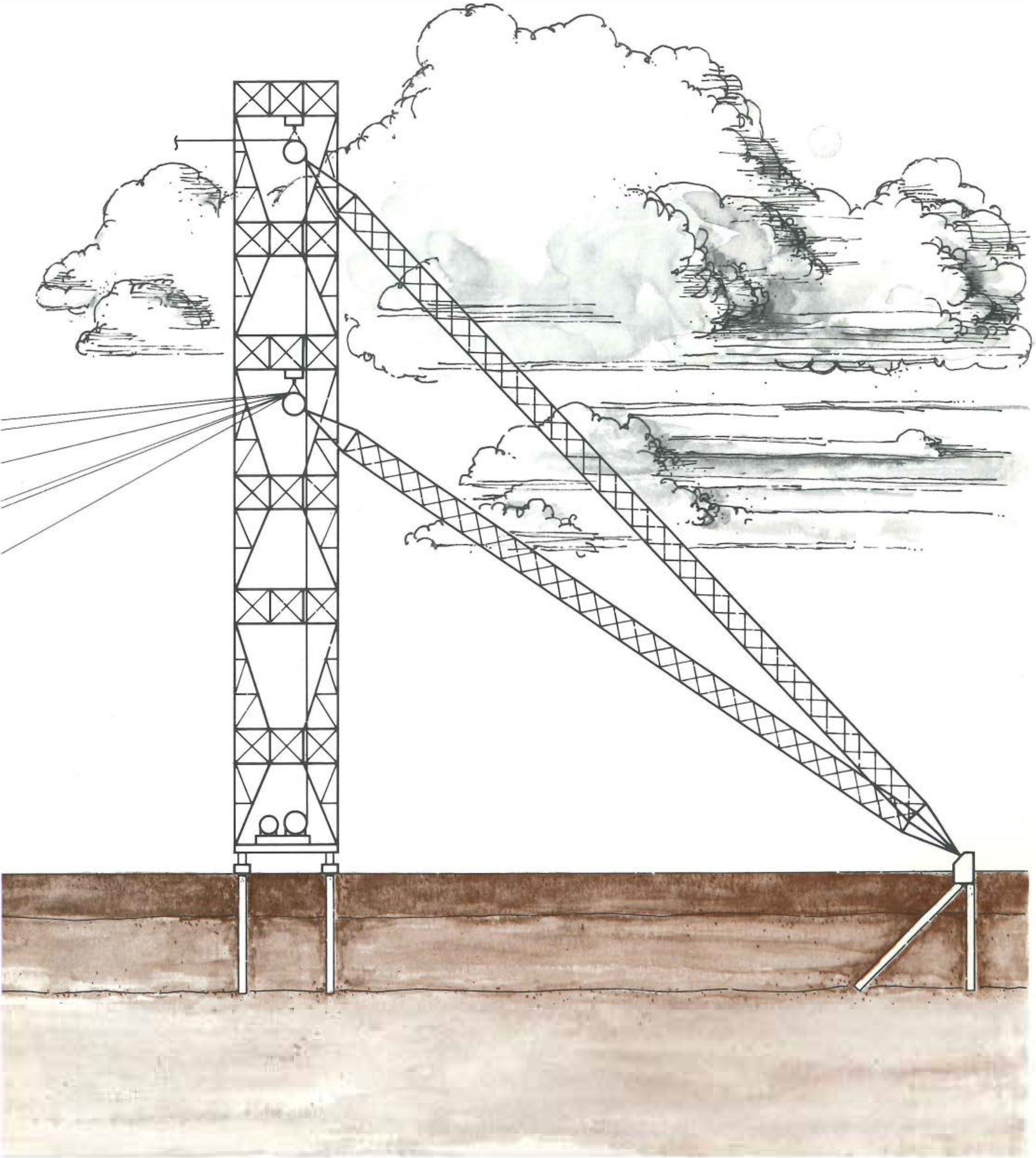
Ebasco Services, Inc., of New York, is supervising design and construction of the facility; Adelphon–TLMRF, Inc., of Fort Worth will own and operate the facility; and EPRI has contracted with Southwest Research Institute to design the experiments and analyze the test data. As EPRI's research will not require 100% of facility time, arrangements can be made through Adelphon for commercial testing by other parties.

The rationale behind the experiments is that utilities must draw a balance between design conservatism and thrift in order to fabricate transmission systems that are both reliable and economical. The only structures that justify a measure of expensive overdesign are the so-called deadend towers, which support each end of a line, anchor sharp turns in the line, and carry conductors across rivers and mountains. But the design of other transmission structures has traditionally been ultraconservative, too; these will now be closely scrutinized for unnecessary extras.

Not only steel towers but also wood poles will be tested at TLMRF, as they are considered a viable, sometimes preferable, alternative for carrying conductors



Towers, poles, and foundations will undergo a battery of tests at EPRI's new transmission line mechanical research facility. Here, a lattice tower, which is used for 345-kV transmission systems, is shown bolted to a testing pad next to a cable-pull tower, or reaction frame. The 180-ft-tall frame, a guyed structure that supports winches, pulleys, and cables for exerting longitudinal, transverse, and vertical loads on the test tower simulates loads that towers encounter in the field. Each test will be monitored by computer in real time, giving engineers a second-by-second report on the way tower components are reacting to various loads. In addition to several of these reaction frames, the facility will include a two-mile tower-and-conductor transmission test system and a sandbox area for testing different soils and their relationship to the way tower foundations respond to loads.



up to 500 kV. Characteristics that make wood an attractive structural material are its high strength-to-weight ratio, the relatively simple tools required for construction and the simple foundations needed. Esthetically, wood structures are uncluttered and have a low profile. Also, because it is a natural material, wood is accepted by the public more easily than other construction materials.

Several types of tower foundations will be tested and compared in the native soil at the Haslet site and in different soils in a sandbox, an area that can be emptied of native soil and refilled with other soil types. By using the sandbox approach, response of foundations to various soil characteristics can be determined. Of equal importance will be EPRI's development of foundation-testing techniques and equipment that can be used for field testing on utility property.

Conductors, too, will undergo tension tests to simulate the stringing process and the effects of galloping. The galloping phenomenon is a spectacular vertical and torsional movement in the conductor (somewhat similar to that of a jump rope) that is generally caused by particular combinations of wind and ice.

Response to loads must be predicted in the process of designing towers and foundations, and these predictions must be verified by full-scale tests. Prediction, in the case of towers, is much easier if the tower is a fairly rigid, latticelike structure. However, highly flexible pole structures are becoming popular because they are deemed to be more esthetically pleasing to the public. Likewise, slender towers supported by guy cables are of interest because they are relatively less costly. In general, design engineers are compelled by public pressure to exercise more options than they had to, say, 10 years ago.

The nonlinear approach

These new tower designs require a different, nonlinear analytic technique to predict their performance. Unlike the response of the more rigid traditional designs, their movement in response to a load is nonlinear (not directly proportional to the load). Southwest Research will develop a comprehensive set of analytic computer programs for EPRI that will be able to accurately model responses to load of all structural components. The first to be developed is the EPRI tower analysis program. Eventually, the software will be verified by full-scale testing of many tower designs at TLMRF. Several utilities already have plans to provide the towers for such testing, and others may wish to participate in this way in the future.

Another type of computer analysis involves the detailed calculation of what constitutes the limit state of a structure—that is, the point at which a tower no longer supports the conductor. In past years it was only possible to compute when a load would cause the first component to bend or fail. Now, because of improvements in computation, programs can be written to describe a consecutive series of component failures. Consequently, the utility industry is gradually moving away from the concept of tower failure defined by a single component toward that of limit-state, or multicomponent, failure. Using limit-state analysis, redundant components that are designed specifically to compensate for single broken components prevent an entire structure from being termed as failed.

Limit-state analysis has been achieved by what is called piecewise, step-by-step linear solution. In this method the highly nonlinear response of a failed component is approximated by a number of minuscule linear responses that must be repeated at great cost in computing time. EPRI has asked Southwest Research to follow up on pioneering work by Bonneville Power Administration to perfect a new limit-state technique that requires only one pass through the computer. This, too, will be verified by testing.

Another TLMRF feature will be real-time computer monitoring of tests, enabling researchers to benefit from a second-by-second computer record of the way in which a structure responds to different loads.

Computer-assisted analysis of data from load tests will help engineers decide exactly how many redundant steel struts, joints, or other backup components there should be. In this way the cost of a structure in materials and labor can be brought to a point where it is justified by a reasonable level of reliability. Eventually, reliability will be given a statistical value, which will be calculated by combining the probability of the occurrence of extreme loads with the probability of a structure's withstanding them.

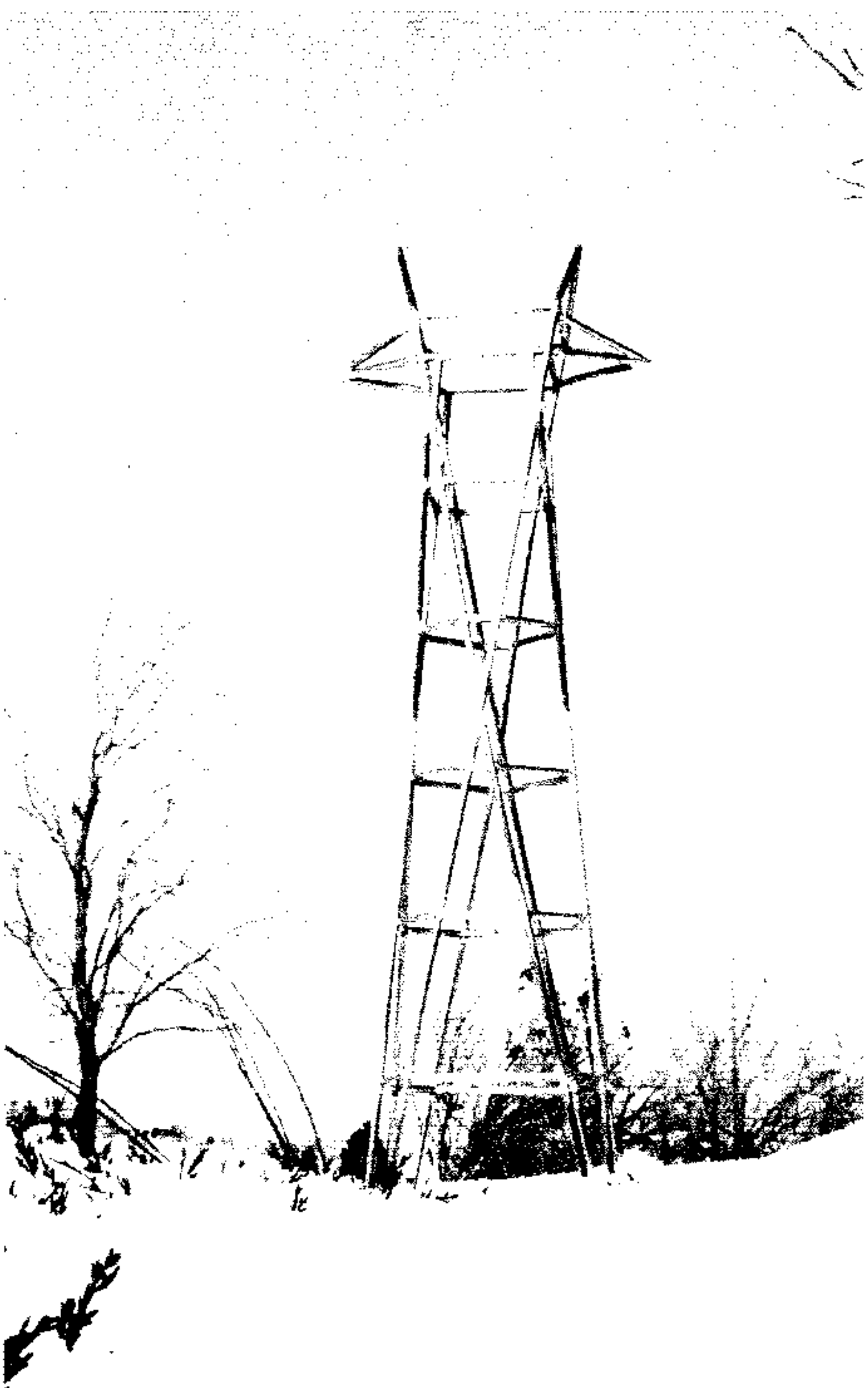
In addition, computer-assisted analysis can help avoid pitfalls in the process called detailing, which deals with the design of small components and connections. An example of a detailing problem arose when the design of a connection between two struts described it as a point. However, in the fabricated structure, this point was larger than 2 ft^2, and the stress was such that both steel struts broke. In another example, a joint formed by two L-shaped steel struts failed in use because the fabricator misinterpreted the design and joined the two short sides of the L instead of the two long sides, as intended. If the first example could have been more accurately modeled on a CRT screen by the designer and the second example could have been transmitted directly in digital form from designer to fabricator, the errors might not have occurred.

Larger network spurs new designs

The transmission network will increase in both rating and extent during the next two decades, and new techniques for design and manufacture of systems will have to cross over from the state of the art to the state of practice. From now until 2000, utilities plan to build about 113,000 miles of transmission line. This represents a 40% increase over the 275,000 miles of line now in existence.

The main reason for this construction is growth in existing demand, plus a shift in the demand pattern as suburbs spread

Up to 15% less steel will be needed to construct the hyperbolic transmission tower developed by EPRI contractor Structural Research, Inc., of Madison, Wisconsin. Fewer components overall will produce a lighter tower; however, its strength will be equal to that of a conventional lattice tower because the main load-bearing components are straight, transferring load directly to the ground instead of passing it through joints, as in a conventional design. Tubular components save steel, offer less surface resistance to wind, and are considered to be more pleasing esthetically.



and new towns spring up. Another reason is that more electricity-generating stations will be situated near coal mines, far from the cities they feed. For instance, power generated in North Dakota is being transmitted to Minnesota and power generated in Wyoming to Oregon. In a few years transmission lines will run from a new Utah coal-fired plant to Los Angeles and from Canada to Nebraska, across North and South Dakota. In some cases the reason for the extra-long-distance transmission line is economic—the line may be seen as a less expensive carrier of energy than the railroad. In other cases there may be political views on the comparative merits of, say, a coal-slurry pipeline versus an electric transmission line that favor the latter.

In any case, because of the increased cost of energy in general, the lifetime cost of power losses from the line is now almost as influential a factor to consider as the cost of constructing the line. For long-distance lines, it is economically imperative to use larger conductors, which in turn call for new designs of stronger towers.

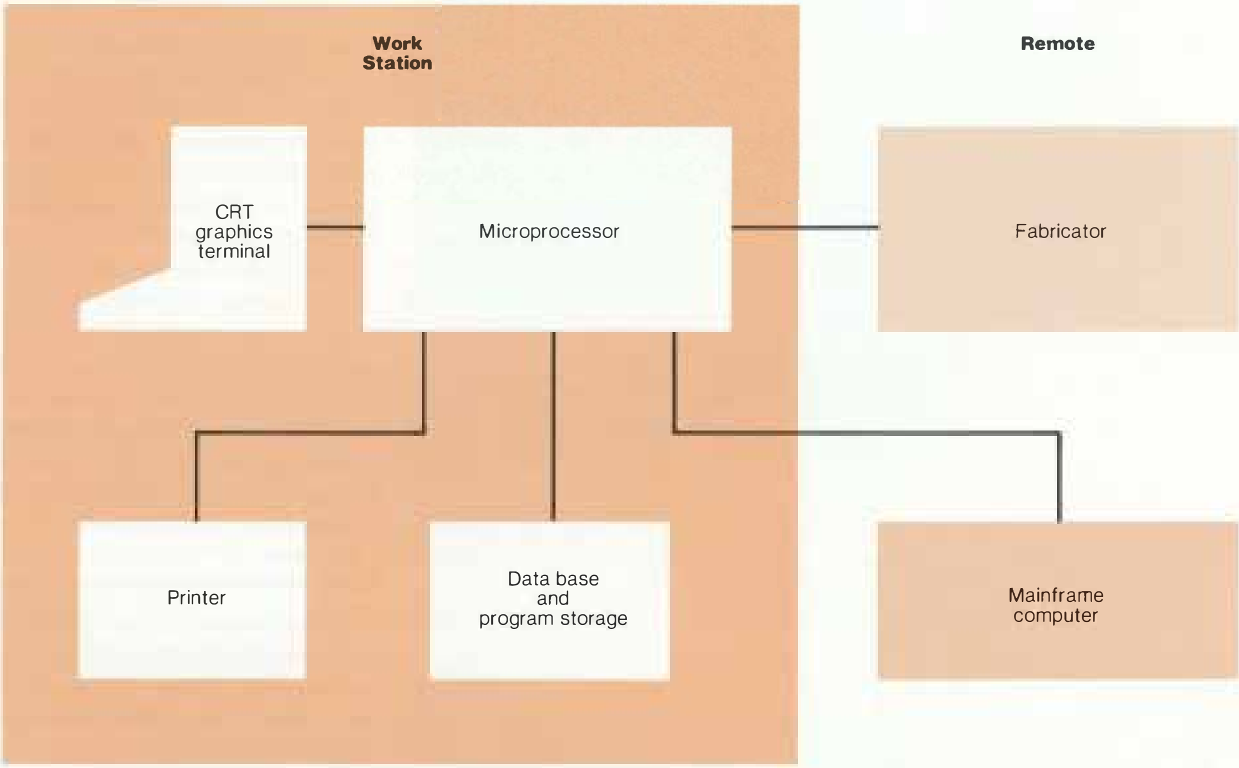
Direct transfer of design to fabricator

The link between the planning and the achieving of efficiency and economy in overhead transmission is the essence of the TLMRF project. The main goal of the EPRI staff and utility advisers is to produce optimal parameters for fabricating a transmission line—computer programs that describe these properties in minute detail. In a few years, the design engineer should be able to enter these design parameters into a computer console, get a picture on the CRT screen to check for possible errors, and obtain costs and sensitivity analyses. When all desired changes are made, the computer will generate the final design, including fabrication details.

This information in digital form can be transmitted to a fabricator, where it is used to program numerical control machines or robots used in the manufacturing process. The shorthand expression for this pro-

TLMRF WORK STATION

Researchers at the transmission line mechanical research facility will have entrée to at least 10 design-engineering computer programs in different U.S. locations through a satellite-connected work station. This work station will have a low-cost microprocessor, operable in a simplified computer language that uses ordinary English terms, plus a cathode-ray tube (CRT) graphics terminal, printer, and data base and program storage. The simplified computer language will allow the user to take advantage of sophisticated engineering programs without having to learn several computer job-control languages. For very complex analyses, the microprocessor can be used to access a mainframe computer located elsewhere. Eventually, computer-assisted design of transmission line structures will lead to their computer-assisted manufacture, with design engineers producing blueprints by dynamic computer graphics. When the design's predicted strength has been verified by full-scale testing, the design data can be sent directly to a fabricator in digital form. Numerical control machines or robots can then interpret the data to select and assemble components.



DESIGN-ENGINEERING COMPUTER PROGRAMS

BRODI2/BROFLX	Calculation of residual longitudinal loads from broken conductors
POLEDA-80	Analysis and design of single-pole structures
PADLL	Analysis and design of high-moment single-pier foundations
CABLE 7	Dynamic broken-conductor load analysis
BPA TOWER	Bonneville Power Administration tower analysis
STRUDL TOWER	General purpose tower design and analysis
ANSYS	Finite-element structure analysis
ETAP*	General nonlinear structure analysis
Unnamed*	Limit-state analysis and design
Unnamed*	Dynamic structure analysis
Unnamed*	Complete computer-assisted design–computer-assisted manufacture (CAD–CAM) system

*Available in the near future

cedure is CAD–CAM (computer-assisted design–computer-assisted manufacture). "The day is not too far away," says Richard Kennon, program manager for overhead lines, "when there will be no paper generated between the design engineer and laying down the fabricated steel at the field assembly site—unless, of course, we need to produce some pictures to obtain budget approval."

UTILITY INVOLVEMENT

Utilities needing to solve a transmission line structural problem have the opportunity to work with EPRI and Southwest Research toward the solution of that problem. The results of EPRI's structural research will be useful only if real problems are addressed.

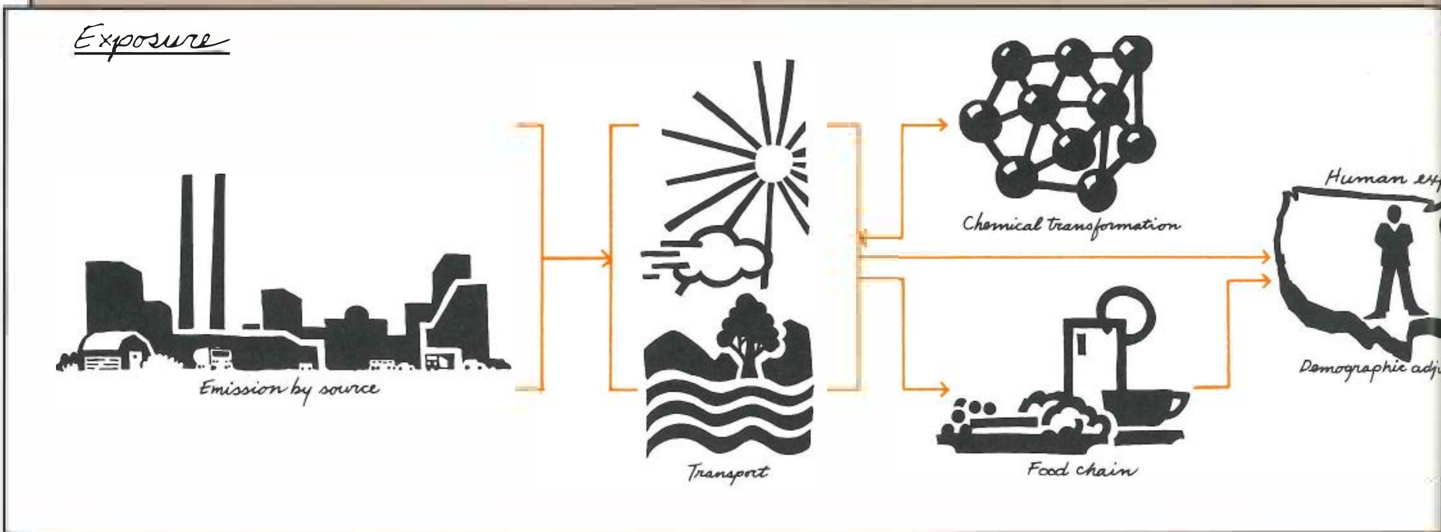
A number of utilities have already indicated a desire to be directly involved. Their specific research needs can be integrated into the EPRI project, with the cost to the utility probably about equal to that of proof-testing a transmission tower. Some utilities may seek a thorough analysis and test of an existing tower design to determine how easily it can be uprated to present criteria. Other utilities may be embarking on the design of a new family of structures to meet changing requirements, while minimizing the cost of these new designs. Both these objectives fit well within the scope of the overall EPRI project. Perhaps more important to the utility engineers, participation in the project means they automatically receive training in the use of the design tools being developed. This firsthand experience will enable them to make better use of these tools when they are generally available. □

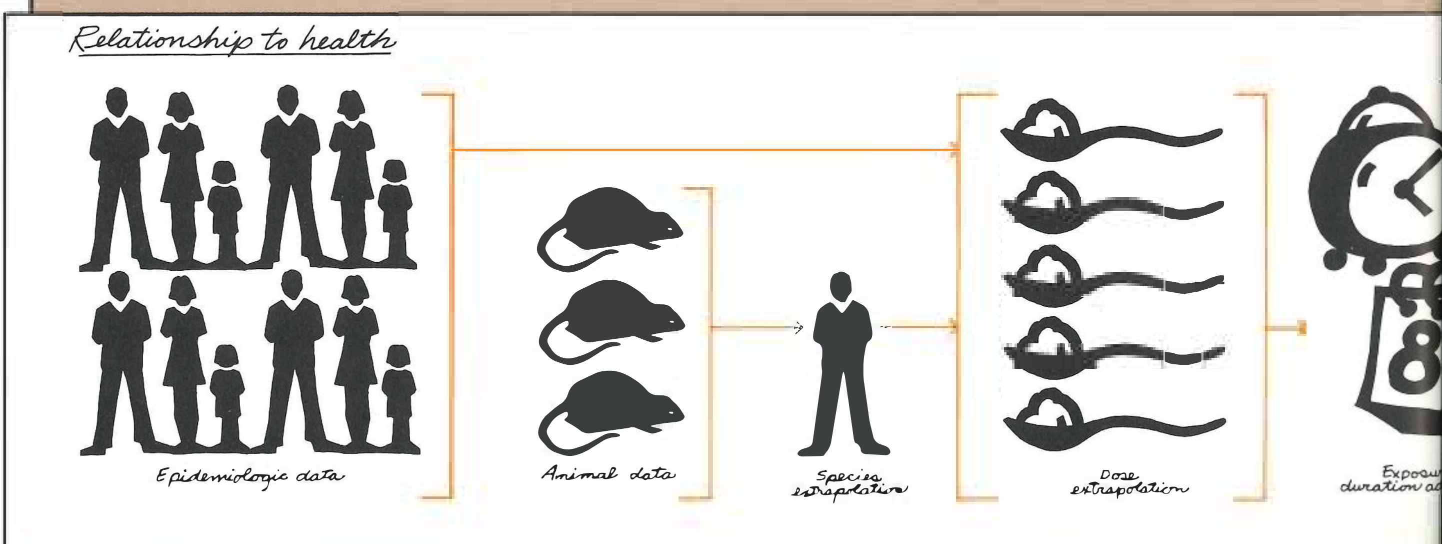
All computer programs for analysis and design, whether originating at the Massachusetts Institute of Technology, Bonneville Power Administration, or other research centers, will be accessible through a satellite-connected work station at TLMRF. Because the work station will use a simplified access language in ordinary English terms, an engineer will be able to employ many sophisticated programs without having to learn the control language for each one. Developing the work station will be a major task of Southwest Research.

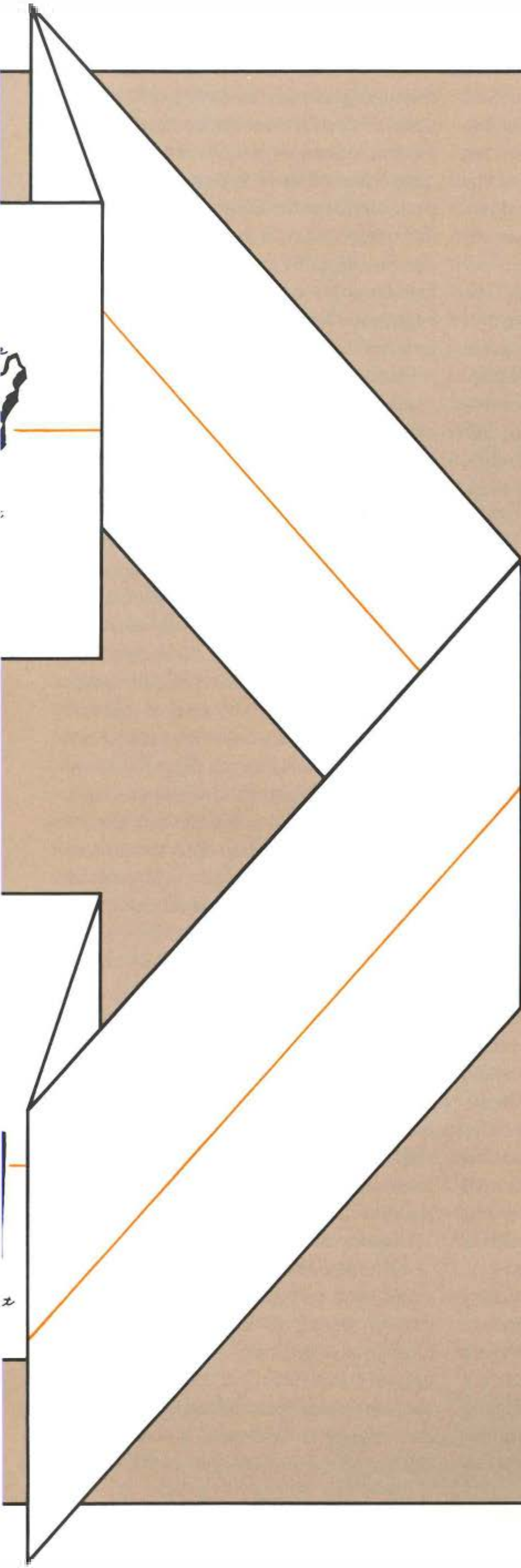
In its simplest form, the work station can be a CRT terminal with all software stored in a mainframe computer. In its most fully developed form, however, it will consist of a microcomputer, local hard-disk storage, and hardcopy output, in addition to the CRT terminal. In the latter setup, maximum economy is achieved by using the microcomputer for local fast-access storage and the generation of graphics and the mainframe computer for input formatted by the microcomputer for high-powered computation.

Before testing takes place, the structural research at TLMRF will be the development of software. Later, the software will be confirmed and improved through full-scale testing over several years. "The challenge of building over 100,000 miles of transmission lines in the next 20 years is formidable," comments Richard Kennon. "Fortunately, there are many transmission options available to the planner and the designer. However, if the planner or designer is to have the options truly available to him, much research and development work is necessary. It is the purpose of EPRI's Overhead Transmission Lines Program to provide utilities with the information and tools required to make rational decisions on the options available." ■

This article was written by Jenny Hopkinson. Technical background information was provided by Richard Kennon, Electrical Systems Division.


Exposure
Emission by source
Transport
Chemical transformation
Food chain


Relationship to health
Epidemiologic data
Animal data
Species extrapolation
Dose extrapolation



Risk assessment results from the convergence of two streams of calculation: the estimated exposure of an individual to a substance (dose) and the determined effect (dose-response). Exposures are estimated by modeling the release from various sources, such as factories, farms, or autos, and following their transport and transformation through water and air to an individual. Additional exposures through the food chain are also modeled, as are the demographic considerations that pinpoint individuals at greatest risk.

Dose-response models are derived from epidemiologic studies and/or animal experiments. Exposures are generally very high in such studies, and adjustments are required to approximate ordinary conditions, that is, long-term exposure to low doses of the substance.

TOWARD BETTER METHODS OF RISK ASSESSMENT

Quantifying the risks to human health is an elusive exercise, but one increasingly required by regulation. Improved tools for prediction and standard setting are urgently needed.

Many new laws and regulations intended to help protect people from such potential hazards as environmental pollution, food additives, pharmaceuticals, workplace dangers, and unsafe automobiles were promulgated during the 1970s. Some of these regulations required new ways of calculating risk, that is, calculating the probability that certain activities will adversely affect health or safety. To help utilities meet this challenge, EPRI is undertaking several projects to provide better data and analytic methods for risk assessment.

More than 10 federal acts now require some measure of risk assessment. Many affect utilities, including the Clean Air Act of 1970 (and amendments), Clean Water Act of 1977, Safe Drinking Water Act, Occupational Health and Safety Act, Resource Conservation and Recovery Act, and Toxic Substances Control Act of 1976. The use of risk assessment varies considerably among these laws. In some cases, specific national standards have been set by the federal government; in others, utilities may participate in establishing regulations at the state and local level.

No human action is devoid of all risk, and legislative, regulatory, and management decisions assess risk whether or not such assessment is stated explicitly. For the most part, people can see obvious risks and will avoid such risks if they are not offset by compelling benefits. But many risks of living in modern society tend to be less obvious and hence more difficult to incorporate into decision making.

The process of risk assessment is plagued by many uncertainties: It is not easily defined and measured. Regulatory agencies have generally faced this problem by adopting very conservative approaches, that is, by choosing the method that will result in the most protective standards. Similarly, the courts have taken a conservative approach, but they have frequently emphasized the need for thorough documentation and clear logic. This approach has resulted in the rejection of a number of risk analyses because of faulty logic or lack of clear proof and a trend toward what is sometimes called the six-inch regulation, a ponderous report of risk assessment presented in defense of a one-line standard, whose ultimate impact on health remains as uncertain as ever.

In response to this conservative approach to risk assessment, EPRI research has three main objectives: to solve some of the scientific uncertainties in risk assessment, to determine how sensitive assessment results are to different assumptions and methods, and to help utilities identify the serious potential risks as quickly as possible. In addition, EPRI scientists are keeping abreast of related work on risk assessment and on the public perception of risk.

What is risk assessment?

For most of human history, risk assessment has been personal and intuitive, and organized attempts to control risk have usually been reactions to readily apparent danger. Early risk evaluation emphasized personal safety, and increased knowledge brought about more effective accident prevention. In 1938 the federal government took its first major step toward regulating health risks by creating the Food and Drug Administration. However, by the 1970s the proliferation of risk-related laws and regulatory agencies brought about an urgent need for better quantitative methods of assessing risk.

Risk assessment is inherently a statistical exercise. The principal tools of statistical analysis of risk are mathematical models that can predict how risk will change as conditions vary. Such models can help provide the basis for controlling risk. A regulator may use one model to set a community's ambient air quality standards and keep health risks below a specified level. A utility engineer may then use another model to determine the emission controls necessary for keeping pollution within the limits set by the standard.

As this example indicates, risk assessment generally involves two separate tasks. First, data from epidemiologic studies and animal experiments are used to determine whether exposure to a suspected agent, such as radiation or a chemical compound, can damage health. Such data are usually gathered on exposures far above those encountered in ordinary experience. Dose extrapolations must then be made to judge the effect of long-term contact with low doses of the agent. The results of animal experiments are extrapolated to humans to produce a dose-response model, which can be used to predict the effect of exposing large numbers of people to a given amount of the agent.

The second task is to estimate the amount of exposure individuals are likely to receive from, say, a power plant. A substance's transport and chemical transformation in air and water are modeled, given the amount and rate of release. Potential exposures from these media can then be estimated, including exposure through the food chain. Once potential exposures have been determined, demographic data are taken into account to find out which individuals will actually be put at risk. If an agent is released only periodically as the result of accidents, the technology that produces the agent must be analyzed to determine how likely such accidents are.

Problems can arise during any of the steps just outlined. Hazardous substances may not be recognized because of inadequate epidemiologic data. Experiments with different animals sometimes give contradictory results. Dose extrapolation is notoriously difficult, thus controversial. Transport and chemical transformation of airborne pollutants are not well understood. And perhaps most important, the cost of testing chemicals for potential hazards is so great that only a small fraction of more than 44,000 compounds subject to the Toxic Substances Control Act have been evaluated in any detail so far.

Implications for electric utilities

The electric utility industry's initial research in risk assessment will be on toxic substances, particularly those discharges that ultimately reach water. Water quality protection is still governed mainly on the state and local level—a tradition established more than 100 years ago. However, the federal government has become involved by recommending to the states a list of 149 pollutants for which water quality standards should be considered. Although it is still not clear which pollutants are most directly connected to power plant operations, utilities must have risk assessment tools available if they are to participate in the evaluation of proposed standards.

The Environmental Protection Agency (EPA) formulates its water quality recommendations in terms of criteria that relate concentrations of various toxic substances to probable levels of health risk. Consideration is given to whether a substance can cause cancer or has other toxic effects and whether its presence makes water taste or smell bad. For example, once a compound has been identified as a potential carcinogen, the EPA performs a risk assessment to determine what water concentration would be associated with a lifetime risk of 10^{-5}—that is, the risk that a person drinking normal amounts of the water and eating food drawn from the water for a lifetime would have one additional chance in 100,000 of getting cancer.

Once a range of such estimates (usually 10^{-4} to 10^{-6}) is available for each pollutant under consideration, state and local authorities decide which risks are acceptable and thus the concentrations to permit in rivers or groundwater. Implementing such a standard requires calculating the discharge level of a pollutant that can be permitted from power plants and other industrial facilities. To issue discharge permits, regulators first have to determine what effluents are being released by each plant and what changes are feasible. They may also choose to reject the EPA's criteria in favor of those from an alternative risk assessment method.

Utilities may have considerable opportunity to influence the course of water quality regulation, but the task will be enormous. There are about 62,000 community water systems in the United States, with 80% of the national population being served by the largest 2500 systems. Such local autonomy provides a setting for creating regulations suited to community needs. Given adequate risk assessment methodologies, utilities can work with local authorities to set priorities for water pollution abatement.

A very different sort of utility response will be required to deal with new provisions of the Clean Air Act that treat carcinogens (Section 112). EPA criteria dealing with the possible health effects of air pollutants are much more comprehensive than those dealing with water, and proposed regulations are generic, rather than specific to a local situation. The problem as defined by EPA is to establish priorities for developing regulations and to suit emissions control standards to the best available technology. Risk assessment is explicitly included as part of this regulation development process.

The main thrust of EPRI's current research work in this area is to help utilities analyze the sensitivity of the required risk assessments to various assumptions. For example, it will be important to know the extent to which final estimates of risk are influenced by the common EPA practice of ignoring all but the most conservative sets of data—that is, those that would require the greatest emissions control. Unlike other regulations, those dealing with suspected carcinogens do not take into account the "reasonable cost" of control measures. Utilities therefore have a vital interest in questioning the assessment method used to select certain carcinogens for high priority in regulation.

The case of arsenic

One of the suspected carcinogens that is a strong candidate for regulation as a pollutant of both air and water is the element arsenic. Since coal-fired power plants are one significant industrial source of this chemical, utilities will be directly affected by new regulations designed to curb its emission. In addition, the problems encountered so far in efforts to determine its effect on human health make it a good subject to illustrate some of the outstanding issues in risk assessment.

Arsenic is ubiquitous. Although its major commercial use is as an agricultural pesticide, there is some evidence that in trace amounts it is an essential nutrient. The total amount of arsenic released by coal-fired plants in the United States is large compared with the amounts released by other human activities, but because these sources are widely dispersed, the resultant exposure has not generally been considered a significant health hazard. Human exposure to concentrated amounts of arsenic in this country has usually resulted from incidents in smelters or from the improper use of pesticides. In fact, inhalation of arsenic in smelters or pesticide plants may have resulted in the increased incidence of lung cancer among workers.

Because of these observed effects, EPA first concluded that the ambient water concentrations (of arsenic) should be zero, even though the agency admitted that this level may not have been attainable at that time. Subsequently, EPA produced criteria for states' use in setting water quality standards that were based largely on epidemiologic studies in the Republic of China (Taiwan). Regulators were told that to limit incremental increases of cancer risk over a lifetime to 10^{-5}, arsenic concentrations in water should not exceed 0.022 $\mu g/l$.

In formulating its criteria, the EPA relied heavily on extrapolation of results from studies of Taiwanese who customarily drank water from artesian wells with arsenic concentrations that ranged from 10 to 1820 $\mu g/l$. Among these inhabitants of the southwest coast of Taiwan, the prevalence of arsenical keratosis and skin cancer was many times higher than normal. Most important, the incidence of these and other symptoms varied consistently with the levels of exposure to arsenic. By developing a mathematical model based on these data, the EPA Cancer Assessment Group deduced the probable health effects of much lower doses.

The EPA document published to support this decision recognized that the calculated level was quite conservative, and that the criterion as estimated by the methodology appeared unreasonably low. The authors of the original study even concluded that some factor or factors other than greater consumption of arsenic-polluted water must influence skin cancer. For example, most of the cancer patients had a history of peeling or cutting the horny layers of keratotic lesions with contaminated nails or knives. Others have pointed out that the levels of contaminated water varied greatly over time and that diet may also have been a factor.

Another major problem with the federal guideline is that it is far below the naturally occurring background level of arsenic in most of U.S. water. An EPA study found an average arsenic concentration of 2.37 μg/l in nationwide samples of tap water, and water from wells in some areas of California, Nevada, and Alaska have much higher levels. The Public Health Service found, for example, a mean arsenic content of 224 μg/l at residences in Fairbanks. Yet even in areas with the highest natural concentrations, no adverse health effects have been discovered. This paradox has led some scientists to question the methods used in the risk assessment on which the present standard was based.

Such problems illustrate the difficulty of basing risk assessments strictly on epidemiologic data. Because of the lack of experimental control, it is very hard to determine what blend of causes may have produced an observed effect. As one leading researcher has put it, "Epidemiology is a very blunt tool that can only pick up effects greater than 10% or 20% over background."

The need for better models

One alternative to epidemiology is to perform experiments on animals. The advantages are that doses can be regulated more precisely, while confounding factors are minimized. The main disadvantage is that applying the results of such experiments to humans requires extrapolation. The metabolism of animals and humans is different in important ways. Rats, for example, are unusually tolerant of arsenic. And critical experiments that might clear up some of the uncertainties just described cannot be performed because no animal has been found that develops cancer from arsenic exposure.

Even when the experiments can be performed—at a cost of perhaps $500,000 and five years of effort—interpretation is difficult. Doses used in the experiments are often very large so that effects can be quantified in a statistically defensible way. This means, however, that risk levels for ordinary exposures to a toxic agent may be only a millionth as large as those observed in the experimental setting. To estimate effects at this lower level, two important issues must be addressed.

The first one is the exactness of risk measurement at a given level of exposure. Such measurement is not exact; in fact, the uncertainty can be thought of as a smudge, rather than a point, on a graph. Confidence that the true value being sought has been included is determined by the size of the smudge. A range estimate—the confidence interval—that yields a 90% chance of including the correct risk value is frequently used. Unfortunately, in animal experiments with toxic substances, this region of uncertainty may extend over a factor of ten, or even a hundred. As a result, the line drawn to represent responses to various doses of a substance will be a series of even bigger smudges. Yet in deriving dose-response relationships, regulators and others often ignore such uncertainties.

The second problem occurs when one tries to extrapolate the dose-response relationship into the low-dose region—drawing the line down toward zero. A series of data points (smudges) that seem to lie on a straight line at one dose level may not accurately predict the relationship at other levels. The true response graph may be an S-shaped curve, which tapers off rapidly below some threshold dose. The question of whether or not human response to exposure to carcinogens would assume this shape is one of the most important—and hotly debated—issues in risk assessment. For example, a major reason why the studies of saccharin were so controversial was that various models (curves) led to a five-million-fold difference in the effect predicted at a given dose.

At present, EPA extrapolates data by approximating a straight line. That is, carcinogens are assumed to be dangerous right down to zero dose. However, even if there is no threshold in theory, there must be one in practice. Again arsenic makes a good example. Eliminating all manufactured sources would still leave enough naturally occurring arsenic to presumably cause some cancers. Eliminating all exposure to arsenic could create other health problems because at very low levels the element appears to have some function in normal metabolism in animals. Even more compelling is that some elements, such as selenium, vanadium, manganese, and zinc, are toxic or carcinogenic at high dosages, but low doses are absolutely necessary for existence.

EPRI's work focuses on the need to develop better models of risk that reflect both a thorough understanding of the phenomenon under consideration and a recognition that compromises must be made if new standards are actually to benefit health. For example, recent studies indicate that a cell may have to pass through several discrete stages before becoming malignant. This multistage model gives low-dose estimates of risk that can be considerably below the straight-line model. Even understanding how sensitive risk assessment is to the choice of model can help make the standards-setting process more rational.

How probable are accidents?

Accidental release of large amounts of a toxic agent increases risk, and evaluating such risk introduces a fundamentally different element into risk assessment. During the 1960s, when engineers in the aerospace industry were concerned about assessing the probability of failure in their highly complex systems, they developed a methodology called fault tree analysis. The various sequences of events that can cause a particular type of failure are traced back to their independent origins, producing a flow diagram that quickly foliates into a tree of causes and effects. Probabilities are then estimated for each event and the overall chance of failure is calculated.

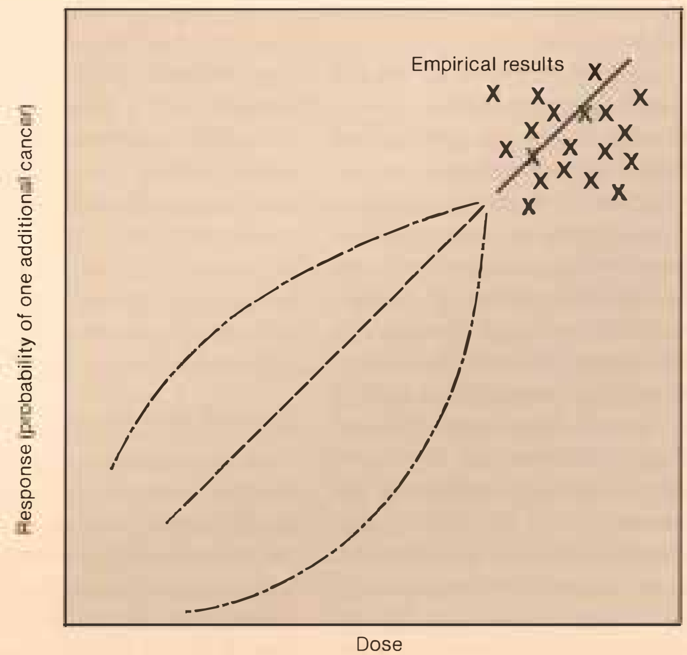
EPRI research has concentrated on using fault tree analysis to study the accidents that are associated with different types of power plants. Using this method, risks are calculated for all stages of energy production from the extraction of a fuel from the ground to its ultimate disposal. The study examines both commonplace and catastrophic events, and produces results for both occupational and public health risks. Because of known inadequacies in the data and models to be used, special attention is being paid to the effect uncertainties can have on the study's conclusions. This work was undertaken to help utilities assemble information required to license new power plants, help designers anticipate risks so that problems can be corrected on the drawing boards rather than through retrofit technologies, provide balanced information for use in the public debates accompanying future energy sources, and help direct planners toward the most appropriate R&D strategies by suggesting those technologies where risks may be of least concern.

Arthur D. Little, Inc., has conducted a study of possible health and safety risks associated with eight power generation technologies. Although it is hoped that this work will ultimately help resolve some of the differences among current risk estimates, initial emphasis has been on developing and applying a consistent methodology. The scope of this study has been restricted to the examination of commonplace or routine risks that are directly attributable to the construction, operation, and maintenance of single power plants, including their associated fuel cycles. The results only apply to particular versions of the power-generating technologies and do not take into account combined effects of many such plants. Results may also differ as the design of a particular technology changes.

The eight technologies considered are the coal-fired steam plant, oil fuel cell, natural gas fuel cell, wood biomass plant, nuclear PWR (with and without fuel recycle), solar-thermal plant, solar-photovoltaic plant, and wind tower. Occupational risks for most of the technologies were in the range of one fatality per GW-year of energy produced, but uncertainties sometimes ranged over nearly two orders of magnitude.

Risks to the public turned out to be more diverse and more difficult to analyze than the occupational risks. In general, however, they were much lower. For coal-fired and wood biomass technol-

DOSE-RESPONSE DILEMMA
One of the central problems in risk assessment is how to extrapolate from the experimentally known effects at high doses to the unknown effects at low doses. A straight line or curves of various configurations are all theoretical possibilities, opening the door to conjecture and controversy. Empirical results at low doses are generally not feasible because of the sheer number of subjects (animals) required. Regulations typically require estimates of the dose that would produce one additional cancer in 100,000 subjects.



ogies, atmospheric emissions appear to be the dominant source of public risk associated with normal power plant operation. For the nuclear fuel cycle, the major sources of radiation risk to the public appear to come from mining, milling, and reprocessing operations—not from the reactor itself.

How people perceive risk

Despite the increasing sophistication of quantitative risk assessment, individuals still evaluate risk according to their own experience. Indirect exposure to a risk, such as by viewing a film or a televised news account, can make the risk seem more real and thus more probable. Experiments have shown that belief that an accident can really happen is greatly strengthened by relating it as part of a lengthy scenario.

Such personal judgments are necessary to cope with everyday hazards. What they lack in scientific accuracy they make up for in vivid reminders of the need for caution. These intuitive strategies can become serious barriers to rational action, however, when they are applied to more remote or technologically complex risks. Studies have shown that even experts tend to place too much faith on the results of limited experience.

Although EPRI work in this field has been limited, the Institute has sponsored conferences and other information exchanges so that developments can be monitored. Just how far off the mark popular perceptions of risk can be has been demonstrated in experiments conducted by Paul Slovic, Baruch Fischoff, and Sarah Lichtenstein of Decision Research in Eugene, Oregon. They asked subjects to judge from selected pairs of common events those most likely to cause death. Discrepancies with actual levels of risk were both widespread and conspicuous.

Accidental death, for example, was thought to be about 25 times more frequent than death from stroke; yet fatal strokes are actually 1.85 times more frequent. A person is 21 times more likely to die from asthma than from a tornado, but tornado fatalities were thought to be nearly three times more common. And the fear of pregnancy is so great that pregnancy is believed to cause 10 times as many deaths as appendicitis; yet death from appendicitis is actually twice as frequent.

Communication is part of the problem. Risk data are commonly related in terms of man-days of work lost at a plant or potential earnings lost for individuals. Although useful for policy planning, such measures bear little relationship to personal perceptions or values. One suggestion on how to better communicate risk data to the public has been made by Bernard L. Cohen and I-Sing Lee of the University of Pittsburgh. They favor casting the relevant statistics in more intuitively accessible units, for example, decrease of life expectancy.

This method of communication has the advantage of being able to rank very different hazards in easily understandable terms. Probably the highest risk for an adult white male, for example, is simply being single, which reduces life expectancy 3500 days from what it would be if he were married. Smoking reduces life expectancy 2250 days. By contrast, the average danger from job-related accidents is only 74 days. This sort of ranking also puts some well-publicized arguments into perspective. The risk associated with nuclear accidents amounts to 0.02 day lost, according to the Rasmussen report, and to 2.0 days lost, according to the much more critical estimate by the Union of Concerned Scientists. Although the two figures differ by a factor of 100, they are both obviously very small compared with other common risks.

The need for more research

New regulations imposed on the utility industry mean that "the burden will be on the industry to demonstrate a superior method of risk assessment to replace today's generalized and perhaps overly conservative approaches," according to Ronald Wyzga, EPRI's technical manager of environmental integration. "In our program, we are trying to develop an assessment framework utilities can use to bring greater realism to the standards-making process. In addition, these methodologies will become very important in allowing us to resolve potential problems for future technologies while they are still on the drawing board."

A less optimistic note has been sounded by William C. Clark of the University of British Columbia, who has studied the history of risk assessment. He concludes there is a danger that it can turn into a witch-hunt, with the primary focus of public inquiry being to find some guilty party. In particular, he compares the proliferation of perceived risks today with the proliferation of witch-hunts in New England that resulted from seventeenth-century efforts to identify and reduce supernatural hazards. "The whole process becomes self-contained and self-amplifying," he concludes. "Many of the risk assessment procedures used today are logically indistinguishable from those used [by the witch-hunters]."

"The necessary response to make the process more rational," says Paolo Ricci, EPRI project manager in the Energy Analysis and Environment Division, is further research that "leads to a consistent understanding of the linkages—the chain of causes and effects—that characterize risk. Above all, we must try to avoid being irrational and aim instead to develop ways of examining risk that are analytically sound. The goal is to develop methodologies that clarify the issues, so that anyone can look at the analysis and accept or reject results on the basis of really understanding what's involved. That's why we're trying to develop better models of risk."

This article was written by John Douglas, science writer. Technical background information was provided by Ronald Wyzga and Paolo Ricci, Energy Analysis and Environment Division.

International Cooperation in Nuclear R&D

Civilian use of nuclear power, beginning with a U.S. program after WWII, paved the way for the current international agreements in atomic energy research.

President Dwight D. Eisenhower, in a dramatic speech before the General Assembly of the United Nations in December 1953, announced the Atoms for Peace program. In his speech President Eisenhower outlined a plan for international cooperation on the peaceful uses of atomic energy. The challenge he described was to use nuclear power to lift the burden of the increasing demand for energy from all mankind. Eisenhower emphasized that the United States was prepared to take the lead in sharing scientific knowledge and nuclear materials internationally.

The benefits to other nations from the U.S. Atoms for Peace program included the training of scientists from Argentina, Brazil, India, Pakistan, Republic of China (Taiwan), and South Korea, as well as from the more technically advanced countries. The U.S. government sponsored nuclear training schools for foreign scientists at the Argonne and Oak Ridge national laboratories. In addition, 39 research reactors were built overseas with U.S. funds and expertise. Another aspect of the Atoms for Peace program was a traveling exhibit that visited many countries around the world and demonstrated advances in nuclear medicine and energy production from nuclear energy.

The Atoms for Peace program revived U.S. prospects for international interaction on nuclear energy. Earlier cooperative efforts had been thwarted by the Atomic Energy Act of 1946, in which Congress expressed its opposition to any U.S. collaboration on military or civilian use of nuclear energy. Spurred by the success of Atoms for Peace, Congress revised the Atomic Energy Act in 1954 and reopened the door for international exchange.

At the same time, the European nations became interested in pursuing an international dialogue on nuclear power, and in 1958 the European Atomic Energy Community (Euratom) was formed. Established as the body of the European Community to be responsible for the peaceful aspects of atomic energy, Euratom's member countries now include Belgium, Denmark, the Federal Republic of Germany (West Germany), France, Ireland, Italy, Luxembourg, the Netherlands, and the United Kingdom.

Euratom established for the European Community a common market for all commercial nuclear materials and equipment and a common external tariff on nuclear imports from abroad. It provided a contracting agency for obtaining supplies of source and special nuclear material with countries outside the Community, including the United States. Euratom also set up its own independent system of nuclear safeguards, which was later brought in line with that of the International Atomic Energy Agency (IAEA).

Euratom also initiated an R&D effort and created the Euratom Joint Research Centre, composed of four research facilities located at Ispra, Italy (the largest); Karlsruhe, West Germany; Petten, the

Netherlands; and Geel, Belgium. The first R&D efforts of Euratom suffered because of internal disagreements; however, by the 1970s major research was under way on reactor safety and waste management.

Providing for Safeguards

The technology for developing nuclear weapons was long recognized as being available to any nation intent on using it, and in 1964 the People's Republic of China proved this by conducting a nuclear weapons test. After this, negotiations began in earnest among a number of nations on a treaty on the nonproliferation of nuclear weapons. They hoped that all nuclear-weapon and non-nuclear-weapon states would join the formal treaty, agreeing not to use civilian nuclear technology for weapons development. Under the treaty, which was completed in 1968, a safeguards system for nonproliferation was developed that was to be administered by IAEA.

The countries agreeing to the nonproliferation treaty must provide records to IAEA on nuclear power plant design, material inventories, and pertinent records and reports. IAEA safeguards are applied to all facilities involved in the various stages of the nuclear fuel cycle, starting with yellow cake, conversion, enrichment, fuel fabrication, power generation, reprocessing, and storage. The safeguards are terminated when IAEA determines that the nuclear material has either been consumed or depleted and is not a weapons threat. However, IAEA is responsible only for safeguards on facilities declared to be conducting peaceful nuclear operations. Article IV of the nonproliferation treaty provides for the fullest possible exchange of nuclear technology between those countries signing the treaty.

With the signing of the treaty, the international nuclear community expressed a commitment to the prevention of proliferation. Yet in 1974 the world was again shaken by the test of a nuclear explosive device, this time in India. This event led to the passage by the U.S. Congress of the Nuclear Nonproliferation Act, which President Carter signed into law in March 1978. The act restricts U.S. nuclear trade and cooperation with those nations opposed to the act's premise that certain nuclear materials are too risky for use as nuclear fuels because of the proliferation potential.

The United States also launched a major international program to investigate future technological alternatives for nuclear power: the International Nuclear Fuel Cycle Evaluation Program. This program was concerned with evaluating alternative fuel cycles and other international measures to ensure access to fuel supplies and spent-fuel storage for those nations sharing common nonproliferation objectives. At the 1977 organization meeting of 40 countries in Washington, it was agreed that the program was to be only a technical and analytic study and not a political negotiation. In addition, no country was to be committed to any results of the study.

The program was concluded in February 1980 with the publication of nine volumes of information: an overview and summary volume and eight volumes of working group reports. The study drew participation from 66 countries and 5 international organizations. One of the main contributions of the study was to stimulate cooperation in nuclear R&D by providing an open forum where the various aspects of the nuclear fuel cycle could be discussed.

There was broad acceptance by the countries participating in the study on these conclusions: proliferation risk is a factor to be considered in making fuel cycle decisions; these decisions are of interest to the international community because of worldwide concern over proliferation; and there are analytic approaches to resource, cost, and program questions that can be used as a common basis for international cooperation.

Multilateral Exchanges

One way to foster productive international discussions is through collaboration on R&D projects of mutual interest, such as nuclear safety analysis and waste management. Some avenues of cooperation, specifically information exchange and the discussion of pertinent issues, are explored by participation in multilateral energy organizations, such as IAEA and the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD).

IAEA, affiliated with the United Nations and located in Vienna, was established in 1957 with the goal of furthering peaceful applications of nuclear energy throughout the world. The agency has a dual role: it is the principal authority for the establishment and application of an international safeguards system against nuclear proliferation, and it is a cooperative forum for information exchange on all facets of nuclear energy. There are now over 100 member countries in the agency.

IAEA does not emphasize cooperative research activities, but it does provide information programs on nuclear safety and standards, nuclear materials safeguards, nuclear materials transfer, scientific information exchange, and technical assistance for the Third World. In 1970 the agency initiated the development of an international system for the collection and dissemination of nuclear information. The International Nuclear Information System indexes and abstracts publications in the nuclear field from throughout the world. IAEA also represents other important nuclear safety functions, designed to harmonize safety standards throughout the world. For example, under its Nuclear Safety Standards, IAEA has

LOFT facility at the Idaho National Engineering Laboratory.

published 5 recommended codes of practice and over 40 safety guides that set minimum standards of safety for nuclear power stations.

Together with representatives from all Nuclear Energy Agency member governments and the Commission of the European Communities, IAEA is represented on the Steering Committee that guides the Nuclear Energy Agency of OECD. Although its sister agency in OECD, the International Energy Agency, conducts R&D on nuclear technologies, the Nuclear Energy Agency specifically promotes cooperation and the sharing of nuclear information by its member governments and encourages common approaches in policies and practices in the nuclear energy field.

Three cooperative international R&D projects have taken place under the auspices of the Nuclear Energy Agency. A reprocessing plant was set up in 1957 in Mol, Belgium—the European Company for the Chemical Processing of Irradiated Fuels (Eurochemic)—and operated until 1974 but is now being transferred to a private Belgian company. Eurochemic was organized for the acquisition of industrial know-how and experience in irradiated fuel processing. The transfer of the facility was arranged under a convention between Eurochemic and the Belgian government. Until the transfer of the site is completed, Eurochemic will continue with its bituminization program for the low- and medium-level radioactive wastes from the company's reprocessing and decontamination activities. By the end of 1980 more than half of the medium-level effluents from the operation of the Eurochemic plant had been processed and put in drums now stored on site in special bunkers.

The second cooperative research program, one in which EPRI is an associate, is the boiling water reactor plant in Halden, Norway. This project dates from July 1958, when the boiling heavy water reactor at Halden, built and owned by the Norwegian Institutt for Atomenergi, became a joint undertaking under an agreement signed by Austria, Denmark, Norway, Switzerland, the United Kingdom, and Euratom. Halden has continued under a series of agreements: the last one completed covers the period 1979–1981. The United States is now a party to this agreement. (The Halden agreement is currently in the process of being renewed through 1984.)

The research work at Halden is divided into three areas: in-core behavior of reactor fuel, emphasizing reliability and safety aspects, studied through irradiation of test fuel elements; prediction, surveillance, and control of fuel and core performance; and applications of process computers to power plant control, for which prototype software systems and hardware arrangements are developed. The current costs of running Halden are charged directly to the participating countries.

The third joint research project was a high-temperature, gas-cooled reactor, called the Dragon, built and operated at Winfrith, England. Although this reactor provided valuable information on this type of gas-cooled reactor, the project encountered financial and technical difficulties and was shut down in 1976.

Recognizing that nuclear safety matters are of prevailing importance, the 23 member countries of the Nuclear Energy Agency have now increased their R&D expenditures on safety research and regulations. The work at the agency is coordinated through the Committee on the Safety of Nuclear Installations, which assists in broadening the pool of technical data available to regulatory authorities and the scientific community in order to contribute to sound and quick solutions to safety problems. For example, the committee sponsored the use of International Standard Problem exercises on the methods used to predict the physical conditions in a water reactor during a hypothetical loss-of-coolant accident and the performance of the emergency core-cooling systems. The data gathered from the tools used, such as complex computer codes, are compared with the results of highly controlled experiments under way at such research centers as the loss-of-fluid test (LOFT) facility at the Idaho National Engineering Laboratory. These comparisons allow for an evaluation of the accuracy and adequacy of the codes.

The agency also uses computer technology to collect and collate nuclear safety data and information. One of its two formal information systems, the Nuclear Safety Research Index, is the basis for collaborative efforts in the field of nuclear safety research. The index lists safety research projects in member countries and describes the projects' status and objectives under an international classification system. The index, which has been prepared annually since 1970, covers approximately 1200 projects and computer codes. The second information system, the Incident Reporting System, allows member countries to share reports on abnormal occurrences in thermal power reactors. This information system provides for prompt notification of incidents, warning responsible government authorities in order to help them take the proper countermeasures, and also provides periodic reports on other operating events in order to better identify generic safety problems.

It is clear that the multilateral energy organizations are concentrating many of their efforts on nuclear power safety requirements. The gathering of data on operating incidents and safety research programs is also an objective of many of the bilateral agreements undertaken by the U.S. government, particularly through the Nuclear Regulatory Commission (NRC).

Lafleur

Bilateral Safety Research

"Accumulating operating experience is one of our highest priorities in the international program at NRC, which has been stepped up since Three Mile Island," says Joseph D. Lafleur, Jr., deputy director of the Office of International Programs at NRC. "We also keep operators in other countries aware of important developments in our own safety research. We send out from 20 to 30 cables a year to operators abroad, notifying them of reactor problems or new safety techniques."

NRC currently has 27 regulatory agreements with both advanced nuclear nations and those developing a nuclear program, which provide for the exchange of regulatory and safety research information. As part of these exchanges, NRC provides notification of its decisions affecting the design and operation of reactors similar to those that have been exported from the United States. Because a license must be obtained from NRC before any export of nuclear material, equipment, or facilities, the agency is aware of all U.S. reactors installed overseas.

In addition, NRC offers on-the-job and classroom training courses for personnel from other countries on a variety of regulatory subjects, such as inspection procedures, analysis techniques, and nuclear power plant design and operation. Lafleur explains, "Other countries can send professional staff members to NRC training courses in Tennessee on a space-available basis. Also, NRC sends one or two training courses overseas each year, usually on boiling water reactor and pressurized water reactor fundamentals. These courses are particularly successful in countries that are beginning to develop a nuclear energy program." NRC has cooperated with South Korea and Taiwan in the startup of U.S. light water reactors and is currently working closely with Brazil, Yugoslavia, and Spain on their nuclear energy programs.

In terms of specific cooperation, NRC has approximately 40 international research arrangements and program cooperative agreements. These agreements include studying systems reliability with the Atomic Energy Authority of the United Kingdom, researching the refinements of calculating reactor accidents by assessing the amount of water passing across the core with West Germany and Japan (the 2D/3D project), and studying debris bed coolability with Euratom and Japan.

Lafleur discusses the largest international nuclear R&D program under NRC, which is located in Idaho. NRC has many bilateral agreements with other nations who are interested in the research at the LOFT facility in Idaho. "LOFT is a reduced-scale power reactor (55 MW th) built specifically to study loss-of-coolant accidents and the effectiveness of emergency core-cooling systems. Several countries—West Germany, Japan, and France—have been contributing $1 million a year to the research effort at Idaho. Technical personnel for these countries participate fully in the experiments at the facility." The LOFT program investigates the margins of safety for emergency core-cooling systems, tests alternative emergency coolant injection concepts, and identifies and investigates unexpected events in the plant or in the engineered safety system. Other countries participating in LOFT include Austria, the Netherlands, the Nordic Group (Denmark, Finland, Norway, Sweden), and Switzerland.

There is also an intergovernment agreement between the U.S. and USSR on scientific and technical cooperation in the peaceful uses of atomic energy. This agreement, for which DOE acts as the executive agent, provides for the exchange of personnel, equipment, and materials and for joint work in the field of the fundamental properties of matter, fast breeder reactors, and controlled thermonuclear fusion. The 10-year agreement was entered into in June 1973, but has been less active during the last few years.

The growing international concern for nuclear safety is exemplified by the eight countries that are members of EPRI's Nuclear Safety Analysis Center (Canada, France, Italy, Japan, Mexico, Spain, Sweden, Taiwan) and make use of NSAC studies and computer data on nuclear safety, and by Spain's membership in the Institute of Nuclear Power Operations.

The funding of large joint nuclear R&D projects through multilateral and bilateral agreements, scientific exchanges, international seminars and studies, and data banks on worldwide safety research are evidence of the complicated world of international cooperation. ■

This article was written by Christine Lawrence, Washington Office.

NSAC Reorganized

Formal incorporation of NSAC into EPRI's Nuclear Power Division brings new delineation of responsibilities.

Nuclear Safety Analysis Center (NSAC) has become part of EPRI's Nuclear Power Division, headed by Division Director John Taylor. According to David Rossin, who took over as NSAC director late last year, the new arrangement will be accompanied by changes in program structure. More emphasis will be placed on studying the probability, consequences, and prevention of severe nuclear accidents, with less emphasis on the day-to-day operating side of the nuclear industry.

The Institute of Nuclear Power Operations will take over several major operations-related projects, such as SEE-IN (the screening and evaluation of licensing event reports) and Nuclear NOTEPAD. These information-sharing programs were initiated by NSAC to increase the industry's ability to learn from the incidents that occur at nuclear power plants.

By investigating the probability of accidents and determining the associated chains of events, NSAC will help the industry put safety issues into perspective, including questions of pressure vessel integrity, removal of core decay heat after shutdown, and anticipated transients without scram. Investigation results can also be used to help establish more realistic regulatory requirements for nuclear power stations.

The increased emphasis on generic safety issues parallels ongoing research concerning severe accidents that could result in a degraded core. NSAC is developing information for use by utilities in responding to anticipated Nuclear Regulatory Commission deliberations on the ability to cool a damaged core and maintain the integrity of the containment building.

NSAC will continue working with the nuclear power industry to find feasible and useful ways to meet Nuclear Regulatory Commission requirements in the control room, particularly in the use of computer-based operator aids, such as the safety parameter display system (SPDS). SPDS, a computer-generated graphics display, gives operators instant access to information about the plant's safety status. Such access could be invaluable during an accident by helping operators verify the safety of the station and monitor the effectiveness of their actions. This first-of-its-kind display system, which is expected to be required in control rooms in 1983, will be tested at the Yankee Rowe nuclear power station under NSAC leadership this year.

NSAC will also work with utilities to develop their own probabilistic risk assessment capabilities, which will help utilities better understand the analysis and formulation of safety margins in plant management and operation. Probabilistic risk assessment is a tool that may prove effective in evaluating the tradeoff between cost and risk reduction of a particular design change. ■

EPRI to Fund Gasification Tests

EPRI has agreed to fund two sustained test runs of high-sulfur caking coals in an Allis-Chalmers Corp. gasifier under terms of a contract signed last month. EPRI's appropriation for the project could total $5.75 million through 1984. The test runs will be made with Illinois No. 6 and Pittsburgh No. 8 coals in the 600-t/d Allis-

Chalmers pressurized air-blown rotary kiln (KILnGAS) pilot plant, currently under construction at Illinois Power Co.'s Wood River generating station.

Under terms of the new agreement, EPRI will not fund design or construction work. Rather, assuming initial tests indicate that the system can be operated satisfactorily, EPRI will pay for two additional sustained test runs in 1984, each costing about $2.5 million. About $750,000 more will be spent planning the tests, procuring instrumentation, and examining analytic needs. The agreement also calls for EPRI to have full voting rights within the project's utility advisory structure.

The $132 million Wood River project currently receives financial support from 10 electric utilities, the state of Illinois, and Allis-Chalmers. Scheduled for completion by the end of 1982, the plant will provide the first opportunity to fully test the feasibility of the KILnGAS process, which has been the subject of experiments and design work since 1972. The rotating kiln gasifier, which has been tested at atmospheric pressure on an experimental level in continuous pilot plant tests and other equipment, is specifically designed to handle high-sulfur caking coals of the Midwest. The use of such coals has been restricted in recent years because of air quality regulations. ■

Starr Speaks on Electrification

In a speech commemorating the centennial of New York City's Pearl Street Generating Station, EPRI Vice Chairman Chauncey Starr called electric power one of the most liberating factors in our society, adding that every aspect of life in the United States has been profoundly influenced by the flexibility and efficiency of electricity.

Starr told the 1982 winter meeting of the Power Engineering Society that the generation of electricity at Pearl Street ranked with the development of the automobile and international telecommunications in shaping our modern world. It was at the Pearl Street site on September 4, 1882, that Thomas Alva Edison first generated electricity on a large scale—ushering in the electric age.

"The centennial of the Pearl Street Station," Starr said, "permits a retrospective look at the social significance of that event." Dramatic industrial growth, demographic changes, and a vastly better standard of living for the entire nation have been possible because of the widespread use of electricity. For example, because electricity is relatively easy to deliver, industry can locate where it wishes rather than being tied to steam- and water-powered mills. This increased flexibility has meant dramatic increases in the overall efficiency with which goods are produced. And at home, electricity keeps food fresh and clothes clean, permitting people to spend more time on leisure activities, many of which are themselves dependent on electricity.

Electricity has removed the technological constraints on providing all peoples of the world with the amenities and services characteristic of industrialized societies; the constraints are economic, political, social, and temporal. ■

Japan Joins Cool Water Project

Representatives of the Japan Cool Water Program (JCWP) partnership visited Palo Alto recently to discuss the coal gasification project with members of EPRI's Advanced Power Systems Division. Of prime interest to the Japanese group were EPRI's evaluations of the gasification–combined-cycle technology and the expected performance of the Cool Water plant, particularly with regard to environmental matters. JCWP signed a $30 million participation agreement in the Cool Water coal gasification program on February 24. Other participants include EPRI, Southern California Edison Co., General Electric Co., Texaco, Inc., and Bechtel Power Corp.

CALENDAR

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

APRIL

5–8
Seminar: Reliability Design of Single-Pole Transmission Structures
West Lafayette, Indiana
Contact: Phillip Landers (415) 855-2307

19–23
Foundation Design of Transmission Line Structures
Pittsburgh, Pennsylvania
Contact: Phillip Landers (415) 855-2307

MAY

3–7
HV Transmission Line Design
Lenox, Massachusetts
Contact: John Dunlap (415) 855-2305

12–14
Workshop: High-Voltage Power System Grounding
Atlanta, Georgia
Contact: John Dunlap (415) 855-2305

13–14
Utility Seminar: Municipal Solid Waste as a Utility Fuel
Miami Beach, Florida
Contact: Charles McGowin (415) 855-2445

18–21
Symposium: Flue Gas Desulfurization
Hollywood, Florida
Contact: Stuart Dalton (415) 855-2467

19–20
Seminar: Improvements in Power Plant Casting Quality
St. Charles, Illinois
Contact: Adrian Roberts (415) 855-2053

25–27
International Conference: Penetration of Electricity in Industry
Montreal, Canada
Contact: Walter Esselman (415) 855-2331

JUNE

7–11
HV Transmission Line Design
Lenox, Massachusetts
Contact: John Dunlap (415) 855-2305

7–11
Foundation Design of Transmission Line Structures
Dallas, Texas
Contact: Phillip Landers (415) 855-2307

14–18
HV Transmission Line Design
Lenox, Massachusetts
Contact: John Dunlap (415) 855-2305

16–18
Symposium: Environmental Analytic Chemistry
Provo, Utah
Contact: Glenn Hilst (415) 855-2591

JULY

7–9
Workshop: Steam Turbine Blade Reliability
Boston, Massachusetts
Contact: John Parkes (415) 855-2451

28–30
Environmental Control Technology for Coal Gasification Processes
Palo Alto, California
Contact: William Reveal (415) 855-2815

AUGUST

2–6
HV Transmission Line Design
Lenox, Massachusetts
Contact: John Dunlap (415) 855-2305

9–11
Conference: Power Plant Availability
Dearborn, Michigan
Contact: David Poole (415) 855-2458

9–13
HV Transmission Line Design
Lenox, Massachusetts
Contact: John Dunlap (415) 855-2305

16–20
Foundation Design of Transmission Line Structures
Denver, Colorado
Contact: Phillip Landers (415) 855-2307

25–27
Incipient Failure Detection for Fossil Plant Components
Hartford, Connecticut
Contact: Anthony Armor (415) 855-2961

SEPTEMBER

8–10
Workshop: Steam Turbine Bearings and Rotor Dynamics
Detroit, Michigan
Contact: Tom McCloskey (415) 855-2655

20–22
International Conference: Compressed-Air Energy Storage and Underground Pumped Hydro
San Francisco, California
Contact: Robert Schainker (415) 855-2549

OCTOBER

13–15
Transmission Line Grounding
Atlanta, Georgia
Contact: John Dunlap (415) 855-2305

18–20
Substation Grounding
Atlanta, Georgia
Contact: John Dunlap (415) 855-2305

25–27
7th International Conference on Fluidized-Bed Combustion
Philadelphia, Pennsylvania
Contact: Shelton Ehrlich (415) 855-2444

NOVEMBER

2–4
Seminar: Hydro Operation and Maintenance
Atlanta, Georgia
Contact: Charles Sullivan (415) 855-8948

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

GAS TURBINE POWER PLANT RELIABILITY

A major focus of the Gas Turbine Reliability Projects Group in EPRI's Power Generation Program is the consolidation and interpretation of data on combined-cycle reliability, availability, and maintainability. The goal is to provide a full understanding of these parameters and to identify precisely the components, failure modes, and operational factors responsible for outages and high maintenance costs. Current projects in this effort include high-reliability gas turbine combined-cycle development (RP1187), data systems and R&D evaluation for power generation needs (RP990), and a survey and analysis of steam system problems in gas turbine combined-cycle plants and their influence on reliability (RP1926). In addition, to establish a forum for collecting and exchanging information on gas turbine power plant experience, EPRI formed the Gas Turbine Operational Development Group in 1976. Last year, this group was incorporated into the Gas Turbine Task Force of the Edison Electric Institute (EEI) Prime Movers Committee. This report summarizes the data and conclusions resulting from these efforts thus far. The data presented are a combination of representative plant characteristics identified in RP1187, Phases 1 and 2, and statistics from the Operational Development Group.

Results from different manufacturers involve differences in both the quality and the quantity of data and in the methods of reduction and presentation. There are also differences in the way various manufacturers define the component distribution among systems, which makes it somewhat difficult to compare ostensibly similar results. Other differences arise from the interpretations manufacturers use in defining a plant's mature operating period. An effort has been made to resolve these problems in presenting the data in this report, and although some uncertainty or ambiguity remains, the discrimination of the data is sufficient to draw general conclusions. To put these data in perspective with technologies that compete with combined cycles, EEI data on fossil fuel steam plants have been used.

Plant and system data

Table 1 presents typical values of key reliability parameters for representative oil- and gas-fired combined-cycle plants. Data are

Table 1
RELIABILITY PARAMETERS FOR COMBINED-CYCLE PLANTS
(oil- and gas-fired units, one manufacturer)

	MTBFO (h)		Mean Corrective Time (h)*		Forced-Outage Rate (%)		Availability (%)		Operating Reliability (%)		Mean Protective Time (h)†	
	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas
Total plant	151	511	25	34	7.9	5.5	85.0	88.4	92.7	94.8	166	197
Combustion turbine system	208	1531	23	41	3.6	2.1	89.1	92.4	95.9	98.0	225	290
Heat recovery steam generator system	735	1365	21	20	1.6	1.1	97.9	98.5	98.4	98.9	66	76
Steam turbine system	4131	4667	75	88	1.4	1.5	98.2	98.2	98.6	98.5	110	125
Balance of plant	4879	5065	14	15	0.2	0.2	99.8	99.8	99.8	99.8	16	16

*For forced outage.

†For planned outage.

given for the entire plant and for major plant systems. Although the data are taken from one manufacturer's preliminary reports for Phase 2 of RP1187, corresponding data from other manufacturers have been found to be quite similar. The table indicates notable differences between oil- and gas-fired units.

At the plant level the commonly used parameters of forced-outage rate, availability, and operating reliability exhibit values comparable to those of other types of thermal power plants. However, the mean time between forced outages (MTBFO) is relatively low—151 h for oil-fired plants and 511 h for gas-fired plants. To provide a frame of reference, here are approximate MTBFO values from the 10-year EEI fossil-fuel-fired steam plant data: 1170 h for 100–200-MW units, 950 h for 200–300-MW units, 740 h for 300–400-MW units, 620 h for 400–600-MW units, 480 h for 600–800-MW units, and 380 h for 800–1000-MW units. (Although the MTBFO of gas-fired combustion turbine plants is similar to those of the larger steam units, comparisons are complicated by the fact that the EEI data cover oil-, gas-, and coal-fired units.)

The combustion turbine system is a prime contributor to the low combined-cycle plant MTBFO, as well as to the other plant reliability parameters. The heat recovery steam generator system is also an important contributor to the low plant MTBFO. A major focus of the analysis has been to understand the reasons for the dominance of combined-cycle plant reliability data by the combustion turbine system.

Table 2 presents data from RP1187 and the Operational Development Group for combustion turbine system components, including the engine and its auxiliaries. (The RP1187 data used here include preliminary Phase 2 data and published Phase 1 data.) The data on forced-outage events indicate the relative importance of failure contributions by controls, the mechanical support system (e.g., fuel, lube oil), and the starting system. Note that none of the engine flange-to-flange components are major contributors to the number of forced-outage events. The data on forced-outage hours indicate the relative importance of failure contributions by controls, the generator-exciter, the compressor, the mechanical support system, the starting system, and the combustion system. Also significant is the category *combustion turbine unit, general.* Among engine components, only the compressor and the combustion system contribute significantly to forced-outage hours.

Figure 1 combines the data on forced-outage events and hours for the systems that

Table 2
CONTRIBUTION OF COMBUSTION TURBINE SYSTEM COMPONENTS TO FORCED-OUTAGE EVENTS AND HOURS

	Forced-Outage Events (%)*	Forced-Outage Hours (%)*
Combustion turbine controls	42.9	18.9
Mechanical support system	23.3	9.9
Starting system	8.6	8.4
Combustion turbine unit, general	6.6	15.4
Generator-exciter	4.6	23.3
Combustion system	4.4	6.5
Balance of combustion turbine unit	2.5	0.9
Exhaust system	2.1	1.2
Electrical support system	1.7	0.6
Compressor	1.4	13.0
Rotor	1.1	1.3
Inlet	0.6	0.2
Turbine section	0.2	0.1

*Percentages are of the total number of events and the total hours attributable to the combustion turbine system.

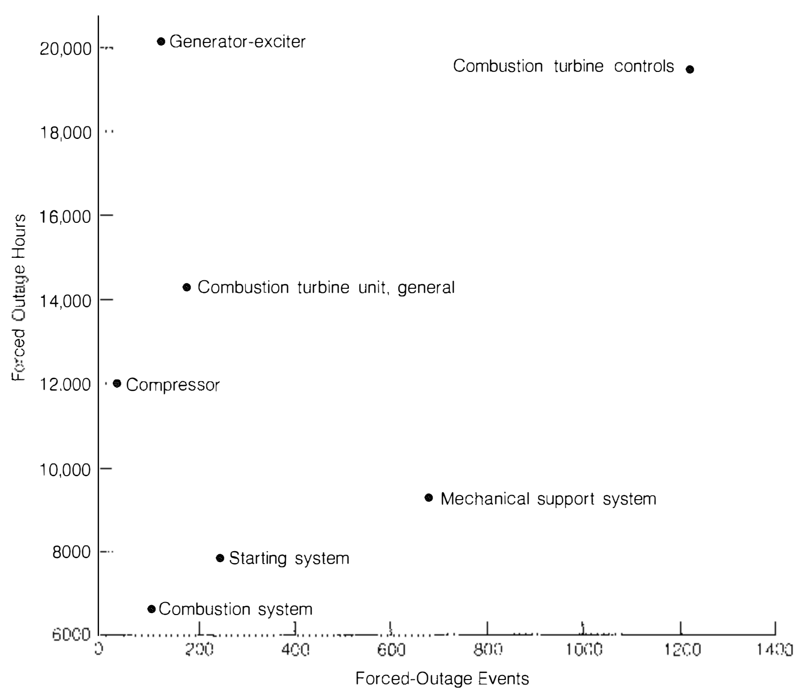


Figure 1 Combustion turbine system components that are significant forced-outage contributors in terms of number of events and/or hours. Data are from RP1187 and the Gas Turbine Operational Development Group.

make the largest contributions. Systems at the top and far right of the chart represent the greatest problems. Controls are clearly a major contributor in terms of both events and hours. The high values of the general combustion turbine unit category indicate a need for better data detail in the future.

Data limitations

Some uncertainties are introduced from time period to time period by such factors as unclear equipment problem indication, personnel changes, and varying operational conditions influencing personnel. For example, a vibration trip of a gas turbine unit as signaled by the annunciator may be an actual vibration trip, a malfunction of the sensor, or a loose wire; the true cause or failure mode may not be determined until later, if ever. Further uncertainties are introduced through insufficient engineering interpretation of the data. For example, recorded steam drum level trips may actually be caused by deficiencies of the feedwater control system. More field data at a greater level of detail are required to resolve such uncertainties. It should be understood, however, that the general conclusions derived from the data are valid in terms of comparing major systems and components.

The preliminary data provided by one manufacturer in Phase 2 of RP1187 (Table 1) indicate the fuel impact (oil versus gas) on a representative combined-cycle plant. However, this impact indirectly includes the effect of duty cycle, as oil firing is more often associated in the United States with peaking and gas firing with baseload. Unfortunately, it is not possible with the available data to separate precisely the effect of duty cycle and the effect of fuel type. Baseload duty may be expected to result in a generally higher equipment reliability, and this is indicated by the Table 1 data and similar data from other manufacturers. This relationship does not, however, appear to hold for starting reliability. Table 3 presents data from the same manufacturer on starting reliability, broken down by type of plant (combined cycle and peaking) and fuel (oil and gas). Clearly, the oil-fired combined-cycle plant has the poorest starting reliability. Peaking units may have better starting reliability because their starting systems are exercised more frequently, but again it is impossible to draw conclusions from available data.

Table 3
STARTING RELIABILITY

Plant Type	Starting Reliability (%) Oil	Gas
Combined cycle (11 gas turbine engines)	65.0	85.3
Peaking (24 gas turbine engines)	80.0	89.1

Current formats for data collection and public reporting on gas turbine power plants have been primarily aimed at establishing overall reliability and availability indexes. To an extent, as demonstrated here, it is possible to use existing and improved data collection and reporting methods to identify individual plant systems to which outages are attributable. This allows the establishment of priorities for investigating and improving those systems responsible for the bulk of outage events and hours. However, the data base does not identify the specific components or failure modes responsible for the outages; this level of detail is lost in the data collection and reporting process. Thus the attack on problem areas cannot be supported solely by the existing data base.

Until now, the root causes of failures have been postulated by manufacturers' or users' engineers mainly on the basis of relatively informal reviews of operating and maintenance experience. In Phase 2 of RP1187 this approach was formalized somewhat through the performance of failure modes and effects analyses, providing the manufacturers' engineers with a structured format for expressing their opinions. These analyses have not always agreed with the opinions of plant personnel. Because of the subjectivity involved, however, both opinions could be inaccurate; objective information is not available at the level of detail necessary to unequivocally establish root causes of failures.

The data base used here involves much information on older peaking units. The use of newer data might well give more satisfactory reliability results. Trends in reliability based on specific models or other criteria have not been extracted from the data.

Conclusions and future efforts

Gas turbine combined-cycle power plants, both gas- and oil-fired, show availability factors, forced-outage rates, and operating reliability factors comparable to those of other types of thermal power plants. The gas turbine system is the prime contributor to plant unavailability. The MTBFO of combined-cycle plants is considerably lower than that of other types of thermal power plants. Again the gas turbine system is a prime contributor, as is the heat recovery steam generator system. This appears to be a major cause of widespread utility dissatisfaction with gas turbine power plants.

Attention should be focused on the following gas turbine systems to reduce the frequency and total duration of forced outages: controls, mechanical support system, generator-exciter, starting system, compressor, and combustion system. Further data collection and analysis efforts are needed to help define specific causes of the outages attributable to these systems and to establish technical approaches and projects to eliminate problem areas. Because solutions to the problems in most of these systems are not expected to depend on advanced technology, gas turbine power plants have good potential for reliability improvement and for providing future power generation with high reliability.

The Gas Turbine Reliability Projects Group is being structured to attack the outstanding issues in cooperation with equipment vendors, utilities, and consultants. New field data collection and analysis efforts that are now being initiated with major equipment vendors and utilities, along with the advent of the EEI Gas Turbine Task Force, promise to yield the type of data needed to pinpoint problem causes. A project aimed at evaluating and improving the reliability of new gas turbine control systems is also being initiated. Other projects are under consideration, as well as a larger effort aimed at ensuring the reliability of new gas turbine models. *Technical Manager: Richard Duncan; Project Manager: Paul Zygielbaum*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

AFBC DEVELOPMENT

For several reasons, atmospheric fluidized-bed combustion (AFBC) of coal presents an environmentally and economically attractive alternative to conventional utility coal-fired boilers. In AFBC, coal is burned in a fluidized bed in the presence of calcined limestone (CaO). The limestone absorbs the sulfur released during coal combustion to form solid calcium sulfate ($CaSO_4$). High-sulfur coals can therefore be cleanly burned without requiring a flue gas desulfurization (FGD) system. Because of the relatively low combustion temperature maintained in the fluidized bed, emissions of nitrogen oxides (NO_x) are well below the New Source Performance Standards. The low combustion temperature also results in greatly reduced slagging and fouling of heat transfer surfaces by coal ash. A very broad range of fuels can thus be burned without requiring modifications for coal ash fusion characteristics. Through a combination of projects encompassing process development units, materials testing, laboratory experiments, and utility boiler design studies, EPRI is developing AFBC for commercial application to utility power generation.

In recent years, EPRI's research has centered on two projects: the 2-MW (e), 6′ × 6′ development facility and the 20-MW (e) pilot plant. The 6′ × 6′ development facility is operated by Babcock & Wilcox Co. at its Alliance (Ohio) Research Center (RP718). The main objective of this project is to test a wide range of operating conditions and process configurations geared toward improving the process performance. The 20-MW (e) pilot plant, built by B&W for TVA, is located at TVA's Shawnee steam plant in Paducah, Kentucky (RP1860). Construction of the facility has been funded by TVA and its operation will be cofunded by EPRI and TVA. The objective of the 20-MW (e) project is to test full-scale equipment and design configurations and to develop scaling parameters for the design of 200-MW (e) and larger units. The 6′ × 6′ development facility has been operating since early 1978, and the 20-MW (e) pilot plant is scheduled for startup in May 1982.

Design improvements

Several major process improvements resulted from the 6′ × 6′ project. Prior to this project, the combustion efficiency of FBC was considered marginally acceptable for utility application because of the high concentration of unburned carbon particles in the fly ash. (Utility boilers require 99% combustion efficiency, whereas typical FBC combustion efficiencies were less than 96%.) Tests at the 6′ × 6′ facility demonstrated that the combustion efficiency could be improved by collecting the fly ash and recycling a portion of it back to the fluidized bed. This recycle configuration increases the residence time of the fine carbon particles in the combustion zone, thus improving the combustion efficiency to over 99%.

Another design improvement is in the area of load following. Most conceptual designs for utility-scale FBC boilers achieve turndown by dividing the fluidized beds into multiple segments and isolating the forced-draft air (air that is blown into the combustor) ducting to each segment. Sequentially shutting off the forced-draft air and coal feed to the segments reduces the area of the active fluidized beds. This on/off control creates a turndown pattern composed of a series of step changes. The size of a step change can be reduced by designing more segments per bed; however, this makes the system more complex and costly. Although this load-following system is feasible and has been demonstrated on a small scale, it creates several design and control problems.

An alternative turndown technique has been demonstrated at the 6′ × 6′ facility that results in a continuous change in steam output rather than in step changes. Turndown was achieved by gradually reducing the air and coal feed rate to the fluidized bed while keeping the entire bed fluidized.

This technique takes advantage of the natural tendency of the fluidized bed to expand or contract as the fluidizing air velocity is alternately increased or decreased. As the fluidizing air is decreased during turndown, the bed contracts and some of the in-bed heat transfer tubes become exposed above the fluidized bed. These exposed tubes absorb heat at a much lower rate than the tubes still in the bed, and therefore a reduced amount of steam is generated. By matching the rate tubes become exposed above the bed with the rate that fuel is decreased during turndown, a heat release–heat absorption balance is maintained, which results in a constant bed temperature over the load range. This constant bed temperature is necessary for efficient combustion and efficient sulfur absorption.

The velocity reduction technique had been tested at other FBC facilities, but only over very limited load ranges. Testing at the 6′ × 6′ facility led to the development of more design data on the relationships between fluidizing velocity, bed expansion, and in-bed/above-bed heat absorption characteristics (these data are necessary for the design of tube bundles that are compatible with velocity turndown). The design data were used to modify the existing in-bed tube bundle in the 6′ × 6′ facility to allow for a 50% continuous turndown capability.

Recent tests successfully demonstrated this 2-to-1 turndown capability. The quick response of the system to load demand changes was further demonstrated by taking the unit through a 50% load swing at a rate of approximately 12% per minute. Based on the results of these tests, it appears that with additional modifications to the in-bed tube bundle, a 3-to-1 turndown ratio is achievable with the velocity reduction technique.

Emissions control improvements

The use of fly ash recycle to improve combustion efficiency has also proved effective in reducing the amount of limestone that is required to reduce SO_2 emissions to acceptable levels. Without fly ash recycle, only 20–25% of the limestone is utilized (converted to calcium sulfate, the product of the reaction of lime with the sulfur released during coal combustion). This low utilization is because of the formation of an outside shell of calcium sulfate over the lime core of the particles. By using finer limestone, which has a higher ratio of surface area to mass, the utilization of the limestone can be increased. However, as with fine carbon, fine limestone is readily blown out of the fluidized bed before it fully reacts. Initial tests in the 6′ × 6′ facility showed that with fly ash recycle the limestone utilization was increased to over 30%.

More recent tests at higher recycle rates resulted in a limestone utilization of over 40%. This improved utilization resulted in 90% SO_2 emissions reduction with a calcium-to-sulfur molar feed ratio of approximately 2 to 1. The low calcium-to-sulfur ratio greatly reduces the projected operating cost of a utility-scale FBC boiler.

NO_x emissions from FBC boilers are relatively low compared with emissions from conventional coal combustion methods. Pilot FBC boilers typically have NO_x emissions in the range of 0.3 to 0.45 lb/10^6 Btu, which is below the federal New Source Performance Standards (0.6 lb/10^6 Btu for bituminous coal and 0.5 lb/10^6 Btu for subbituminous coal).

Some regions of the country, however, have NO_x emission standards that are below the 0.3–0.45 lb/10^6 Btu levels. In addition, continuing environmental pressures may result in a further lowering of the New Source Performance Standards. Therefore, there was an impetus to investigate further NO_x reduction methods for FBC boilers.

The technique of overfire air, similar to that employed in conventional coal combustion systems, was tested at the 6′ × 6′ facility and was effective in significantly reducing NO_x emissions. In this technique, a portion of the fluidizing air is diverted to above the fluidized bed. This reduces the amount of excess air in the fluidized bed without going below the stoichiometric coal-air ratio. At 10% overfire air (8% excess air in-bed), the NO_x emissions level was reduced to 0.25 lb/10^6 Btu. At 18% overfire air (0% excess air in-bed), the NO_x emissions level was reduced to 0.15 lb/10^6 Btu. Tests on superheater materials at these operating conditions showed no marked increase in corrosion potential. Therefore, by using a moderate amount of overfire air (about 15% of the total), NO_x emissions from an FBC boiler can be reduced to 0.2 lb/10^6 Btu without fear of excessive corrosion.

Scale-up of the process

The four years' testing in the 6′ × 6′ facility have resulted in improving the process to the point where AFBC can simultaneously achieve the following.

- 99% combustion efficiency
- 90% SO_2 emissions reduction at a 2-to-1 calcium-sulfur ratio without requiring additional flue gas scrubbing
- NO_x emissions of 0.2 lb/10^6 Btu

In addition, a 3-to-1 turndown ratio appears achievable and the facility has demonstrated that it can operate efficiently with a wide range of fuels. The next step is to apply these improvements to units of larger scale.

Before confident scale-up of these process design improvements to commercial plants can be made, further development of the peripheral systems surrounding the basic FBC boiler is necessary. The major systems include the coal and limestone feed system, the recycle system, and the control system. Numerous options currently present themselves in the design of these systems for large commercial-size units in the 100–600-MW (e) range, such as the 150-MW (e) unit planned by TVA. Further evaluation is necessary because of the impact the various options will have on the basic configuration and economics of commercial FBC systems. In addition, the optimal configuration could change greatly with unit size, cycling requirements, and fuel type. It will be the role of the 20-MW (e) pilot plant at TVA to provide the basis for these types of system configuration decisions to be made by future plant designers.

Scheduled for completion in the spring of 1982, the 20-MW (e) pilot plant was designed with sufficient flexibility to allow comparison of two entirely different methods of feeding coal and limestone to the boiler. One method is by pneumatically transporting, splitting, and distributing the coal and limestone mixture to the base of the bed; the other method incorporates conventional coal spreaders to feed and distribute the coal from over the bed. With the latter technique, limestone is fed by gravity to a single point above the bed. Selection of a system for scale-up will be based on the trade-offs that each system presents for capital and operating costs.

The 20-MW (e) facility also incorporates many of the recent improvements developed at the 6′ × 6′ facility, such as overfire air and high recycle capability. Provisions for future gravity recycle of solids to the bed have been made as an alternative to pneumatically feeding and distributing the fly ash to the base of the bed.

For control system development, the 20-MW (e) plant is equipped with a direct digital control system. This system permits easy control system modifications and is compatible with supporting advanced analytic control system designs. The plant size (20 MW) and steam conditions (2400 psig, 1000°F; 165 MPa, 538°C) present a prototype boiler system whose inherent dynamic and control characteristics, once evaluated, will have a substantial effect on the configuration and heat exchanger surface arrangement of a commercial FBC system.

In support of the facility, the TVA–EPRI test program (RP1860) has provided a mechanism for operator-engineer training, test procedure development, and an effective data analysis system design. The focal point for these activities is the test plan, which defines an overall strategy for process and systems evaluations; materials of construction and reliability investigations; and control system development. The current test program is scheduled to run through mid-1986.

The next step in scale-up beyond the 20-MW pilot plant will be a demonstration AFBC boiler in the 100–200-MW (e) range. EPRI has initiated work in this phase of the utility FBC development by soliciting host utilities as cosponsors. Site selection is expected to be completed by June 1982. Following the site-specific design development, construction is expected to begin in 1985, with the plant fully operational by 1990. *Project Managers: Callixtus Aulisio and William Howe*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

TRANSMISSION SUBSTATIONS

Vacuum fault current limiter

An earlier status report (*EPRI Journal*, September 1980) discussed the exploratory work being done by Westinghouse Electric Corp. on the use of a vacuum device as a fault current limiter for high-voltage ac circuits (RP564). This report also announced the initial application of the technology—not as a current-limiting device but as a high-voltage dc circuit breaker for switching converter stations operating in the monopolar mode from ground return to metallic return, the metallic return transfer breaker (MRTB).

Subsequent articles (*EPRI Journal*, December 1980 and May 1981) reported this application in greater detail and its successful field trials and installation on the Pacific Intertie at the Celilo DC Terminal. Since completion of the MRTB application, work has resumed on the more demanding application of this technology to an ac fault current limiting device for 72.5/145-kV and above systems.

The arrangement of the major elements of the fault current limiter (FCL) is shown in Figure 1. The action of the FCL on a fault current is shown in Figure 2. The contacts of the vacuum current limiter (VCL) and the vacuum interrupter (VI) are closed to carry the normal system current. At the detection of an abnormal fault current, the contacts of both devices rapidly part and reach the gap required for commutation (approximately 1–2 cm; 0.39–0.8 in) in about 2 ms. During this open period, a stable low-voltage arc is formed between the VCL contacts. When the required contact gap is reached, an oscillating transverse magnetic field is applied, rapidly increasing the arc voltage. This rapidly increasing arc voltage causes the fault current to be diverted from the VCL (initially into a parallel capacitor and ultimately into an energy-absorbing resistor, where it is controlled). The standard VI is operated in series with the VCL to withstand the recovery voltage associated with this transfer process.

The objective of the present period of the development has been to examine the application of this principle to a 145-kV FCL as a preliminary feasibility study of this technology. In this application, two 72.5-kV modules would be connected in series in each phase. Each module would consist of a double-VCL element and a single-break VI, together with the associate parallel capacitance and energy-absorbing resistor.

At this time, work was concentrated in four major areas.

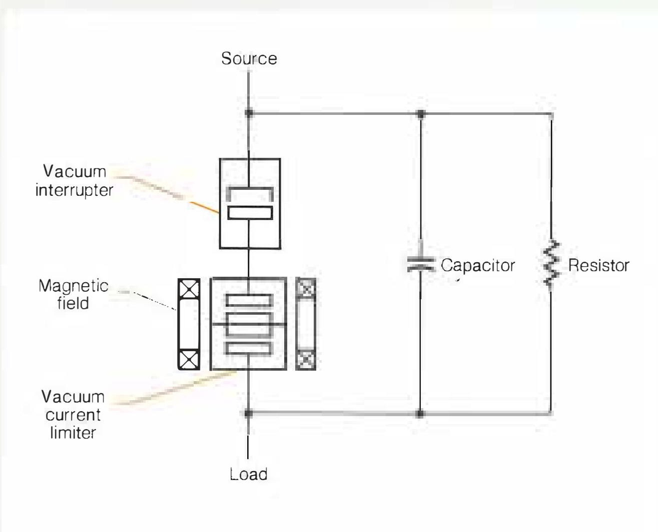


Figure 1 On contact separation and application of the magnetic field, the vacuum current limiter transfers the current initially into the capacitor and ultimately into the energy-absorbing resistor. The series-connected vacuum interrupter withstands the ensuing recovery voltage.

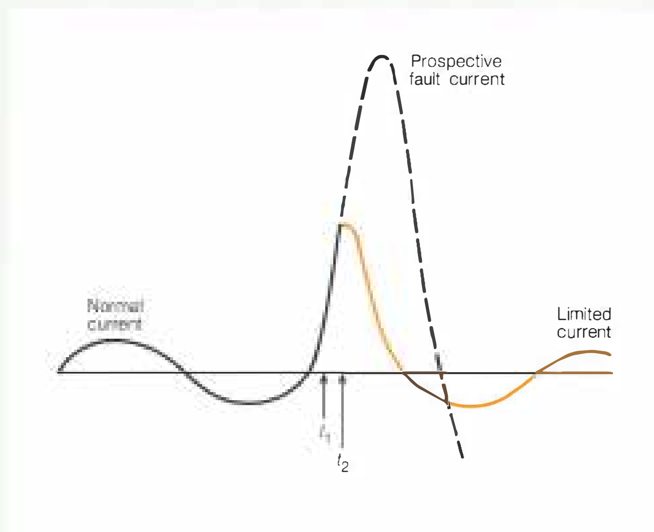
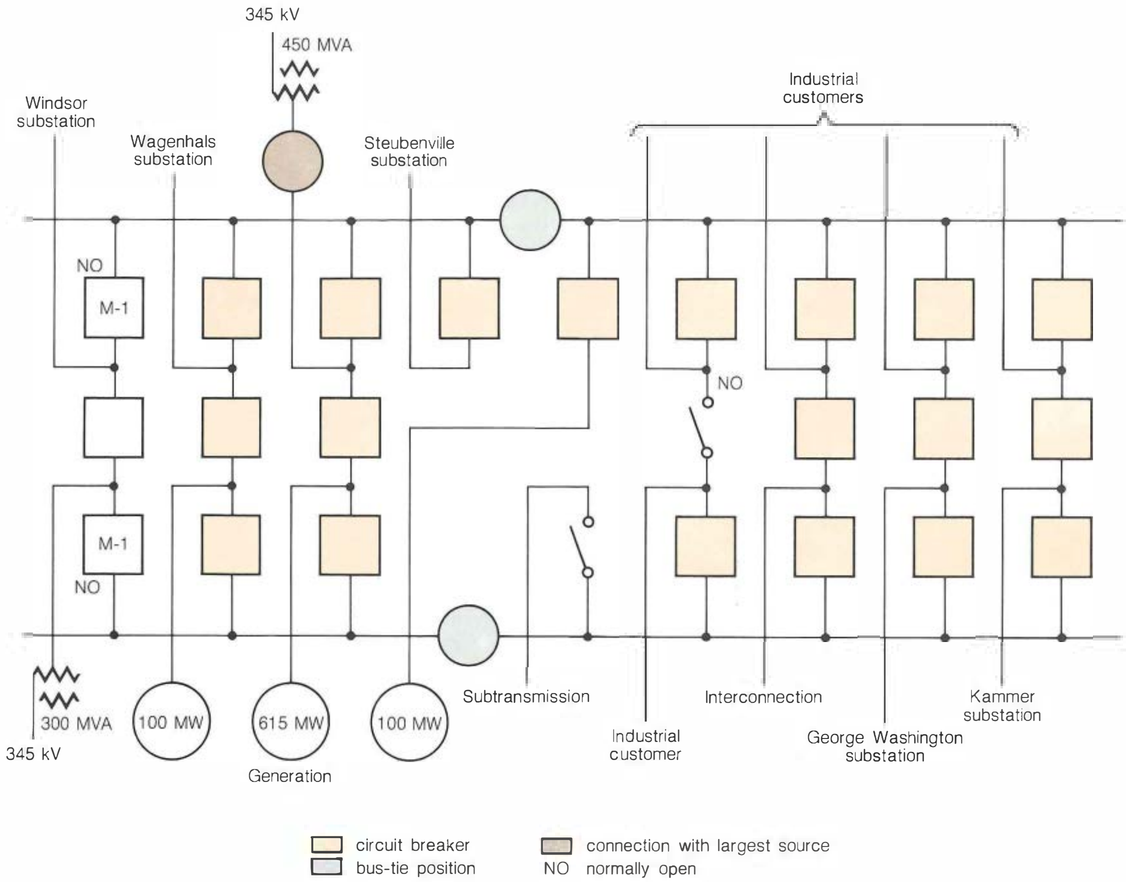


Figure 2 Action of the fault current limiter on fault current. Fault is sensed at t_1 and the vacuum current limiter and vacuum interrupter are parted. Critical commutating gap is reached at t_2 and the field of the vacuum current limiter is energized, thus commutating the fault current.

Figure 3 Application of the fault current limiter on the Tidd substation of the American Electric Power Co. system. Reduction of short-circuit current is desired at the circuit breakers. This could be achieved by installing fault current limiters at bus-tie positions or in series with a large source.



▫ Defining FCL application and specifying its major operating requirements

▫ Reducing FCL cost and complexity

▫ Increasing FCL reliability

▫ Maximizing VCL performance

To determine application and operating requirements, Westinghouse examined candidate applications for fault current limiting from another EPRI project (RP1498). The Tidd substation on the American Electric Power Co. system was found to be representative of the most severe applications examined. To bring the maximum fault current levels down to the desired level at the breaker position points (Figure 3), the two FCLs could be installed in the bus-tie positions where the maximum current rating would have to be 40 kA. Alternatively, one FCL could be installed at the point where it would limit the contribution of the largest source to achieve the desired current limiting at the breaker positions. In this case, the maximum current rating of the FCL to achieve the required results would be reduced to less than 15 kA rms. Installation at the bus-tie positions has the advantage that the fault contribution of any additional sources connected to the system would not exceed the rating of the circuit breaker.

However, this requires two FCLs with high fault current ratings. Installation of one FCL at the point of connection with the largest source would achieve the desired results at a much reduced FCL rating but could require that an additional FCL be installed in series with any additional new sources that are connected to the system. The VCL would prove suitable for this application.

To reduce the cost and complexity of the FCL, several concepts are being explored. A capacitor bank is a costly element. Reducing either its surge voltage or capacitance will have a proportional influence on its cost. The value of the capacitance is determined largely by the capability of the VCL to force a current-zero in the presence of an oscillating transverse magnetic field. A reduction in capacitance involves achieving enhanced arc instability with VCL. In addition, once the current is forced to zero, the initial rate of change of voltage (dv/dt) is inversely proportional to the size of the capacitor. Improvements in the di/dt and dv/dt performance of the FCL are being sought by modification of the design.

The parallel energy-absorbing resistor is another large-cost element in the FCL. Studies have shown that substitution of a metal oxide, nonlinear resistor will substantially reduce the energy dissipation required in comparison with a conventional linear resistor, hence reducing both cost and size. The use of a nonlinear resistor would have several other important benefits. If connected across individual modules, it could aid in dividing the voltage between modules, and more important, would limit the voltage stress across an individual module should the modules not clear simultaneously. In addition, it would clamp the peak recovery voltage appearing across the capacitor and hence permit a reduction in capacitor surge voltage capability over that required for a linear resistor.

To improve both reliability and performance, it is currently contemplated that the VCL will consist of two gaps in series per module. These would be driven by a common coil to achieve simultaneous forced current-zeros in each gap. An even more important reliability feature is the redundancy inherent in the FCL design. The VCL and the VI are connected in series and are operated simultaneously. In the event the VCL should fail to force the fault current to zero, it would be interrupted in a conventional manner at the first current-zero by the VI. This failure mode would permit the first current loop of the fault current to pass through unlimited, which may cause some damage to devices on the system. However, limiting the duration to a single loop would minimize the damage and should prevent catastrophic failure of any of the power system elements.

At the present state of development the VCL has reliably commutated instantaneous currents of 15 kA with a 50-μF parallel capacitor (this translates into 25 μF for a two-module, 145-kV FCL). With this capacity, it can be used to limit fault currents in circuits with up to 15 kA rms available fault current (approximately 35 kA peak available current). Although this performance is sufficient for the cases studied, work is being carried out to improve the performance of the VCL. Improvements in performance would reduce the size and cost of the parallel capacitor and/or increase the rating, where necessary, of the FCL. Currently being tested are scaled-up versions of the standard VCL, which have interrupted 16 kA with a 48-μF parallel capacitor and show promise of commutating instantaneous currents of 15 kA with a 30-μF parallel capacitor (this translates into 15 μF for a two-module 145-kV FCL). In addition, a new concept is being developed at the State University of New York at Buffalo under a supporting contract (RP993). This concept, which also uses a transverse magnetic field, has the additional feature that the magnetic field increases as the arc plasma approaches the contact surface. This magnetic field gradient provides additional force that further increases the arc voltage and instability. Although this concept is still in the early stages of development, it has achieved high commutation currents.

The current-limiting concept employed in this investigation appears to be technically feasible now. Work is continuing to further improve its cost competitiveness and application flexibility. *Project Manager: Joseph Porter*

GIS fault detectors

Gas-insulated substations (GIS) require less space, have a totally enclosed and grounded construction, and are immune to weathering and contamination problems. However, whenever a problem is encountered, such as internal corona activity or an insulation system breakdown, it is often difficult to ascertain the precise location of the problem. During the decade-long history of GIS equipment, ultrasonic radiography or hard X-ray techniques have been used to locate problem areas, but neither approach has been totally satisfactory. For example, the ultrasonic detection method requires reenergization of the faulted segment; radiography can illuminate major problem areas, but only if one knows where to look.

Two research projects were initiated in 1978 to develop new techniques to locate and analyze faults in GIS equipment, with the ultimate objective of reducing the duration of any equipment service outage.

A project with Ontario Hydro (RP1360-1) was initiated with the following objectives.

- Investigate the feasibility of and then develop a fault detection technique employing insulated tape for gas-insulated substations
- Through the use of an infrared camera, develop and package a fault detection system capable of scanning the station equipment and recording the video image on a magnetic recording system, which could later be replayed to evaluate information that might aid in fault location
- Through an extensive test program, study the arc behavior within the coaxial electrode geometry commonly employed in the GIS equipment design to better predict the consequences of faults

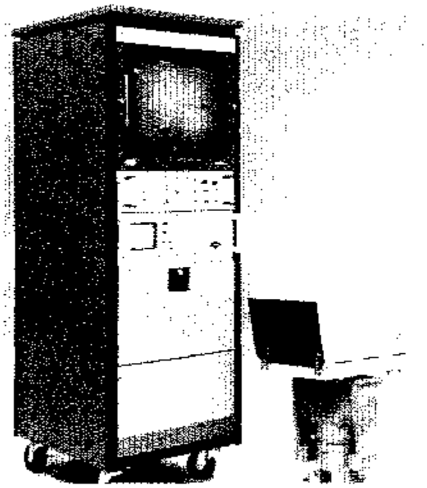
Through this recently concluded project, the fault detection method employing the insulated tape method was investigated and found to be unsuitable for this application. The basic assumption that the outside enclosure voltage at the point of electrical breakdown will rise because of the well-known transient overvoltage phenomenon did not prove out. The rapid voltage collapse in SF_6 leads to an extremely fast wavefront (on the order of a few nanoseconds). This high-frequency transient travels along the inside surface of the ¼-in-thick aluminum enclosure, rather than penetrating it. This leads to the transient overvoltage appearing at the terminations well in advance of the fault origination point. Although this work did not result in any usable fault detection technique, it did bring about a proper understanding of the overvoltages resulting from arcs in SF_6 gas and provides useful information for proper grounding procedures.

This project with Ontario Hydro, however, resulted in two fault detection schemes that can easily be retrofitted on existing equipment. The simpler of the two is an application of a temperature-sensitive paint. This paint is commercially available and can be applied by spraying or brushing on the outer enclosure. To improve the durability of the paint so it can withstand the full range of climatic conditions prevailing in an outdoor environment, a protective coating is also recommended. Through aging tests, it was concluded that the paint with the protective coating should last as long as five years. For indoor substations, no additional protection is required, and it is anticipated that the coating will not degrade with time. Interested users are encouraged to buy the required quantity of this temperature-sensitive paint directly from the paint manufacturer, and EPRI will provide technical assistance as required.

The second concept of fault detection employs an infrared video system. Through an application of commercially available infrared video systems, a detection scheme has been developed that can reveal local temperature variations with reference to time. Through this monitoring scheme, it will be possible to assess the location, severity of the damage, and range of arc travel during the high-energy fault. This system will be tested at Louisiana Power & Light Co. under a field evaluation program. Figure 4 shows the console, which is equipped with a TV screen and a tape recording system. Also shown is the infrared camera head with tilt and panning capability.

The camera head is suitably packaged

Figure 4 A fault detection system for gas-insulated bus employing an infrared camera. The equipment consists of a console equipped with a TV screen and a video tape recording system. The infrared head is shown as a separate unit.



for an outdoor installation and should be mounted at a location that will maximize the surveillance of the equipment. (Some substations may require more than one camera to ensure complete coverage.) The camera head can be linked to the console, housed inside a control room, through a 100-ft (30-m) shielded cable.

A high-frequency transient resulting from a flashover in the gas bus will automatically turn the whole system on, and the camera will pan through a preprogrammed path and record the infrared image on the tape, which can be replayed later for further interrogation. This fault detection method will not detect flashovers under high-voltage tests nor will it offer any information on incipient faults, except in cases where the fault was caused by improperly mated current-carrying contacts that result in a significant generation of heat.

The final report on this project discusses experimental results on the behavior of an arc in SF_6. Discussions on arc velocity and gas pressure rise, as well as burn-through probabilities, are included (EL-2248).

Through a project with General Electric Co. three sensor designs for GIS application have been developed (RP1360-2). Typically, one sensor will monitor a small gas bus zone (about 20–30 ft; 6–10 m in length), and thus many such sensors are required to monitor an entire substation. The three designs to detect faults are thin film (chemical), optical, and magnetic.

The thin-film (or chemical) sensor (Figure 5a) employs a special resistive element. Through a chemical reaction with the by-products produced from an arc in SF_6, it temporarily changes into a low-impedance resistor, resulting in an increased sensor current. This sensor can detect corona activity, which may later lead to a power fault. However, the sensor must be incorporated in the gas volume, and thus the equipment most likely would have to be shut down to install these sensors in energized equipment.

An optical sensor (Figure 5b) is sensitive to the optical energy resulting from either a fault or corona activity. This sensor is also difficult to incorporate as a retrofit on energized systems and, like the chemical sensor, may require an equipment outage. In addition to incipient faults, the sensor can detect flashovers during dielectric acceptance (hi-pot) tests and thus is the most versatile of all the fault detection systems.

The magnetic sensor (Figure 5c) is a noninvasive type and can be applied externally on the enclosure. The magnetic field effect is so localized that sensors should be applied only where the insulators are located. As the vast majority of faults occur at or near the insulators, this should lead to a practical fault detection scheme. A magnetic sensor obviously will not detect flashovers during electrical testing, nor will it offer any information on incipient faults.

Each of the three sensors is packaged in an outdoor-type Nema box measuring 6 × 4 × 4 in (15 × 10 × 10 cm) and is self-powered by a small battery with an expected one–two-year life. The chemical and optical sensors are fitted with 1-in IPS pipe fittings that can easily be mounted either on existing gas fill or on bypass piping. All sensors come with magnetic flip-disks and display a bright color spot that indicates tripping of the sensor.

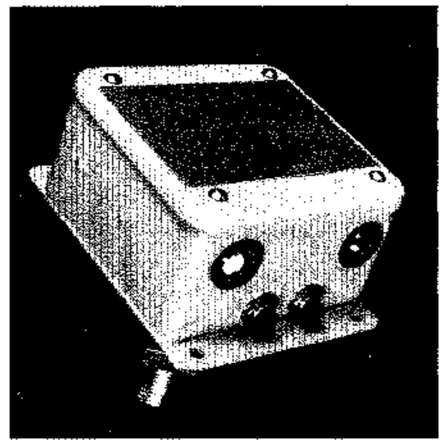
These sensors are currently being field-tested at Consolidated Edison Co. of New York, Consumers Power Co., and Louisiana Power & Light Co. *Project Manager: Vasu Tahiliani*

Advanced operating mechanisms

The conceptual design of advanced operating mechanisms for substation switching devices has been completed and the results are very encouraging. This portion of the work by Westinghouse determined the mechanism requirements for high-voltage substation switching devices in the foreseeable future, such as high-speed grounding switches, fault current limiters, and power circuit breakers (RP1719). Westinghouse also developed conceptual designs for suit-

Figure 5 **(a)** A thin-film (chemical) fault detection sensor with a special resistive element. This resistive element is sensitive to the by-products generated from an arc in SF_6 gas. **(b)** An optical fault detection sensor. The fiber-optic tip picks up any illumination generated by an arc and feeds the signal to a phototransistor. **(c)** A magnetic fault detection sensor designed to detect localized magnetic fields resulting from an arc between the high-voltage conductor and the grounded enclosure of GIS equipment.

a



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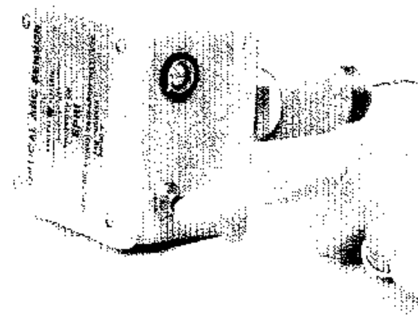

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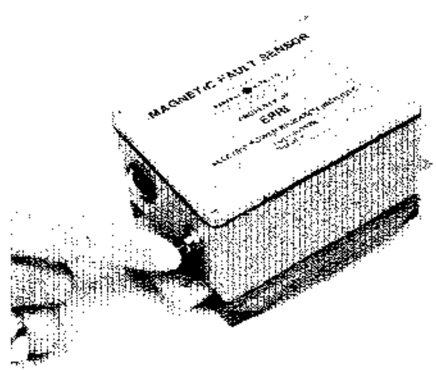


able mechanisms that use chemicals as an operating energy source.

The substation devices studied have a broad range of operating requirements, ranging from those of very fast opening time with short-stroke, low-mass contact devices to the long-stroke, large-mass contacts with relatively slow operation of power circuit breakers. The operating energy requirement for the SF_6 puffer-type circuit breaker is particularly high because of the additional requirement to provide the necessary gas flow for arc interruption during the opening operation. This type of breaker is becoming dominant, and as current interrupting and voltage ratings increase, the operating energy requirements will become much greater. One of the most efficient means of providing this energy is in chemical form where the energy is released by combustion. It is also one that is versatile in that a single type of energy unit may be employed in a broad range of applications and has the advantage of fast triggering, which is necessary for fast operating times. These mechanisms will be simpler in design than those in use today. The use of a chemical energy source will eliminate the need for support systems, such as air reservoirs, motors, compressors and their controls for pneumatic systems, and similar components for hydraulic systems. These items account for a major portion of the maintenance on today's operating mechanism systems. Auxiliary power will not be required except for cabinet spaces, heaters, or a service supply similar to present practice.

Breaker reliability should also be improved. Nearly a third of all breakers that fail to operate on command have a mechanism system malfunction. The chemical-actuated mechanism with its basic operator simplicity and reductions in auxiliaries should be inherently more reliable. A prototype mechanism applicable to a puffer-type SF_6 circuit breaker is to be built and tested on this project; it is scheduled for completion in 1982. *Project Manager: Narain Hingorani*

UNDERGROUND TRANSMISSION

Losses in pipe-type cables

Because of the growth of urban areas over the years, utilities have used pipe-type cables of ever-higher voltage and current ratings to supply the larger blocks of power required. For the most economic transmission, it is necessary to accurately calculate the losses and load capabilities of these systems.

The most commonly used equations are based on the 1957 AIEE Transactions Paper by J. H. Neher and M. H. McGrath, "The Calculation of the Temperature Rise and Load Capability of Cable Systems." Although these equations are applicable to a wide range of conductor sizes and voltage ratings, their empirically derived factors are based on pre-1957 copper conductor cables rated up to 138 kV.

Over the past 25 years, significant changes in manufacturing techniques have been introduced. Further, 345-kV cables are in common use, and both 550-kV and 765-kV cables have been developed. Because of these changes, it was considered necessary to test whether extrapolation of the Neher-McGrath equations would cover the larger systems.

A project was jointly funded with DOE and General Cable Corp., now Pirelli Cable Corp., to achieve the following objectives, and the final report (EL-1125) is available.

- Verify the adequacy of the Neher-McGrath equations by measuring resistance ratios on conventional pipe-type cable systems rated 115, 345, and 765 kV
- Develop a computer program for calculating the resistance ratio of these systems that is based more heavily on electromagnetic fundamentals and requires fewer empirical factors

The most significant result of this work was that with some modification of empirical factors and the introduction of a new one, the Neher-McGrath equations are adequate for modern higher-voltage cable systems of conventional design. The computer program developed under this project provided only limited agreement with measured values because of the nature of the boundary conditions and the precision with which detail could be modeled.

The results suggested additional work was desirable, and two new projects were instituted.

The first, jointly funded with Pirelli Cable Corp. (RP7832-2), has the following objectives.

- Investigate the effect of oil pressure on ac/dc resistance ratios
- Provide additional measurements on very large conductor, three-phase systems in conventional carbon steel pipes
- Investigate the technical and economic aspects of low-loss systems employing stainless steel pipes; low-loss high-permeability magnetic liners within the conventional carbon steel pipe; single-phase-per-pipe configurations with nonmagnetic pipes; and pipes made from a multilayer laminate of sheet steel and epoxy resin (Dunlopipe)

The principal results of this work are that oil-pressure variations have no effect on ac/dc resistance ratios of copper conductor cables, and that conventional systems with carbon steel pipes are still the most economical. None of the low-loss systems provided sufficient savings in energy costs to compensate for the increased capital costs.

A project with Cable Technology Laboratories seeks to develop analytic techniques based on electromagnetic fundamentals that will permit accurate calculation of ac/dc resistance ratios with a minimum of empirical factors (RP7832-3). Preliminary results with concentric copper-conductor cables in carbon steel pipes show excellent agreement between calculated and measured values. *Project Manager: Felipe Garcia*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

BIOLOGICAL EFFECTS OF DC TRANSMISSION

*In the late nineteenth century, ac transmission overtook dc as the preferred means of transmitting electric energy (*EPRI Journal, *June 1978, p. 6). After this phase of competition between the two technologies, engineers began to recognize that owing to its unique properties, dc could serve a complementary role in the established ac system. The advantages of dc, however, could not be exploited because of the exorbitant costs of ac/dc converter stations. Recent progress in converter technology allows for cost-effective overhead dc transmission at distances exceeding a few hundred miles. Currently three overhead dc lines operate in the United States, with a combined distance of 2755 km and a total capacity of just under 3000 MW. Questions have arisen about whether dc lines present health risks. A subprogram was initiated in 1979 in EPRI's Environmental Assessment Department to investigate the biological effects of exposure to overhead dc transmission lines. A counterpart subprogram for overhead ac transmission has been under way since 1973, and experience with that effort has demonstrated the importance of establishing biological and health effects data for new or expanding technologies.*

A dc transmission line consists of two conductors, one energized to a positive voltage and the other to a negative voltage. For example, the Celilo-Sylmar intertie in the western United States is energized to ±400 kV. The environmental agents generated by transmission lines can be divided into two main categories: (1) the electric and magnetic fields produced by the applied voltages and currents, and (2) the agents produced as a result of corona, such as air ions.

Magnetic and electric fields

The magnetic field created by a dc line results from the current flow through the conductors. At ground level the field strength rarely exceeds 0.5 G (0.05 mT)—the same value as the earth's natural field. Magnetic fields of these magnitudes are not causally associated with any known health effect and are, therefore, not under investigation in the dc subprogram.

The electric field introduced by a dc line has two sources. One is the voltage applied to the line; the field produced by this voltage is termed the nominal field. Beneath the ±400-kV Celilo-Sylmar intertie, the nominal field has a maximum value of about ±8 kV/m. The other source is space charge, an invisible cloud of air ions that is generated by line corona (described below). The presence of a space charge field can increase the total electric field considerably. As indicated by measurements under the Celilo-Sylmar intertie and at General Electric Co.'s Project UHV, the total field (scalar value) may be two to four times the nominal field (Figure 1). Because of the way space charge

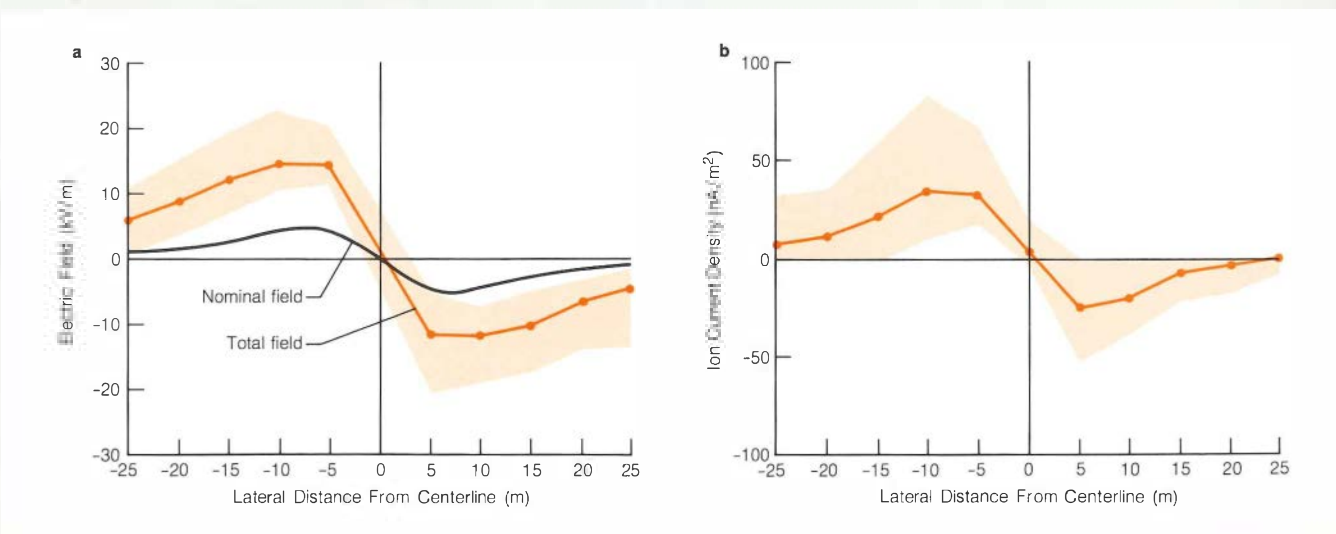


Figure 1 Profiles of electric fields (**a**) and ion currents (**b**) at ground level beneath a test line at General Electric Co.'s Project UHV. The line has a single 5.07-cm conductor, pole spacing of 7.6 m, and a midspan height of 10.7 m. In all tests, the line was energized to ±350 kV. The shaded area in each graph represents the values between the 5th and 95th percentiles, and the colored curve represents the median. (Source: Michael Comber and Gary Johnson, from a paper presented at IEEE PES 1981 T&D Conference.)

is transported by the wind, the field varies with time. Consequently, the electric fields beneath dc lines are expressed either as median values or as a range of possible values within percentile brackets. The electric field created by a dc line is considerably greater than the earth's natural electric field in fair weather (about −150 V/m). The possibility that large static dc fields produce biological effects has not been extensively investigated.

Corona and air ions

Corona is a process involving ionization of the air in the region directly adjacent to a line. It occurs when the electric field at the line's surface exceeds a threshold called the breakdown potential, which is a function of the electrical properties of air. The magnitude of the electric field at the line's surface (and therefore the extent of corona effects) depends on the applied voltage, the line's physical design (e.g., height, conductor diameter, spacing), the amount of extraneous particles and organic matter (e.g., insects) deposited on the conductor, and weather conditions (corona tends to increase in foul weather).

At the inception of corona, the ionization of air molecules in the breakdown region increases dramatically. Ozone, audible noise, and electromagnetic noise in the radio-television band are also produced, but measurements indicate that these are not generated by dc (or ac) lines in large quantities. Such is not the case, however, for the ionized air molecules, commonly known as air ions. They are created in the corona zone when the electric field dislodges an electron from a neutral molecule. A charge pair is created, consisting of a positively charged molecule (e.g., CO_2^+) and, following capture of the ejected electron, a negatively charged molecule (e.g., O_2^-). Soon after pair formation, each charged molecule is surrounded by a small cluster of water molecules. The resulting aggregates are called small air ions. Electrostatic principles dictate that ions of the same polarity as the adjacent conductor flow away from the conductor, while those of opposite polarity are captured. Most of the ions that flow away are eventually transported to the ground; the nature of this trip is determined by the electric field, the local wind conditions, and the physical alteration of the ion en route to the ground. An ion might combine with other molecules or particles to form a large air ion, or it might combine with molecules or particles of the opposite charge and be neutralized.

Why have air ions not been an issue with ac lines? The answer lies in a physical characteristic of air ions called mobility, which is represented by the ratio of ion velocity to electric field strength. The mobility of a small air ion is about $1.6 \times 10^{-4} \frac{m/s}{V/m}$. This means that in the absence of wind, a static field of 10 kV/m will transport a small air ion 1.6 meters in a second. With a 60-Hz ac line, an air ion does not have sufficient time in the course of a half cycle (8.33 ms) to break free and migrate outward from the region in which it was created.

The net effect of ionization on a dc line is a continuous flow of space charge into the ground beneath the line. Measurements conducted by DOE and EPRI show that positive and negative ion currents peak beneath the conductors of respective polarity and fall off with increasing lateral distance from the line (Figure 1). Spatial distribution of the currents is, as in the case of space charge fields, influenced by local winds. Exposure of people and animals to the ion currents per se is not viewed as an environmental health concern because of their extremely low magnitude. A man standing by himself at the point of maximum ion flow under existing lines would collect less than 5 μA of current through his entire body.

Despite the low current flow, the presence of space charge does alter the environment by increasing the electric field, as discussed above. Also, the concentration of air ions is increased. A cubic centimeter of clean outdoor air carries between 500 and 2000 ions of each charge. Directly under an operating dc line, concentrations may range between 10,000 and 100,000 ions per cubic centimeter. These numbers diminish with distance from the line. The ion literature suggests that air ions at the concentrations found beneath dc lines might have physiological and behavioral effects. However, the results are often inconsistent, and a critical review reveals that many studies did not use correct ion exposure practices.

Research objectives

The dc subprogram is designed to investigate possible health effects of exposure to large static dc fields and air ions. First, dose-response and time course–response data on the individual environmental agents are needed; then an evaluation of the combined field-ion environment will be conducted.

Two projects on air ions are under way, one focusing on biological effects and the other on behavioral effects. In the biological effects studies, researchers at the University of California at Berkeley are administering lifelong exposures of air ions to mice (RP1640). At regular intervals, the animals are weighed and their blood is drawn and analyzed. Upon death the internal organs of the mice will be examined for effects. In this way the potential of ions to cause progressive changes can be assessed. A separate experiment is examining whether ion exposure alters resistance to influenza virus infection. The behavioral studies are being conducted at Rockefeller University (RP1817). The test subjects are rats, and the length of exposure is usually less than three days. The experiments are designed to detect whether ion exposure alters the concentrations of specific chemicals in discrete brain regions and whether, in subsequent observations, correlative behavioral effects can be seen. To date the major accomplishment of both projects has been the design, construction, and implementation of ion exposure chambers (Figure 2). Preliminary biological data have been collected, but no trends are yet apparent.

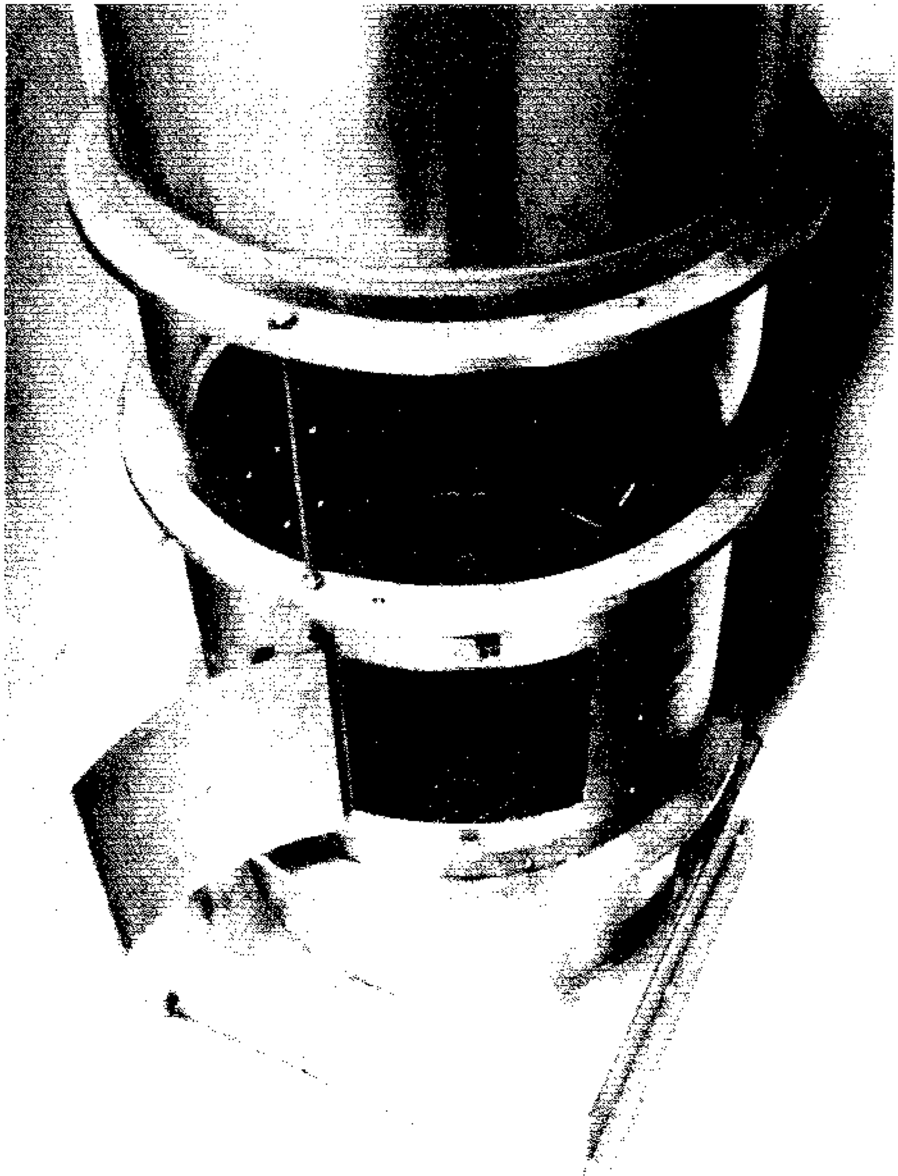
The aim of a third dc project, which is being conducted at Battelle, Pacific Northwest Laboratories, is to construct a system for exposing rats to a combined field-ion environment (RP1774). Because of scaling factors, the animal chamber will require a field of at least 100 kV/m to simulate human exposures of at least 10 kV/m. (The ion chambers mentioned above also require dc fields to generate the ions and propel them toward the animals, but when scaled to man these fields are relatively small.) The application of the exposure system in biological studies is expected to begin in 1983. The knowledge obtained in the two ongoing ion projects will be used in developing a study design for this effort.

As the development of overhead dc transmission progresses, the Environmental Assessment Department will continue to address the environmental health concerns related to this technology. The aim is to gather the data required for a comprehensive health risk assessment of overhead dc transmission that would cover people, animals, and plants. The information generated by the dc studies should prove to be of benefit to the industry and to the public. *Project Manager: Robert Kavet*

ISSUES IN LOAD RESEARCH

Load research is the study of patterns of electrical demand through the metering of sample customers in order to infer the demands of represented customer groups and end uses. It can provide vital information for many functions within a utility company, from cost-of service and rate design to forecasting for systems and corporate planning,

Figure 2 Ion exposure chamber for rats, one of four recently constructed at Rockefeller University as part of RP1817. The floor diameter is 14.75 in.



both long and short term. Load research is a distinct and complex discipline that requires a wide range of expertise and draws on statistical analysis, metering hardware, and computer data management capabilities. EPRI's work in this area involves two kinds of activities: participation with utilities in group load research on national samples to develop end-use data; and the improvement of techniques, methods, and equipment to permit better and more cost-effective load research in individual utility companies. Also, two reports of the Rate Design Study have focused on load research. RDS No. 74 reviews existing load research data, and RDS No. 86 (Topic Paper 3) discusses the state of the art in load research as it relates to cost-of-service, regulatory, and load management considerations.

Load research is needed in many utility functions, such as rate design, forecasting, planning, load management, marketing, and distribution engineering. Its requirements include metering equipment, customer billing files, data processing (translation, hardware, software), analysis, administration, and customer contact.

The general issue of the organization of functions necessary to perform the load research emerged in a project on load data management and analysis (RP1588). This project, which entailed two independent studies, focused on the technical issues surrounding the establishment of a data management system for load research data. However, both studies (published together in EPRI EA-2178) cite the importance of sufficient resources and coordination in establishing a truly effective load research program. This basic issue is seen as underlying the more technical questions of data processing.

Group load research

Several EPRI projects have involved the conduct of actual load research on major generic loads. These projects have been undertaken on a national sample and have gone hand in hand with the development of engineering or simulation models, thus serving two major purposes. First, primary load shape data on specific end uses are needed for forecasting and other applications, such as estimating the impacts of conservation and load management. Second, by contributing to an understanding of the nature of specific loads, this work supports data transfer and also helps make it possible to avoid the need for new data when determinants change. Instead, field-calibrated models can be used to estimate the effect of changing conditions.

The research has focused first on the major residential loads. Projects have already examined heating, ventilating, and air conditioning systems (RP137), heat pumps (RP432), and electric water heaters (RP1101). Because of the dual nature of the projects (model development and load data acquisition) and because of the very high costs involved, the sample sizes and designs were not intended to enable broad or general conclusions to be drawn from the data. In the water heater project, for example, test sites were chosen from among single-family residences with a certain appliance portfolio, in part to reduce the cost of instrumenting the sites (many of the same homes had been used previously in the heat pump project). No attempt was made to develop a demographically representative cross section, recognizing the virtual impossibility of doing so with finite resources, especially on a national basis. Instead, these projects attempted to develop engineering and use pattern detail for a few test sites to help in modeling specific end uses.

This is not to imply that the data per se are not useful. There have been a number of requests from modelers and analysts eager for any real data on residential hot water draw schedules, for example. Previously the only ones that were generally available were DOE's appliance efficiency test protocol, hypothetical schedules, or other unpublished work.

These projects have underscored the extreme costliness of load research and the difficulty of coordinating nationwide load research efforts. As the new generation of microprocessor-based recording systems proves to be reliable and effective, perhaps the situation will change; but with current magnetic tape and translator technology, the expense, time, and data losses mount quickly. Careful conception and design of nationwide projects are necessary to cope with the wide differences among regions in terms of loads, weather, building stocks, demographic factors, and utility practices. Some loads may prove to be generic and thus amenable to study on a national level. Many loads are highly particular, however, and must be studied in their specific context.

Load research methods

Other EPRI research is actively seeking ways to reduce costs and improve the effectiveness of load research. Projects are under way in several areas, ranging from instrumentation and statistical analysis to the organization, conduct, and uses of load research.

Studies conducted under RP1588 offer specific guidance on data management issues as they relate to the overall load research effort. To put such an effort in perspective, consider that a 200-customer program with 15-minute-interval recorders generates over 7 million data points a year. The magnetic tapes used to record meter pulses must be translated on special minicomputers, and extensive error checking and data correction (editing and validation) performed to deal with the many equipment problems that result in faulty data. Even assuming the eventual implementation of solid-state systems, which should eliminate many of those difficulties, there will remain huge quantities of data that must be maintained in orderly fashion if they are to be useful. A data management system must provide for updating, audit trails, sample maintenance, scheduling, data quality information, summary statistics, and customer data. The whole aspect of report generation relies on adequate design for flexible retrieval of data according to customer groups and for statistical analysis according to various formats and summary data needs.

The wider relevance and increasing use of load research in regulatory and planning activities will depend heavily on the development of sophisticated data management systems.

Remote power sensor

The need for more detailed end-use data to improve our understanding of the components of a customer's load is well recognized. However, as was confronted in the EPRI group load research projects, the expense and difficulty of carrying out such measurements have been all but prohibitive. A major part of the cost is in the installation (mostly labor) of metering equipment—dedicated circuits to the appliances of interest and in the mounting of extra pulse-initiating meters.

A device has been developed that can be very easily installed and that eliminates the need for both rewiring and extra meters (RP1589). A small solid-state metering device combined with a transponder is placed at the appliance. Load information is transmitted over the house wiring to a receiver located at any convenient position on the same distribution transformer secondary, where output pulses can be fed to a magnetic tape or solid-state recorder. Up to eight loads can be monitored simultaneously by one receiver. This device will offer more than cost savings: it will make possible data gathering that was not previously feasible.

Statistical methods

Another project is exploring the application of innovative statistical methods to the analysis of load data (RP1816). One important topic involves the use of sample design techniques or cluster analysis (as well as factor or discriminant analysis) to identify subsets of customers whose loads exhibit more homogeneous patterns than are found for an entire customer class. It is hoped that good mathematical characterizations of load data can be obtained by applying various probability distribution functions to these better-behaved data subsets. Early work has indicated some success with beta distributions. European investigators have also found gamma functions to be useful.

This work is distinctly exploratory in nature and is based on the premise that loads, or as much as can be known about them through data gathering, are a random process in the statistical sense. The issue then becomes to develop the understanding and techniques to distill the real information content of data as it relates to subsequent analyses and decisions.

On a more immediate front, sophisticated statistical analyses continue to be performed by practitioners of load research facing current regulatory requirements in ratemaking, forecasting, and load management. Of particular concern is the issue of sample design and the later expansion of sample data to estimates for an entire population of customers. A project is being initiated to evaluate alternative approaches to these questions.

Transferability of load data

The increasing demand for load data and the high cost of conducting load research suggest that there are potentially substantial benefits in being able to borrow load research data. Efforts are under way to examine the feasibility, limitations, and techniques of load data transfer (RP1820).

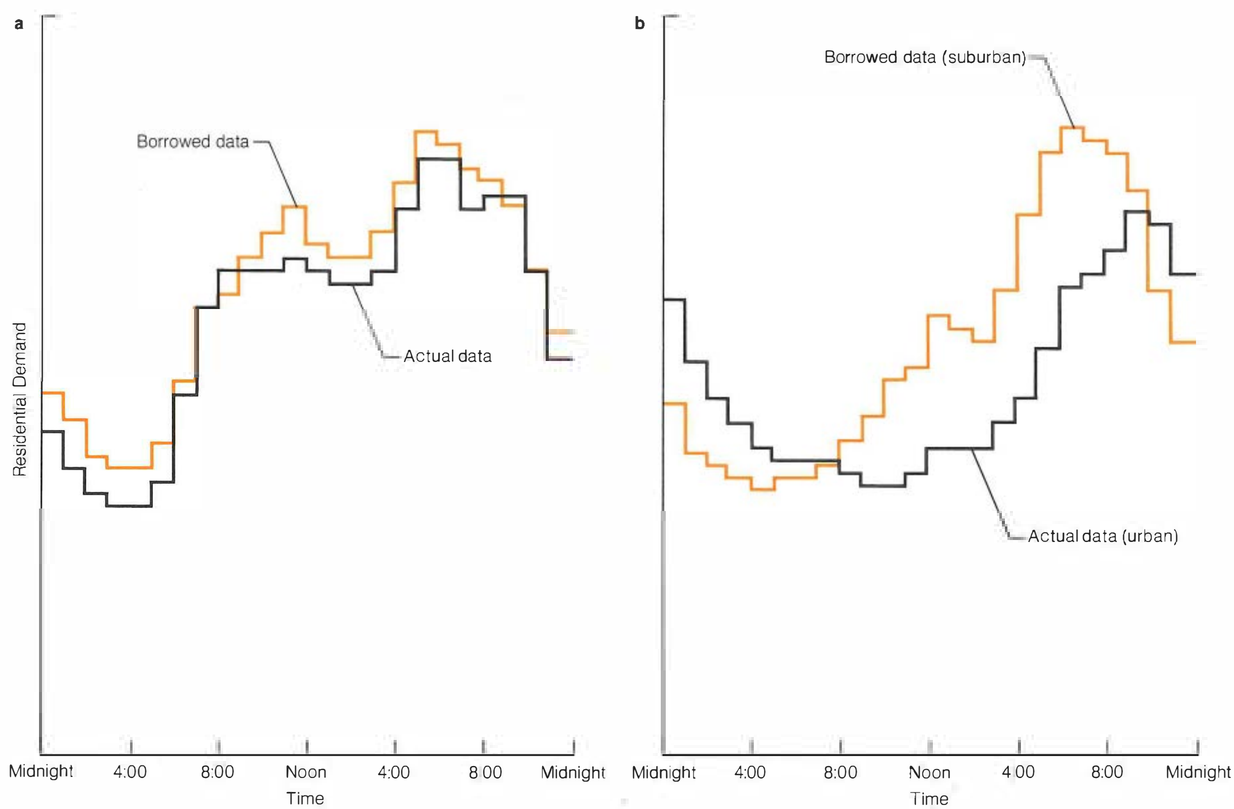
Clearly, there will not be a definite yes or no answer to the question of whether data can be transferred. In all cases it will be a matter of degree as to how data that have been borrowed and adjusted can be substituted for a utility's own load research. Experiments are being conducted involving pairs of utilities with comparable load data so that transferred data can be evaluated against actual data.

The key to successful transfer is to identify the factors that determine loads and that cause them to be different, such as weather, geography, demographics, appliance holdings, lifestyle, and even seemingly obvious things like one's location (east-west) in a time zone (which can shift the load shape up to one full hour).

The end-use modeling approach being used in RP1820 allows explicit correction for differences in appliance saturation and end-use load shapes between two service territories. Figure 3 shows two such experiments with residential customer class load shapes. In one case, the correspondence between the actual load curve and the curve based on borrowed data is good; the important differences have been accounted for. In the other case, the attempt is less successful. The factors causing a suburban service territory and a large urban service territory to be different—possibly lifestyle and housing mix, for example—were not adequately taken into account in the adjustment process. A more detailed adjustment is clearly called for.

It can be expected that data transfer will be more feasible between near-neighbor utilities. However, further experimentation should produce more definitive indications about which kinds of load data can be reliably borrowed and how they might be adjusted to provide a supplement to or a replacement for a utility's own load research data. *Project Manager: Edward Beardsworth*

Figure 3 In each of these two load data transfer experiments, the actual residential class load curve for a typical summer day from one utility is compared with a load curve that has been developed by borrowing and adjusting data from another utility. In one case (**a**), involving utilities with similar service areas, the curve based on the borrowed data compares well with the curve based on the actual data. In the other case (**b**), involving one utility with a large urban service area and one with a suburban area, the correspondence is not as good, indicating the need for further adjustment of the borrowed data.



R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

BETA BATTERY DEVELOPMENT

Among the means being studied by EPRI for load-leveling energy storage are various new battery systems. One of these systems is the beta battery, so named because of its use of a particular crystalline compound of sodium and aluminum oxides as an electrolyte. The battery is unique in that the electrolyte, beta alumina, is a solid; as a solid there can be no loss of electrolyte, as occurs with aqueous systems. The chemical reactants are sodium metal and sulfur—both low-cost chemicals that produce a high-energy system. Because of the high energy and potential low cost, this battery is also attractive for use in electric vehicles.

Energy storage is one of the more powerful means available to utilities to effectively meet the varying daily and weekly electric power demands of their customers. The power demands that exist during peak load periods (those hours during a day that can exceed the base and intermediate capacity of the utility system) can be provided by stored electrochemical energy. The energy to be stored can be supplied by baseload plants at times when the electrical load is below full capacity. The effect of such an approach to energy management is to allow the substitution of coal and nuclear fuels used in the baseload plants for premium liquid or gaseous fuels required in peaking plants.

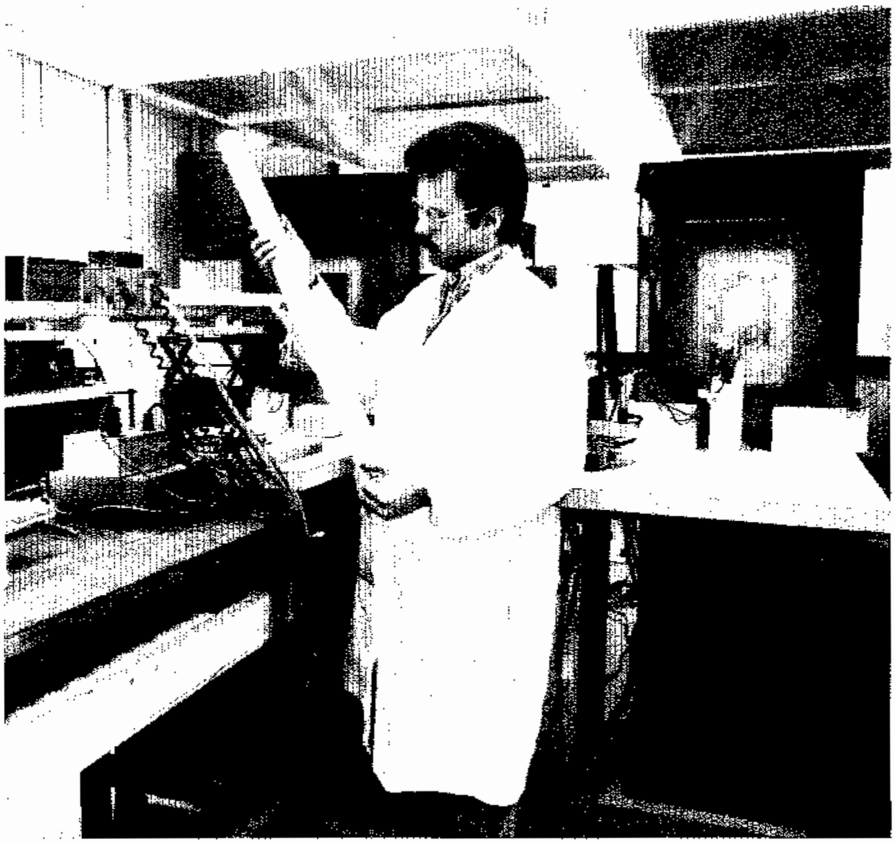
The energy generated during off-peak periods can be stored in a variety of ways, such as mechanically with compressed gases, with water in elevated reservoirs, or electrochemically in batteries. The use of batteries is particularly appealing because batteries can be turned on and off almost instantly and can be available in small unit sizes capable of being sited at distribution substations. Many battery systems are now under investigation for utility service—for example, in addition to the beta battery, the zinc chloride, zinc bromide, and optimized lead acid batteries.

The beta battery system, based on sodium and sulfur as reactants, has several characteristics that are attractive for utility load leveling. The system is thermodynamically stable with regard to its electrolyte (the solid beta alumina). Losses encountered with aqueous systems because of decomposition of the electrolyte (e.g., release of hydrogen or oxygen gases) do not occur. Also, the cell voltage of the beta battery is at the high end (2 V) of the range for secondary (rechargeable) batteries under development. Further, the battery has a proven capability of giving back all the electric charge put into it (its coulombic efficiency is 100%). Thus the energy efficiency is quite high—a full-cycle energy efficiency can be above 80%. Coupled with these enticing electrochemical characteristics is the inherent low cost of the components. These attractive characteristics have warranted development of the beta battery, not only for load-leveling applications but also for electric vehicles.

The typical construction of the beta battery is a long, up to 30 in (75 cm), tube about 2–4 in (5–10 cm) in diameter. The tube is made of steel coated with any of a number of protective materials and contains the necessary electrode materials and electrolyte tube (Figure 1). Sodium, which is the reactant at the negative electrode, is in the center of the electrolyte tube, and the sulfur, the positive reactant, is on the outside of the electrolyte tube, just inside the outer steel tube. Some designs reverse the order, but the energetic reactions remain the same. Both the sodium and the sulfur are liquids at the operating temperature of 300–350°C. The cell, as described, is in the fully charged state; as discharge proceeds, the sodium is consumed and the product, sodium polysulfide, is formed in the sulfur compartment. The sodium is transported as an ion through the solid electrolyte, which is a unique characteristic, along with the high energy, of this battery system. The 0.3–1.0-kWh beta cells are configured in various parallel and series arrays to factory-made 50–100-kWh modules. These modules are the building blocks of a 100-MWh battery energy storage system.

Interest in the sodium-sulfur beta battery has grown since it was introduced by Ford Motor Co. in 1966. The inherent attractiveness of the system has stimulated worldwide interest and has resulted in nine major projects. There are three projects in the United States, two in England, and one each in Germany, Japan, France, and the People's Republic of China. In 1976 DOE and EPRI initiated sodium-sulfur battery workshops to provide an opportunity for these developers to exchange recent nonproprietary information. Since then, four workshops have been conducted. Participation in these workshops increased from three U.S. developers in 1977 to all nine developers in 1980. The primary objectives of the workshops were to avoid unnecessary duplication of work among the developers, identify new solutions to existing problems, assist in the planning and management of the individual projects, and identify additional opportunities for developers to enter into further cooperative arrangements. Thanks to the cooperation of every partici-

Figure 1 The ceramic heart of a beta battery is a tube that separates (in the usual role of an electrolyte) the two reactants of the cell. The manufacture of the tubes involves the high temperatures suggested by the furnace at the right.



pating organization, all these objectives have been attained.

Through a cooperative arrangement with DOE, EPRI has supported development at General Electric Co., now teamed with Chloride Silent Power, Ltd. (CSPL), and DOE has supported development at Ford and Dow Chemical Co. Although EPRI has been financially supporting one major beta battery development project, it has also been providing technical assistance to all the developers to ensure that the industry will acquire a product that is compatible with utility needs. Further, EPRI can provide information on utility interest in, and the market for, battery energy storage, which helps the developers to properly focus their projects. In line with this broader mission, EPRI has established several R&D contracts that directly support all beta battery development and still others that are supportive of all battery systems—for example, the Battery Energy Storage Test (BEST) Facility.

Progress to date

Most beta battery developers are at the cell development stage where hundreds of full-scale cells, made of commercially acceptable components, are routinely fabricated and tested. Performance (efficiency and capacity) characteristics are fully acceptable for utility application. Typical cell life is about 500 cycles (about 10–20% of the goal for utility application). Failure of a cell is usually the result of failure of the electrolyte, the exterior seal, or the container, in that order. However, these sources of failure vary with developer. Interesting to note, solutions to failure mechanisms adapted by one developer do not necessarily work for the others. For example, one developer, British Rail, has found that a combination of lead acetate coatings on the electrolyte and oxygen getters in the sodium dramatically prolong electrolyte life. Other developers that use different electrolyte compositions have not observed this effect.

A key to success in increasing cell life is understanding the degradation mechanisms of the beta alumina electrolyte. Degradation typically results in decreased efficiency of the cell and, eventually, cell failure from fracture of the electrolyte tube. Several mechanisms have been proposed, based, for example, on mechanical stresses, electric fields, and chemical degradation. Most developers experience unacceptable electrolyte degradation, and those that have been most successful appear to have done so as a result of good fortune and not necessarily technical insight. In fact, British Rail had virtually no electrolyte problem for the first 10 years of its development program. Then, in 1978, almost every cell experienced rapid electrolyte degradation. Valid explanations are just now being formulated. As the electrolyte is the most vulnerable component, EPRI has initiated supporting R&D contracts to understand electrolyte degradation mechanisms and changes in cell materials that influence electrolyte degradation. Contracts have been or are being negotiated with Lawrence Berkeley Laboratory, Compagnie Générale d'Electricité, and Argonne National Laboratory.

The development of cell designs and materials to achieve safe operation has been a major accomplishment. Despite the fact that a sodium-sulfur reaction is highly energetic and can be violent, today's beta cells do not breach when the electrolyte is broken. The key to this accomplishment has been the use of various methods to restrict the flow of sodium to the reaction site. Batteries have been designed so a breached cell does not cause failure propagation to other cells (a domino effect).

General Electric has had an active beta battery project since 1968. EPRI became involved in supporting this effort in 1973 when the project was transferred to EPRI from the Edison Electric Institute (RP128). From 1974 through 1980, RP128 was conducted as an EPRI–General Electric project. In 1981 General Electric and CSPL joined forces in development of the beta battery. The combined program is now jointly sponsored by General Electric, CSPL, Department of Industry of England, New York State Energy Research and Development Authority (NYSERDA) and EPRI. This joint program is directed toward the development of the beta battery for use in both load leveling and the electric vehicle. The primary goal of the combined program is to demonstrate by the end of 1982 the manufacturing approach and design concept in about 200 commercial-type cells having the performance and safety

Figure 2 The Chloride Silent Power, Ltd., beta battery manufacturing plant in England, which is entirely devoted to the development and manufacture of beta batteries.

characteristics desired for utility application. In addition, considerable R&D is under way to understand the causes of electrolyte failure and to develop electrolyte compositions that have acceptable durability. Numerous commercial-type cells will be tested in 1982 to evaluate life with the objective of achieving at least 1500 cycles. Success in these areas, along with continued evidence of economic acceptability, will justify design and construction of batteries suitable for load leveling, now scheduled for completion during the 1984–1985 period. Construction will be at the CSPL plant in England (Figure 2). Actual test of a 2.5-MWh load-leveling battery is scheduled for 1986.

Two developers, Brown Boveri Corp. and CSPL, have established pilot manufacturing facilities. These pilot lines are based on extensive manufacturing development and use highly automated equipment. Most of the other developers have devised simple cell fabrication procedures that typically require only unskilled labor.

Over the past two years many of the developers have been integrating cells into small battery systems. Most notable of these efforts has been the fabrication and successful testing of a 512-cell, 100-kWh battery by Ford. Testing started in February 1981, and about 300 cycles have been accumulated.

Expectations

Although progress in beta battery development has been slower than originally expected, continued perseverance has brought the system to a stage where commercial cells (size, design, and materials) are being routinely built and successfully tested. The vulnerable electrolyte is slowly yielding to scientific investigation. As a result, cell lifetimes are expected to increase from 500 cycles to at least 1500 cycles by December 1982. Sufficient work has been done to suggest that major materials issues are coming under control, desired performance can be achieved, and engineering scale-up of cells into batteries should be straightforward. Commercial battery systems should be on-line in the early 1990s. *Project Manager: Robert D. Weaver*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Director

SELF-POWERED NEUTRON DETECTOR SENSITIVITY MEASUREMENTS

Self-powered neutron detectors with rhodium emitters are used in many reactors to monitor power distribution within the core. The supply of rhodium nuclei in these detectors is depleted with use, resulting in a loss of sensitivity. Because of uncertainties in quantifying the loss of sensitivity during a detector's lifetime, utilities are now required to replace a detector before its sensitivity is reduced by 50%. However, this practice is costly: used detectors are highly radioactive, new detectors are expensive, and replacing detectors often extends the length of a refueling outage. To reduce these uncertainties and to allow detectors to be used longer, EPRI is sponsoring an experimental investigation of the sensitivity losses associated with detector rhodium depletion. (RP1397).

A self-powered neutron detector works by emitting a β particle (electron) each time a rhodium nucleus captures a neutron. The β particles are collected to produce an output current that is proportional to both the local neutron flux density and the number of rhodium nuclei in the detector's emitter (Figure 1).

Once a rhodium nucleus emits a β particle, however, it becomes a palladium nucleus, which does not interact with neutrons. The number of rhodium nuclei is thus depleted, and the sensitivity of the detector to neutrons is reduced. Uncertainties about this depletion contribute to the overall uncertainty in computing core power distribution from the detector signals. As noted above, utilities presently limit depletion-related uncertainties by the costly replacement of detectors before their sensitivity is reduced by 50%. The purpose of RP1397 is to accurately characterize detector rhodium depletion in a power reactor over as much of the operating life of the detector as feasible. The data collected will be used to reduce uncertainties about detector sensitivity so that the instruments will not have to be replaced as frequently as they now are.

Sources and effects of uncertainties

The ability of a detector to produce an electron depends not only on the number of rhodium nuclei in the emitter but also on the following factors.

- The ability of a neutron to reach a rhodium nucleus. This depends in part on the distribution of rhodium and palladium in the emitter, a distribution that changes with detector use.
- The ability of the rhodium nucleus to capture a neutron. This varies with the energy of the neutron; in turn, the relative number of neutrons at a given energy level (i.e., the neutron energy distribution) varies with reactor design.
- The ability of the β particle to make its way out of the nucleus, through the emitter, and across the detector's insulation to the outer sheath, where it is collected as an electron.

Uncertainties about these factors have made it difficult to predict how detector sensitivity will change in a given reactor as the

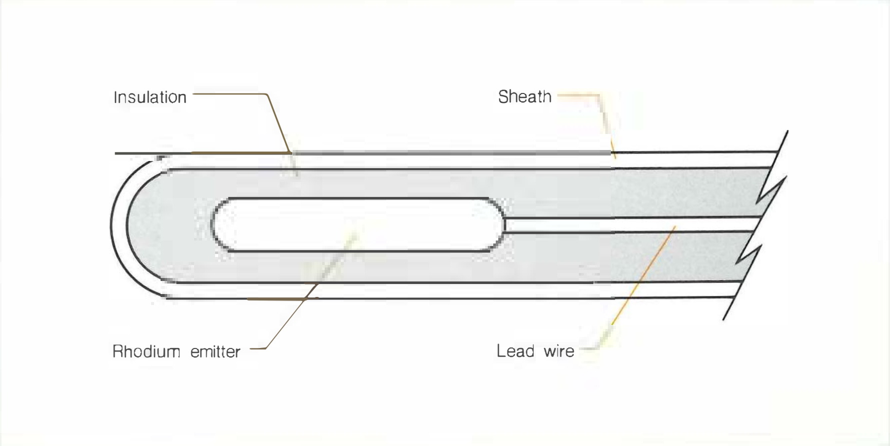
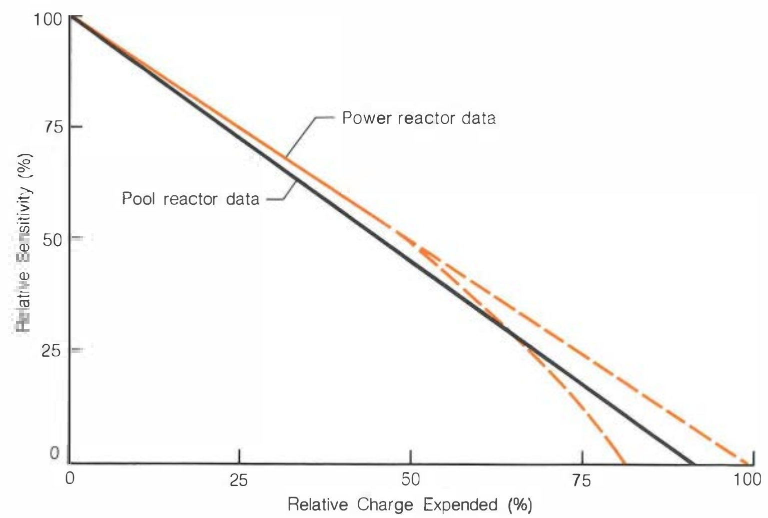


Figure 1 A self-powered neutron detector (shown in cross section) comprises a rhodium wire emitter, a lead wire, electrical insulation (usually aluminum oxide), and a conducting outer sheath. A rhodium nucleus emits a β particle after it captures a neutron. The β particle leaves the emitter and passes through the insulation to the sheath, where it is collected as an electron by an attached instrument (not shown). An electron also travels from the instrument to the emitter via the lead wire to complete the electrical circuit.

Figure 2 Decrease in detector sensitivity with expended charge (expressed as a percentage of total available charge). Data from a power reactor (RP1397) show the curve to be linear to about the 50% depletion point. No data exist from a power reactor beyond that point; it has been theorized that depending on conditions, the curve will either remain linear or turn downward. On the basis of data from an experimental pool reactor, the sensitivity curve is predicted to be linear and to have a different slope.



rhodium is depleted (Figure 2). One theoretical study indicates that depending on the assumptions about these factors, the curve that describes the sensitivity reduction can be entirely linear or can turn downward after initially being linear (*1*). These assumptions also affect predictions of the total number of electrons that a detector will emit during its lifetime.

In order to characterize detector behavior, scientists have supplemented their predictions with experimental data. Detectors have been depleted in two types of experimental reactors: a low-power reactor and a zero-power pool reactor. For the former, the detector sensitivity curve was linear at first and then turned downward, similar to one of the curves predicted by the study cited above; for the latter, the curve was entirely linear. It is believed that a difference in the reactors' neutron energy distributions was the primary cause of the observed difference in detector behavior.

Power reactor results

Detector depletion has also been measured in a power reactor since 1976. In this experiment the signals from two fixed-position rhodium detectors have been compared monthly with the signals from a movable rhodium detector. The emitter of the movable detector is positioned next to the emitters of the fixed detectors during each test. Then, at the end of a test, the movable detector is partially withdrawn from the reactor so that its rhodium emitter will not absorb neutrons. Thus the sensitivity of the movable detector remains virtually undiminished. The currents from the fixed detectors are continuously integrated to record the charge (number of electrons) expended by the detectors.

This experiment has now run for four fuel cycles. It was sponsored by Babcock & Wilcox Co. for the first two cycles and by EPRI (RP1397) for the last two. The sensitivity of the two fixed detectors has been reduced to about 53% of the original value.

Data show the sensitivity curve to be linear to this point (Figure 2). Uncertainty about its slope has been reduced to less than 0.3%. In addition, when the revised detector sensitivity depletion correction factors derived from these data are used in the on-line measurement of core power distributions, the results agree more closely with the distributions predicted by more sophisticated off-line computer codes. However, the slope of the sensitivity curve is about 8% less than that predicted on the basis of the pool reactor data; that is, the total number of electrons expected to be emitted by the detectors is about 8% greater than predicted. The reasons for this difference are not yet known.

The experiment will continue for another fuel cycle so that the detectors' behavior can be characterized past 50% depletion in a power reactor and so that uncertainties in extrapolating the sensitivity curve can be reduced. The results to date are reported in NP-1405 and NP-1715. *Project Manager: Gordon Shugars*

Reference

1. T. Laaksonen and J. Saastamoinen. "Calculation Studies of Sensitivity Characteristics and Their Burnup Behavior for Rhodium Self-Powered Neutron Detectors." *Proceedings of the IAEA Specialists' Meeting on In-Core Instrumentation and Failed Fuel Detection and Location.* AECL-5124, p. 111. May 1974.

WELD CROWN CONTOURING MACHINE

In typical nuclear power plants there are between 500 and 1500 stainless steel welds that must be tested ultrasonically before the plant goes on-line, during its normal operation, and after any equipment has been modified. Often, as-deposited weld crowns must be ground to acceptable finished surfaces before reliable ultrasonic testing can take place. Currently, weld crowns are ground by hand, and the quality of surface finish can vary greatly from weld to weld, depending on the operator's skill. Under such conditions it is difficult for inspectors to establish unquestionable weld integrity. The weld crowns themselves sometimes create barriers to the proper placement of test equipment; in other cases, misleading signals are produced by inconsistently finished surfaces. Also, the hand-grinding process is time-consuming and costly and may require additional radiation exposure control efforts. In response to this situation, EPRI initiated work to develop a device capable of contouring weld crowns semiautomatically. This effort, now being funded by the Boiling Water Reactor Owners Group, has proceeded to the testing stage. A prototype device was delivered in early 1982 to EPRI's Nondestructive Evaluation (NDE) Center in Charlotte, North Carolina, for tests to determine its readiness for field application (RPT120-1).

Feasibility study and initial development

Phase 1 of this effort entailed a study to determine the feasibility of designing, developing, and using a semiautomatic weld crown contouring device (TPS78-793). The contractor, Sigma Research, Inc., investigated grinding and cutting methods that could be used to contour stainless steel weld beads. As the work progressed, one conceptual design appeared to be superior: a compact external lathe with a microprocessor-controlled cutting head and inner and outer hinged shells. The inner (stationary) shell would lock onto the pipe, providing a fixed base about which the outer shell (carrying the cutting tool) would rotate.

Utility representatives around the country were surveyed to obtain information on the physical parameters within which the device would be required to perform in construction and maintenance operations. The basic requirements set for the contractor were that the device be able to operate in tightly restricted locations with clearances of 6–8 in (15–20 cm); be able to operate on pipe ranging from 4 to 36 in (10–91 cm) in diameter; be able to handle such special conditions as misalignment and out-of-roundness; and be portable, rugged, reliable, and easy to operate.

Reassured by the positive feasibility results, the contractor went beyond the contract requirements of the paper study and constructed a simplified test machine to confirm the proposed technical approach. In addition to furnishing concrete data on single-point weld crown contouring, the simplified unit served as the mechanical basis for later development of the microprocessor-controlled radial drive. The Phase 1 results are reported in NP-1107.

With confirmation of the basic concept, the development program moved into Phase 2, during which microprocessor hardware was built, software was written, and tests were conducted on the proof-of-concept machine (equipped with a new cutting head and the necessary electronics).

The on-board electronics, which were powered by 24-V direct current (dc) through slip rings, consisted of a serial interface to provide communication with the control microcomputer, a stepper motor drive circuit, and an analog-to-digital converter that monitored tool bit position. Dc-to-dc converters supplied the required voltages, and appropriate control circuitry was used for multiplexing and demultiplexing communications to and from the microcomputer.

Also during Phase 2, various tools and feeds were used on a large engine lathe in cutting-force tests. The results indicated that depending on tool shape, radial cutting forces would be less than 100 lbf (445 N). A large commercial stepper motor was selected as the design base, and a high-efficiency drive train was designed. For maximum drive efficiency, the toolholder was supported on linear ball bearings and driven by a ball lead screw. The radial drive force for a 100% efficient system was calculated to be 1000–1500 lbf (4450–6670 N); however, frictional losses in the drive (and possibly the presence of motor resonances at low speeds) reduced the actual drive force.

Initial cuts were made on stainless steel weld beads on a carbon steel pipe. Tests with hand files indicated that these beads were appreciably harder than normal welds on such materials, perhaps because of an alloying process. Tool configurations used in the cutting-force tests would not cut this material and tended to ride up onto the surface of the weld bead. New configurations produced inward radial forces that exceeded the capacity of the drive mechanism. Although these difficulties were attributed to the unusually hard weld material, a more powerful radial drive was considered necessary for field application. In addition, the need for rigidity in the entire cutting head was demonstrated by the high circumferential and axial forces experienced when the tool bit cut too deeply into the weld.

More testing was conducted on carbon steel welds. The computer was able to control the tool bit and produce the specified surface contour, although the surface finish was somewhat rougher than desired, a result attributed to insufficient mechanical rigidity and to the single-pass removal approach. A two-pass approach was considered more desirable—a coarse-cut first pass to remove most of the material and a second pass to produce the desired high-quality surface finish.

Although the reliability of digital data communication across slip rings was a matter of concern before testing, no communication errors were detected in over 100 test hours. This work demonstrated that microprocessor control of an external lathe was a practical means of contouring weld crowns on large-diameter piping.

Prototype device

During Phase 3 of the development effort, recently completed, a prototype contouring machine was constructed for laboratory testing under simulated field conditions (Figure 3). The frame of the prototype machine is

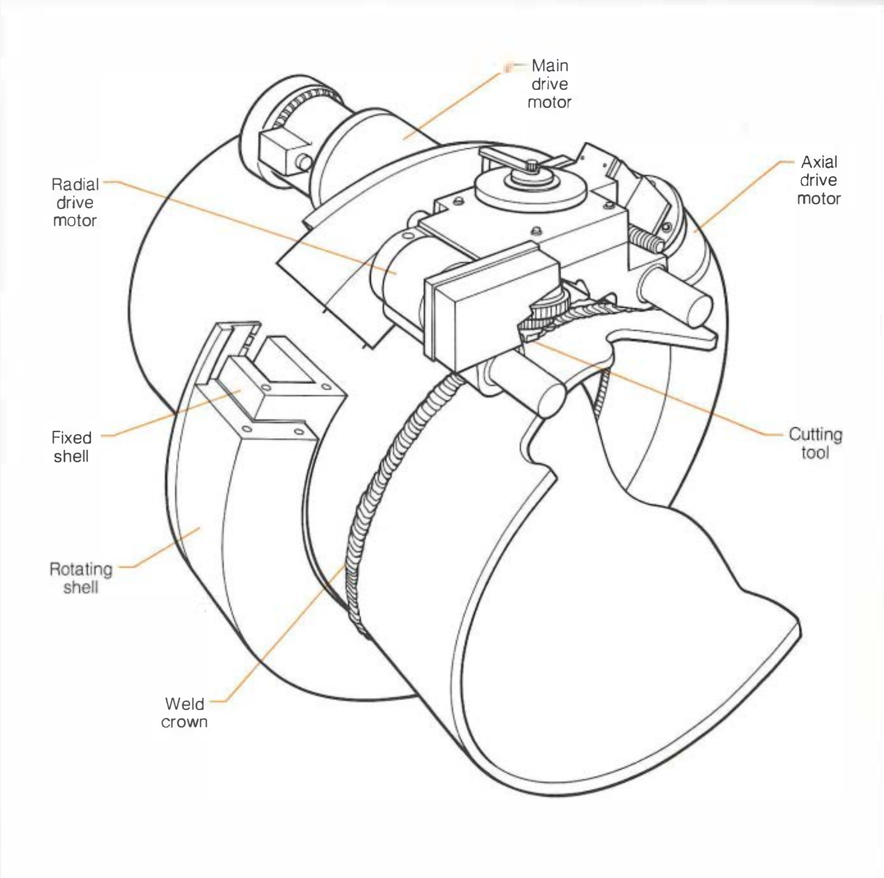


Figure 3 Single-point weld crown contouring machine.

clamped to the pipe by several wedges that form a large collet, ensuring rapid installation and secure centering. The frame consists of one stationary and one rotating shell, each fabricated in two pieces that are drawn together by eccentric cams and fastened by studs. Four slip rings are mounted on the stationary shell, and the corresponding brushes are mounted on the rotating shell. The final design calls for the frame to be made from webbed steel plates, a very sturdy and yet inexpensive fabrication method. Similar frames are now used on machines to prepare pipe for welding.

The cutting head design of the Phase 3 prototype is shown in Figure 4. Electrocraft E660-A permanent-magnet motors provide axial and radial drive. The cutting head is supported by two 1.25-in (3.18-cm) linear ball bearings on hardened steel guide pins. The collet assembly holds the toolholder, which contains either the tool bit or a profile-following stylus. The toolholder is coupled to a linear potentiometer with a 1-in (2.54-cm) range. This provides for easy interchange between the profiling stylus and the cutting tool and enables each frame to accommodate a range of pipe sizes.

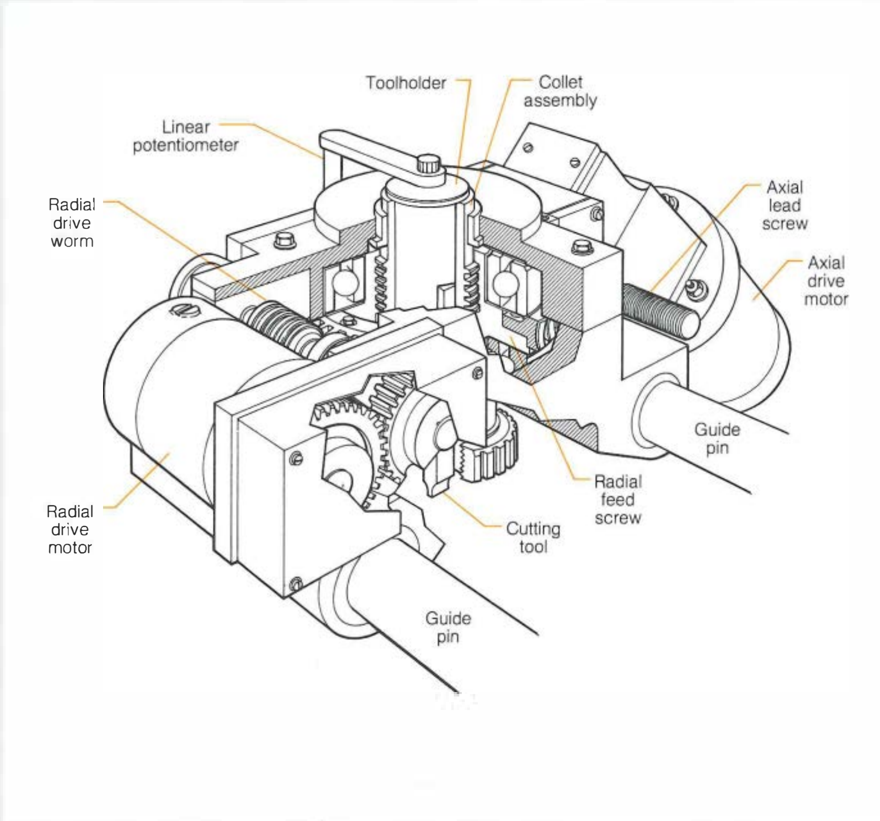
Requirements for increased radial drive forces led to the selection of dc servomotors for the radial and axial drives. This arrangement increased the amount of communication necessary between the computer and its peripherals and led to a decision to mount the microprocessor on the rotating frame, minimizing the amount of communication across the slip rings.

Each drive is connected to an optical encoder, and each encoder generates two pulse trains 90° out of phase. From these data the computer determines the speed and direction of each motor. The encoder pulse frequencies, which are proportional to motor speed, are compared with a computer-set reference frequency, and the difference is used to control motor speed.

The computer monitors tool position and updates direction and speed commands as required to follow the desired crown profile. In addition to the optical encoder on the radial drive, the linear potentiometer monitors tool bit position and eliminates backlash in the drive train. Limit switches protect the cutting head should the computer control system fail.

Circumferential position is monitored by a segmented slip ring whose segments are approximately 1° long (except for the "home" segment, which is 6° long) and are spaced every 2°. This slip ring alternately grounds and opens a control line, monitoring angular

Figure 4 Cutting head of weld crown contouring machine.



position. The system is a well-shielded low-impedance circuit and should not be subject to electrical noise.

Pipe profiles and tool position are monitored by the linear potentiometer and are read by a 10-bit analog-to-digital converter that gives an accuracy of 0.001 in (0.025 mm). The on-board system also includes a microprocessor computer (Z80), read-only memory for program storage, random-access memory for profile storage, counters and timers for speed and position monitoring, ports for serial and parallel data transfer, and a current loop line transceiver for communication with the stationary system.

To facilitate efficient development and laboratory evaluation, the operator interface for the prototype is based on an Apple II microcomputer and has keyboard and control stick inputs. As prompts are displayed on the video monitor, the operator enters the appropriate response. The control stick can slew the cutting head in both radial and axial directions. Calculation of the required tool position depends on the crown profile desired (e.g., flush, stepped, rounded). For routine field use, this system will be replaced with a hand-held control terminal.

After the device is installed on the pipe, the operator inserts a profiling stylus in the toolholder and slews the cutting head to one side of the weld bead to take the first profile. A second profile is taken on the other side of the weld, and a final profile is taken at the center. (The order in which these are taken is not critical because the computer knows the axial position in each case.) On operator command, the cutting head is slewed to the location of the innermost profile. The computer displays the greatest depth of metal to be encountered during cutting and asks the operator to specify the number of passes that should be made to contour the weld. After entering this number and removing the stylus, the operator instructs the computer to position the toolholder so that it has a sufficient range of movement to contour the weld. A tool is inserted in the holder and locked in place with the tip touching the pipe surface; the tool bit is then retracted from the surface to well above the highest point on the pipe.

The system is now ready to begin the cut.

The operator specifies the desired profile and commands the device to start. After the system begins rotating, the computer lowers the tool to the cutting depth for the first pass and proceeds with the cut. When the first pass is completed, the tool is retracted. The cutting head is again slewed to the inside of the weld, and if necessary, another pass is made. This sequence is repeated until the specified number of passes has been made and the contour finished as desired.

A technical review of the prototype was conducted in February 1982, and the device is now undergoing extensive testing at the EPRI NDE Center. Technical and nontechnical factors in the application of the device are being monitored and evaluated; the results will be used to guide any required modifications. The device is expected to be ready for selected on-site testing by mid-1982.

Nontechnical issues

A review of nontechnical factors affecting the introduction of the device into the field was initiated during Phase 3 to consider the climate for technology transfer, especially with regard to the craft unions. Molly Ackley-Cook is the consultant handling this work. Results of the first phase of the review—which involved personal, mail, and telephone interviews with utility personnel, union officials, construction supervisors and engineers, and pipe fabrication shop personnel—indicated several probable concerns of craftsmen that would affect acceptance of the device. These include machine reliability, job security, union involvement, operator versus machine control, the need for training, jurisdictional disputes, and the role of the supervisor.

Information from these interviews confirmed the findings of a literature review and emphasized the very close relationship between the weld contouring process, in-service inspections, and plant safety. During the present phase of the review, in-service inspection personnel and architect-engineers are being interviewed to obtain another perspective. At the same time, the consultant is continuing to document the technology transfer process and to establish and maintain communication with all interested parties. The goals are to enhance the exchange of information about the development of the device and, through improved communication, to minimize nontechnical problems as the device is introduced into the field. The consultant will participate with the technical staff in the training, testing, and evaluation activities at the NDE Center and later at selected plant locations. *Project Manager: Gary Dau*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP475-11	Storage of 1-MW (th) Ceramic Tube Solar Receiver and Supporting Equipment	2 years	36.0	Cummings Solar Corp. *J. Bigger*
RP1038-7	Model Conversion: Gasification–Combined-Cycle Plant	6 months	13.9	Philadelphia Electric Co. *G. Quentin*
RP1038-8	Sulfur Removal Model Support	11 months	15.0	Systems, Science & Software *G. Quentin*
RP1348-11	Strategy Alternatives for Wind Power Development	6 months	115.3	Strategies Unlimited *E. DeMeo*
RP1799-11	Environmental Test Reports for the Ruhrkohle-Ruhrchemie Coal Gasification Plants	10 months	37.2	Radian Corp. *T. O'Shea*
RP1923-3	Minimizing the Cost of Availability Improvement for Advanced Power Systems	8 months	72.8	Boeing Computer Services, Inc. *J. Weiss*
RP1977-1	Wind Turbine Dynamic Impacts	22 months	29.9	Systems Control, Inc. *F. Goodman*
RP1990-1	Cost Estimates: Water/Steam Rankine-Cycle Solar Central Receiver Power Plant	10 months	146.7	Bechtel Group, Inc. *S. Kohan*
RP2029-1	Coproduction of Electric Power and Methanol	10 months	123.3	Burns & Roe Humphreys & Glasglow Synthetic Fuels, Inc. *B. Louks*
RP2029-2	Engineering and Economic Evaluation of Coal Gasification Alternatives	10 months	69.2	General Electric Co. *B. Louks*
RP2029-3	Gasification–Combined Cycles With Dry Cooling	10 months	74.9	Westinghouse Electric Corp. *B. Louks*
RP2111-1	Transportation and Handling of Medium-Btu Gas	9 months	55.6	Air Products and Chemicals, Inc. *G. Quentin*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Coal Combustion Systems				
RP422-9	San Juan Wet/Dry Testing—Site Use Agreement	3 months	22.0	Public Service Co. of New Mexico *J. Bartz*
RP422-10	San Juan Wet/Dry Testing—Management and Test Plan	3 months	60.0	United Engineers & Constructors, Inc. *J. Bartz*
RP1261-6	Single-Vessel Combined Makeup-Sidestream Softening Test	4 months	106.1	Stearns-Roger Engineering Corp. *W. Chow*
RP1266-26	Self-Heating Susceptibility During Storage and Handling of Coal Used for Electric Power Generation	1 year	81.2	University of Illinois *I. Diaz-Tous*
RP1336-4	Hot-Gas Filtration for Pressurized Fluidized-Bed Combustion	14 months	296.9	Acurex Corp. *S. Drenker*
RP1341-2	Physical, Chemical, Biological Analysis and Evaluation of Coal Waste Blocks in Fresh Water	10 months	50.7	State University of New York *D. Golden*
RP1400-08	Procurement of CONSCAN Instrumentation for EPRI Coal Cleaning Test Facility	8 months	290.8	Science Applications, Inc. *R. Sehgal*
RP1455-8	Coal-Water Slurry Evaluation Tests	15 months	400.1	Babcock & Wilcox Co. *R. Manfred*
RP1610-2	Economic Evaluation of FGD Systems	15 months	50.0	Stearns-Roger Engineering Corp. *T. Morasky*
RP1864-1	Vibration Signature Analysis for Predictive Maintenance at Philadelphia Electric Co.	35 months	795.2	Shaker Research Corp. *A. Armor*
RP1877-1	FGD Reagent Preparation	20 months	312.4	Radian Corp. *D. Stewart*
RP1884-8	Development of Advanced Rotor-Bearing Systems for Feedwater Pumps, Phase 4	1 year	94.2	Energy Research & Consultants Corp. *I. Diaz-Tous*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1884-9	Development of Advanced Rotor-Bearing Systems for Feedwater Pumps—Set Up and Test Fluid Annulus Test Rig	10 months	95.0	Franklin Research Center *I. Diaz-Tous*
RP1894-1	Eddy-Current On-Line Monitoring for Crack Detection	25 months	396.0	General Electric Co. *A. Armor*
RP1895-4	Coal-Water Slurry Burner Technology Development	8 months	262.0	Combustion Engineering, Inc. *R. Manfred*
RP1959-2	Emissions Control and Test Facility (Arapahoe)—Operation and Maintenance	68 months	175.0	Public Service Co. of Colorado *L. Rettenmaier*

Electrical Systems

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1497-1	Remote Control Maintenance Device	16 months	185.2	Southwest Research Institute *J. Dunlap*
RP1724-1	Optimal Power Flow Research and Code Development	28 months	836.1	Energy Systems Computer Applications, Inc. *J. Lamont*
RP2004-1	Development of a Surge Arrester Tester	34 months	304.4	McGraw-Edison Co. *H. Songster*
RP2115-2	Evaluation of Compact Capacitor Design Concepts	4 months	25.3	Westinghouse Electric Corp. *S. Nilsson*
RP7858-2	Development of Splices and Terminals for 230-kV and 345-kV Extruded Dielectric Cables	5 months	24.0	Detroit Edison Co. *F. Garcia*
RP7860-3	Concrete Cutting With Abrasive Jets	5 months	30.0	Fluidyne Corp. *T. Rodenbaugh*
RP7876-18	High-Pressure AC Dielectric Strength Tests of Paper-Polypropylene Insulation	3 months	25.0	Pirelli Cable Corp. *S. Kozak*
RP7888-1	Development of ± 500–600-kV Solid-Type (Nonpressurized) Oil-Paper DC Cable	47 months	858.4	Phelps Dodge Cable & Wire Co. *F. Garcia*
RP7894-1	Evaluation of Pipe-Type Cable Restraint Systems	2 years	274.7	Pirelli Cable Corp. *S. Kozak*

Energy Analysis and Environment

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1479-3	Geostatistical Estimation of Coal Seam Characteristics and Coal Reserves	13 months	12.0	Norwest Resource Consultants, Inc. *J. Platt*
RP1630-21	Regional Air Quality Model Assessment and Validation, Phase 1	2 years	891.2	SRI International *G. Hilst*
RP1744-2	Atmospheric Emissions From Cooling Systems	22 months	135.0	SRI International *J. Guertin*
RP1819-1	Development of Utility Planning Model	6 months	154.8	Arthur Andersen & Co. *L. Rubin*
RP1910-3	Inventory of Acid Rain Research Projects Funded by the Private Sector	6 months	11.5	General Research Corp. *R. Brocksen*
RP1921-1	EPRI–DFI Fuel Supply Strategy	6 months	178.5	Decision Focus, Inc. *J. Platt*
RP1955-1	Load-Shape Forecasting Model	16 months	236.1	ICF Incorporated *A. Faruqui*
RP1982-1	Impact of Rail Investments on Coal Transportation Costs	1 year	100.0	Arthur D. Little, Inc. *E. Altouney*
RP1998-1	Effect of End-Use Technologies on Utility Costs	13 months	119.9	General Electric Co. *D. Geraghty*
RP2050-8	Load Management: Methods to Analyze Implementation Issues	17 months	20.9	Energy Management Associates, Inc. *N. Hassig*

Energy Management and Utilization

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP635-3	Zinc-Bromine Battery Development	13 months	370.4	Energy Research Corp. *W. Spindler*
RP1191-10	Passive Solar Test Building Data: Implications for Electric Utilities	1 year	75.0	San Diego Gas & Electric Co. *G. Purcell*
RP1199-17	Conceptual Design and Cost of a Superconducting Magnetic Energy Storage Power Plant	19 months	399.8	Bechtel Group, Inc. *R. Schainker*
RP1569-3	Planning for Expanded Use of Electric Vehicles in Commercial Fleet Operations	5 months	49.7	The Detroit Edison Co. *J. Mader*
RP1745-3	Hydro R&D: Assessment of Status and Implementation of Technology Transfer	13 months	98.1	Northeast Utilities Service Co. *J. Birk*
RP1791-7	Experimental/Laboratory Studies on Bubble Nucleation in Water-Compensated CAES Plants	8 months	93.5	Duke University Medical Center *R. Schainker*
RP1979-1	Development of a Load Survey System	7 months	64.9	New England Power Service Co. *T. Yau*
RP2033-7	Heat Pump Manual	5 months	38.5	Jeffrey M. Seisler *J. Calm*
RP2038-1	Comparative Evaluation: Acoustic Flow Measurement System	3 months	70.0	U.S. Department of the Interior *A. Ferreira*
RP2039-1	Ultrahigh Head Development Program	26 months	1,050.0	Hydraulic Turbines, Inc. *A. Ferreira* *J. Birk*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Nuclear Power				
RP399-8	Turbine Missile Technology Transfer	10 months	68.4	Structural Mechanics Associates, Inc. *G. Sliter*
RP606-10	Evaluation: Southwest Research Institute Ultrasonic Data Bank	6 months	14.0	Southwest Research Institute *S. Liu*
RP620-42	Review of LMFBR Development	4 months	21.5	Burns and Roe, Inc. *K. Winkleblack*
RP620-44	Review of LMFBR Development	4 months	26.0	Stone & Webster Engineering Corp. *K. Winkleblack*
RP620-46	Review of LMFBR Development	4 months	16.5	General Electric Co. *K. Winkleblack*
RP694-5	Assessment of Current Modeling and Qualifications Practices in the Simulator Area	7 months	49.5	Stone & Webster Engineering Corp. *J. Sursock*
RP822-9	Development of Commercialization Strategies	4 months	10.0	Sigma Research, Inc. *G. Dau*
RP895-22	Generic Software Improvements	7 months	100.0	Systems Control, Inc. *A. Long*
RP1233-9	Probabilistic Reactor Safety Study	2 months	12.1	Exxon Nuclear Company, Inc. *I. Wall*
RP1391-7	Generation Availability Data System	3 months	20.0	Control Data Corp. *J. Huzdovich*
RP1391-9	Generation Availability Information System	2 months	13.7	Los Alamos Technical Associates, Inc. *C. Chan*
RP1438-2	Equation of State for Water in Metastable States for Critical Power	2 months	23.0	University of Houston *G. Srikantiah*
RP1444-3	Analysis of Foreign Structural Data	1 year	22.7	Science Applications, Inc. *R. Oehlberg*
RP1543-7	Flow Evaluation Criteria for Nuclear Power Plant Piping	10 months	101.6	General Electric Co. *D. Norris*
RP1557-3	Identification of Radwaste Sources and Reduction Techniques	15 months	119.3	Gilbert Associates, Inc. *M. Naughton*
RP1557-4	Radwaste Incineration Experience	16 months	119.6	Gilbert Associates, Inc. *M. Naughton*
RP1561-2	Transient Testing and Data Acquisition at Grand Gulf BWR 6	25 months	320.0	Middle South Energy, Inc. *P. Bailey*
RP1628-2	Alternative BWR Control Blade Design	78 months	445.5	Aktiebolaget ASEA-Atom *H. Ocken*
RP1754-5	Maintenance of a BWR Core Flow Analysis Capability	10 months	14.8	NUS Corp. *J. Naser*
RP1757-9	Technology Transfer, Support Activities	7 months	15.0	Science Applications, Inc. *D. Norris*
RP1811-1	Set Point Testing of Safety Valves With Alternative Test Media or Method	19 months	218.0	Crosby Valve & Gage Co. *B. Brooks*
RP1932-9	Hydrogen Combustion Studies	2 months	96.0	Atomic Energy of Canada, Ltd. *L. Thompson*
RP1932-12	Documentary Film: Hydrogen Research	10 months	62.4	Argonne National Laboratory *L. Thompson*
RP1932-13	Coupling of Hydrogen Generation and Thermal Hydraulics in Reactor Core Under Core Uncovering Conditions	14 months	97.8	University of Illinois *B. Sehgal*
RP1932-14	Hydrogen Igniter Behavior	2 months	26.4	Atomic Energy of Canada, Ltd. *L. Thompson*
RP2006-6	Mechanisms of Environmentally Assisted Cracking in BWRs	30 months	369.5	General Electric Co. *J. Gilman*
RP2008-1	Corrosion Product, Cobalt Release Rates	35 months	990.0	Atomic Energy of Canada, Ltd. *T. Passell*
RP2056-2	Primary Pressure Boundary Requalification	2 years	576.5	Babcock & Wilcox Co. *S. Tagart*
RP2058-4	Improved Stress Corrosion Resistance of High-Strength, Age-Hardenable Alloys	1 year	105.7	Babcock & Wilcox Co. *A. McIlree*
RP2060-1	High-Purity Steels for Utility Components	25 months	164.2	Japan Steel Works America, Inc. *R. Jaffee* *A. Roberts*
RP2063-3	Cleaning Power Reactor Wastewater With Durasil Exchangers	3 months	31.2	NPD Nuclear Systems, Inc. *B. Williams*
RP2079-3	Gas-Cooled Reactor Technology	4 months	14.1	General Atomic Co. *M. Lapides*
RP2119-1	Development of Improved BWR Control Blade Replacement Methods	17 months	140.9	Dominion Engineering, Inc. *T. Law*
RP2135-1	Study of Scale-up Effects in Reactor Accident Evaluation	6 months	25.0	Nuclear Safety Associates *R. Vogel*
RP2135-2	High-Concentration Aerosol Modeling and Experiments	11 months	61.8	Science Applications, Inc. *R. Vogel*
RP2170-1	Experimental Study of Downtime Distribution	3 months	113.4	Science Applications, Inc. *D. Worledge*

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.

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ADVANCED POWER SYSTEMS

Combustion Turbine and Combined-Cycle Field Problems

AP-1981 Annual Report (RP1802); $8.00

This report details EPRI efforts to coordinate research on combustion turbine and combined-cycle plant operating problems. The results of investigations into five areas are presented: fuel-filter plugging, apparent compressor surge, oily waste water, compressor wheel failure, and combustor problems. The contractors are Coecorp and Aptech Engineering Services. *EPRI Project Manager: R. L. Duncan*

Design, Fabrication, and Evaluation of a Spiral-Flow Letdown Valve

AP-2044 Final Report (RP777-1); $9.50

A spiral-flow letdown valve for service in coal liquefaction plants was designed, fabricated, and tested. This report describes the design and presents laboratory and field test results. It also presents recommendations for development work in the areas of valve-plugging prevention, use of erosion-resistant materials and coatings, and application of the spiral-flow concept to a noncavitating liquid letdown valve and other pressure reduction devices. The contractor is Consolidated Controls Corp. *EPRI Project Manager: N. C. Stewart*

Operation of Gasification–Combined-Cycle Power Plants on a Utility Network: Simulation Analysis

AP-2053 Final Report (RP1133-1); Vol. 1, $15.50; Vol. 2, $29.00

Volume 1 summarizes the results and conclusions of a simulation analysis in which models of gasification–combined-cycle (GCC) plants were inserted into a power system model. The four case studies presented (involving the oxygen-blown entrained GCC plant model) show that GCC plants can provide rapid response for both load following and regulation. Volume 2 details the GCC plant models developed for the analysis. It describes their transportability, plant dynamics, heat rate, modularity, validation, and parametric coefficients. The contractor is Philadelphia Electric Co. *EPRI Project Manager: G. H. Quentin*

Component Failure and Repair Data for Coal-Fired Power Units

AP-2071 Topical Report (RP239-2); $12.50

A complete and consistent set of failure rate and time-to-restore data for components of a coal-fired generating unit was developed for use in the validation of a reliability and availability assessment model. This report presents the data and describes the principal methodology used—a failure modes analysis. It also includes process flow diagrams. The contractor is Fluor Power Services, Inc. *EPRI Project Manager: Jerome Weiss*

Preliminary Reliability and Availability Analysis of the Heber Geothermal Binary Demonstration Plant

AP-2085 Final Report (RP1900-2); $9.50

An assessment of the reliability and availability of the Heber geothermal binary-cycle demonstration plant was performed on the basis of preliminary design information. This report covers the characterization of plant design and equipment, the construction of system fault trees, data collection and data base development, the adaptation and application of an existing reliability and availability methodology to the Heber plant design, and reliability growth potential estimates. The contractor is ARINC Research Corp. *EPRI Project Manager: Jerome Weiss*

Proceedings of the Fifth Annual Geothermal Conference and Workshop

AP-2098 Proceedings (WS81-197); $23.00

This report compiles the formal presentations and the results of workshop sessions of the Fifth Annual Geothermal Conference, sponsored by EPRI and held in June 1981 in San Diego, California. Special consideration was given to the role of demonstration projects in the development of geothermal resources for electricity production. The conference covered current progress in demonstration plant development, related research, and planned activities, both in the United States and abroad. The contractor is Altas Corp. *EPRI Project Manager: Vasel Roberts*

Upstream H_2S Removal From Geothermal Steam

AP-2100 Final Report (RP1197-2); $15.50

A new heat exchanger process for removing H_2S gas from geothermal steam upstream of a power plant turbine was evaluated. This report describes the test unit and summarizes the field test objectives and results. Design and cost estimates are presented for 2.5-MW (e) and 55-MW (e) units and for two design options to improve heat transfer in the heat exchanger—a vertical tube evaporator using fluted tubes and a horizontal spray film evaporator. The contractor is Coury and Associates, Inc. *EPRI Project Manager: E. E. Hughes*

Economic Evaluation of Gasification–Combined-Cycle Power Plants Based on the Air-Blown KILnGAS Process

AP-2103 Final Report (RP239-2); $15.50

This report presents a detailed evaluation of the KILnGAS coal gasification process for combined-cycle power generation with currently available gas turbines (2000°F firing temperature). It includes background information, case studies, technical and economic criteria, and plant descriptions. Operating and economic results are discussed, along with potential improvements. The contractor is Fluor Engineers and Constructors, Inc. *EPRI Project Manager: M. J. Gluckman*

Survey of Diesel Generation by Small U.S. Utilities

AP-2113 Final Report (TPS79-770); $11.00

This report presents a concise overview of the present state of diesel generation by small U.S. utilities—that is, utilities with an average plant size of 5.5 MW (e) and an average system size of 7.7 MW (e). Included are data on diesel engine use, information on operating practices and experience from interviews with over 50 small utilities, a profile of utility diesel engines, broad-range operating statistics, and trends and needs in the use of diesel engine generators. The contractor is A. C. Kirkwood & Associates. *EPRI Project Manager: Henry Schreiber*

Characterizing Wyoming Subbituminous Coals and Liquefaction Products by Fourier Transform Infrared Spectrometry

AP-2115 Final Report (RP1604-2); $14.00

This report examines the potential of the analytic technique of Fourier transform infrared (FTIR) spectrometry to correlate liquefaction yields and product structure with coal structure information for Wyoming subbituminous coals. FTIR analyses on coals, recycle solvents, and liquefaction products are reviewed; coal liquefaction products are compared with the starting material to trace the chemical changes that occur during liquefaction; and model compound library development and library search routines are described. The contractor is Advanced Fuel Research, Inc. *EPRI Project Manager: L. F. Atherton*

Fundamental Studies in the Conversion of Coals to Fuels of Increased Hydrogen Content

AP-2117 Interim Report (RP1655-1); Vol. 1, $21.50; Vol. 2, $9.50

This report summarizes investigations of thermal coal dissolutions at short reaction times, a first step toward exploring the interrelationship of thermal and catalytic processes in coal liquefaction. Volume 1 presents details on procedures used in coal conversion experiments, new characterization techniques and the characterization of reaction products, and coal dissolution in high-boiling solvents. Volume 2 contains appendixes covering (1) the analyses performed on the coals, solvents, and products, and (2) the computer programs used for data correlation. The contractor is Mobil Research and Development Corp. *EPRI Project Manager: L. F. Atherton*

Shale Oil: Potential for Electric Power Fuels

AP-2186 Final Report (TPS80-710); $11.00

This report reviews the status of the oil shale industry and the impact it will have on the electric power industry in the years 1990–2000. The available technologies for producing shale oil (including mining and retorting technologies) are evaluated; nontechnical obstacles to commercial development, crude shale oil characteristics and uses, and power generation requirements are summarized; the current status of oil shale projects is documented; and a prediction of shale oil production in the 1990s is provided. The contractor is Occidental Research Corp. *EPRI Project Manager: W. S. Reveal*

COAL COMBUSTION SYSTEMS

Power Plant Performance Modeling: Dynamic Model Evaluation

CS/NP-2086 Interim Report (RP1184-2, RP1163); $9.50

The performances of the modular modeling system (MMS) and RETRAN in modeling the turbine and feedwater train of a 550-MW oil-fired plant are described. MMS simulations are compared with the results of transient tests conducted on an operating power plant. The level and type of modeling effort required, as well as computer run time, are discussed. The contractor is Bechtel Group, Inc. *EPRI Project Managers: A. F. Armor and A. B. Long*

Assessment of Atmospheric Fluidized-Bed Combustion Systems

CS-2091 Final Report (RP1180-1); $14.00

This report presents a technical and economic evaluation of atmospheric fluidized-bed combustion (AFBC) power plants with recycle systems. These plants are compared with two alternative designs: AFBC plants with carbon burnup beds and conventional pulverized-coal-fired plants with flue gas desulfurization systems. The analysis considers 1000-MW (e) plants burning both eastern and western coals. The contractor is Burns and Roe, Inc. *EPRI Project Manager: C. R. McGowin*

Behavior of Fine Particles in a Fluidized Bed of Coarse Solids

CS-2094 Final Report (RP839-1); $15.50

This report presents the results of a wide range of experiments investigating the behavior of fine particles in a fluidized bed of coarse particles. Conducted over a three-year period in several room-temperature fluidized-bed vessels, the tests covered entrainment from a fluidized bed with and without simulated heat exchange tubes, radial and vertical dispersion of recycled fines, bed expansion, interaction of fine and coarse particles, and particle residence times. The contractor is the University of Bradford (England). *EPRI Project Manager: C. Aulisio*

Dynamics of Low-Tuned Turbine Generator Foundation Systems

CS-2111 Final Report (RP984-2); $9.50

This report describes theoretical and experimental work conducted to compare the characteristics of low- and high-tuned turbine generator foundation systems and to assess the suitability of low-tuned foundations. Parametric studies were performed to assess the effects of various system characteristics (including damping and unbalanced loads), and experimental measurements were made of both frequency spectra and amplitudes on each foundation during steady operation. The contractor is Kenneth Medearis Associates. *EPRI Project Manager: I. A. Diaz-Tous*

In-Bed Corrosion Tests of Superheater Alloys in a 10-ft² AFBC

CS-2118 Final Report (RP979-2); $20.00

This report presents the results of tests conducted in an atmospheric fluidized-bed combustor approximately 1 m² in area to study high-temperature materials degradation processes. The goals of this and related work are (1) to help in selecting the best materials for components for fluidized-bed combustion systems, and (2) to determine safe limits of system operation to avoid unacceptable materials degradation. Materials investigated included low-, medium-, and high-chromium ferritic steels, iron-based austenitic steels, and nickel-based alloys. The contractor is the Coal Utilization Research Laboratory, National Coal Board (England). *EPRI Project Manager: John Stringer*

Review of Corrosion-Resistant Coatings for Steam Turbine Components

CS-2124 Topical Report (RP1408-1); $11.00

The state of the art of coating technology is reviewed for applicability to large steam turbine low-pressure components. On the basis of a literature review, discussions with vendors, and experimental results at two utilities, 24 coating systems are identified as feasible for the subject application. Secondary factors—such as deposited surface roughness, residual stresses, the need to reheat-treat the material after coating, and costs—are discussed. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: B. C. Syrett*

Groundwater Quality Monitoring at Coal-Fired Power Plants: Status and Review

CS-2126 Final Report (RP1457); $11.00

This report describes current efforts by coal-fired electric utilities to monitor groundwater at disposal sites handling flue gas desulfurization wastes, fly ash, bottom ash, and other combustion and cleaning wastes. Typical waste streams, available groundwater monitoring alternatives, and relevant federal and state regulations are discussed. The strengths and limitations of current groundwater monitoring practices are cited, and recommendations for improvements are made. The contractor is Emcon Associates, Inc. *EPRI Project Manager: D. M. Golden*

U.S.–Japan Seminar: Measurement and Control of Particulates Generated From Human Activities

CS-2145-SR Proceedings; $27.50

This report contains 44 papers that were presented at a U.S.-Japan seminar on particulate measurement and control held in November 1980 in Kyoto and Tokyo, Japan. The papers, by investigators from six countries, detail research into particle measurement, electrostatic precipitation, fabric filtration, granular bed filters, wet collectors, gas cleaning at high temperature and pressure, and diesel exhaust and related health effects. *EPRI Project Manager: O. J. Tassicker*

Fossil Plant Heat Rate Improvement: 1981 Conference and Workshop

CS-2180 Proceedings (WS81-221); $41.00

This report contains the proceedings of an EPRI workshop on fossil plant heat rate improvement that was cohosted by Duke Power Co. in Charlotte, North Carolina, in August 1981. Formal presentations are included, as well as summaries of the six working group sessions, which covered utility heat rate improvement programs, plant testing, instrumentation, advanced plant designs, retrofittable features for improved heat rate, and plant modeling and performance analysis. The contractor is Wood-Leaver and Associates, Inc. *EPRI Project Managers: A. F. Armor and D. V. Giovanni*

ELECTRICAL SYSTEMS

Probability-Based Design of Wood Transmission Structures

EL-2040 Final Report (RP1352-1); Vol. 1, $18.50; Vol. 2, $17.00; Vol. 3, $9.50

Volume 1 documents research on wood material properties, particularly the strength and stiffness of wood poles in service. The results of nondestructive and destructive tests performed on transmission poles removed from service are presented, and a new nondestructive evaluation method is described. Volume 2 establishes the feasibility of applying a new probability-based design method to single-pole wood transmission structures. It describes the development of the method and of an analytic procedure that recognizes the nonlinear behavior of unguyed wood poles. On the basis of this work, a computer program was developed for use in designing and analyzing single poles. Volume 3 presents a user's manual for the program. The contractor is the Research Institute of Colorado. *EPRI Project Manager: Phillip Landers*

Application of Induction Generators in Power Systems

EL-2043 Final Report (RP1945-1); $23.00

Comparative studies of induction and synchronous generator performance were conducted, and a series of static and dynamic situations were analyzed to assess the advantages and disadvantages of the large-scale use of induction generators in power systems. This report presents the results and discusses the fundamentals of induction generator transient behavior, the effects of modeling detail, and the importance of rotor-flux transient effects in high-efficiency designs. The contractor is Power Technologies, Inc. *EPRI Project Manager: J C. White*

Unified Active and Reactive Power Modulation of HVDC Transmission Systems

EL-2101 Final Report (RP1426-1); $20.00

The coordinated modulation of active and reactive power was investigated in HVDC digital and analog simulator studies to determine feasibility, advantages, and techniques for design and evaluation. Details are provided on preliminary conceptual studies, test system development, dynamic stability studies, control design considerations, a cost-benefit evaluation, and a definition of a demonstration controller. The contractor is General Electric Co. *EPRI Project Managers: John Reeve and S. L. Nilsson*

Soil Thermal Resistivity and Thermal Stability Measuring Instrument

EL-2128 Final Report (RP7861); Vol. 1, $12.50; Vol. 2, $9.50; Vol. 4, $6.50

This report describes work to fully characterize soil thermal parameters and their effect on underground cable design. This effort included the development of improved apparatus and methods for measuring soil thermal properties and methods for incorporating historical weather data into thermal design. Volume 1 discusses the determination of soil thermal stability and other soil thermal properties. Volume 2 is a detailed operating manual for the hardware developed for analyzing soils in situ, called the thermal property analyzer (TPA). Volume 4 is a brief TPA operating manual designed to stand alone. The contractor is Ontario Hydro Research Laboratory. *EPRI Project Manager: T. J. Rodenbaugh*

Air-Cycle Cooling of Electric Power Cables, Phase 1

EL-2130 Final Report (RP7866-1); $11.00

A study was conducted to determine the feasibility of using an air-cycle system for cooling underground transmission cables. This report presents a concept evaluation and an economic evaluation and summarizes the advantages of the air-cycle system as compared with the conventional vapor-cycle system: lower initial investment, comparable or lower operating cost, and lower present-value cost. The design, fabrication, and laboratory testing of a small-scale model of the air-cycle system are also described. The contractor is AiResearch Manufacturing Co. of California. *EPRI Project Manager: T. J. Rodenbaugh*

Development of Bulk-Graded, Filled Polymer Insulators

EL-2142 Final Report (RP1496-1); $12.50

This report describes work to develop bulk-graded, filled polymeric insulation systems. Investigations were conducted on three grading concepts—nonlinear resistive, linear resistive, and capacitive. The design, development, and testing of graded post insulators are discussed, as well as the techniques involved in developing the flux plots, the rationale that led to the design, and the modeling of the filler system to achieve optimal filler content. The contractor is General Electric Co. *EPRI Project Manager: B. S. Bernstein*

DC Line Insulators

EL-2151 Final Report (RP1206-1); $15.50

This report presents the results of R&D work on the evaluation, optimization, and use of composite insulators on HVDC lines. The three project tasks involved materials studies, the performance of insulators under contamination, and the improvement of resistance to flashover by means of a weakly conductive film deposited on the insulating surface. Also, the effect on total line cost of reducing insulator string length was estimated. The contractor is Sediver, Inc. *EPRI Project Manager: J. H. Dunlap*

Workshop on User Experience With Gas-Insulated Substations

EL-2189 Proceedings (WS81-185); $9.50

This report contains the highlights of presentations and discussions at a workshop on user experience with gas-insulated substations that was held in Portland, Oregon, in July 1981. Topics include substation design and layout, specification and acquisition of equipment, installation and commissioning, and operation and maintenance. *EPRI Project Manager: V. H. Tahiliani*

Workshop Proceedings: Transmission Planning

EL-2190 Proceedings (WS79-230); $21.50

This report contains papers presented at an EPRI transmission planning workshop held in June 1980 in New York City. Currently employed methods, procedures, and computer programs for both long- and short-range transmission system planning are reviewed, and the need for new methods and computation tools is highlighted. A streamlined procedure to address the environmental, regulatory, and governmental issues involved in planning new transmission facilities is described. *EPRI Project Manager: N. J. Balu*

ENERGY ANALYSIS AND ENVIRONMENT

Power Shortage Costs: Estimates and Applications

EA-1215 Final Report, Vol. 3 (RP1104-1); $17.00

This report concerns the shortage costs of electricity outages. It presents results from a case study of an outage that occurred in March 1978 in San Diego, California; results from a study to determine the long-run impacts of a shortage in Key West, Florida, in the summer of 1978; and a discussion of the various types of utility applications of shortage cost estimates. The contractor is Jack Faucett Associates, Inc. *EPRI Project Manager: A. N. Halter*

Case Study Comparison of Utility Corporate Models

EA-2065 Final Report (RP1303-1); $14.00

This report presents a study of corporate models by the second working group of the Utility Modeling Forum. The study was undertaken primarily to identify the strengths and limitations of various modeling approaches currently in use in order to direct future modeling efforts. The analytic approach, quantitative results, and conclusions are presented, along with an evaluation of process issues. The contractor is Booz, Allen & Hamilton, Inc. *EPRI Project Manager: Dominic Geraghty*

Sulfur Gas Emissions From Stored Flue Gas Desulfurization Solids

EA-2067 Final Report (RP856-2); $9.50

This report characterizes emissions of volatile, sulfur-containing compounds from the surfaces of 13 field-storage sites for flue gas desulfurization (FGD) solids. Detailed descriptions of the FGD solids collection and disposal systems are presented, and FGD solids from plant-scale ponds and landfills are ranked by total sulfur flux. The contractor is the University of Idaho. *EPRI Project Manager: Charles Hakkarinen*

Field Evaluation of Chlorine Monitoring Techniques

EA-2070 Final Report (RP879-1); $11.00

This report presents the results of a field evaluation of four instrumental methods for analyzing total residual chlorine: manual amperometric titration, automatic amperometric titration, amperometric back titration, and chlorine-flux monitoring. These methods were selected in an earlier laboratory study as the most suitable for power plant application. The evaluation was conducted at three sites covering a range of salinity and water quality conditions. The contractor is Public Service Electric and Gas Co. *EPRI Project Manager: Robert Kawaratani*

The Demand for Electric Automobiles

EA-2072 Final Report (RP1145-1); $11.00

This report describes a project that specified and estimated ordered logit models suitable for predicting the private market demand for electric vehicles, taking into account their key limitations relative to conventional alternatives. Two existing sets of data were used to estimate and validate the models of multivehicle households' choices of their smallest cars. The models exhibit the first quantitative estimates of the penalties consumers attach to the negative attributes of electric vehicles. The contractor is Charles River Associates, Inc. *EPRI Project Manager: J. B. Wharton*

Heat Pump Demand Characteristics: Impacts of Residential Heat Pumps on Utility System Loads

EA-2074 Final Report (RP1100-1); $14.00

Data on the hourly power demand and heating- and cooling-mode energy use of electric air-source heat pumps in single-family residences were analyzed and correlated. This report details the analysis of electric heat pump diversified demand, the development and testing of a Monte Carlo heat pump demand model, and the testing (using previous field data) of a building heating, ventilating, and air conditioning system simulation model. The contractor is Gordian Associates Inc. *EPRI Project Manager: Edward Beardsworth*

Demand 80/81: Forecasts of Energy Consumption to the Year 2000

EA-2078 Final Report (RP1747-1); Vol. 1, $12.50; Vol. 2, $17.00

This report presents national forecasts of end-use consumption of electricity, liquid hydrocarbons, gaseous hydrocarbons, and coal for 1980–2000. The forecasts are based on an econometric model whose equations represent energy consumption of each energy form in each end-use sector. Volume 1 presents the main results and the assumptions used regarding energy prices and conservation policy, compares the results with those of other studies, and describes the model's equations. Volume 2 (technical appendixes) documents the detailed forecasts for the 12 final scenarios. The contractor is Applied Forecasting & Analysis, Inc. *EPRI Project Manager: L. J. Williams*

Cogeneration and Central Station Generation

EA-2084 Proceedings (RP1050); $47.00

The papers in this report were presented and discussed at an EPRI workshop on cogeneration held in April 1979 in San Antonio, Texas. The report is the third in a series of project reports that review the state of the art of energy demand analysis and the cost-effectiveness of conservation technologies. Cogeneration and its advantages and disadvantages over conventional baseload and intermediate-load electric power plants are summarized. The contractor is the University of Arizona Engineering Experiment Station. *EPRI Project Managers: S. D. Braithwait and L. J. Williams.*

PILOT-1980 Energy-Economic Model
EA-2090 Interim Report, Vol. 1 (RP652-1); $24.50

This volume describes PILOT-1980, a long-range optimization model that interfaces a detailed representation of the energy sector with a less detailed description of the rest of the economy. The industrial energy services module, the consumers energy services module, and the coal module are summarized. A detailed mathematical description of the model is included. The contractor is Stanford University. *EPRI Project Manager: S. S. Sussman*

Effects of Natural Gas Curtailments on Industrial Electricity Demand
EA-2104 Final Report (RP1215-1); $14.00

This report describes a project that examined the potential effects of natural gas curtailments on industrial electricity demand by studying how energy, particularly electricity, is used in three major energy-intensive industries: paper and allied products; stone, clay, and glass products; and primary metals. An econometric model, developed to simulate the demand for coal, electricity, and fuel oil when the availability of one of the fuels is constrained, is presented and estimated. The contractor is Resource Planning Associates, Inc. *EPRI Project Manager: S. D. Braithwait*

Design of a Forecasting Model of Regional Electricity Consumption and Peak Demand
EA-2108 Final Report (RP1007-1); $15.50

This report presents a research plan for an integrated regional economic and electricity demand forecasting system. The system encompasses the forecasting of electricity sales to major classes of service, peak demands, and regional economic and demographic growth that will substantially determine regional electricity demand. The report also reviews the state of the art of electric energy and peak load modeling and regional economic modeling. The contractor is Charles River Associates, Inc. *EPRI Project Manager: L. J. Williams*

WEFA Multiregional Model Project
EA-2109 Final Report (RP1293-1); Vol. 1, $9.50; Vol. 2, $14.00

Volume 1 describes the specification and design of a 20-region model of the United States intended to examine how energy consumption and peak demand are affected by such factors as regional economic growth, energy prices, and public policy. The problems and issues involved in regional and multiregional modeling are reviewed, along with past and current modeling efforts. Volume 2 documents a complete operational multiregional model of the nine U.S. Census Bureau regions, which was revised as part of this project. The contractor is Wharton EFA Inc. *EPRI Project Manager: L. J. Williams*

Power Plant Intake Systems Data Base
EA-2127 Final Report (RP1488-1); $14.00

This report presents the design and requirements for the development of a data base on power plant water intake systems. Information is provided on the data base contents, data acquisition procedures, data availability, and data deficiencies. The report also describes a questionnaire created to obtain environmental and engineering design data and operation and maintenance data on existing water intake systems. The contractor is Tetra Tech, Inc. *EPRI Project Manager: I. P. Murarka*

Review of the RAm Utility Financial Forecasting Model
EA-2133 Final Report (RP1483-2); $8.00

This report presents the results of a review of RAm, a regulatory analysis model that was developed to analyze the financial and economic impacts of a privately owned utility's operating decisions. Details are provided on the model's modules (build, performance, plant, aggregation, fixed obligations, finance, and report writer). The contractor is Economic Resource Associates. *EPRI Project Manager: S. D. Hu*

CRA–EPRI Coal Market Analysis System: Integration and Other Improvements
EA-2148 Final Report (RP1430-2); $9.50

Research was conducted to prepare the CRA–EPRI Coal Market Analysis System (CMAS) for integration with the Gordian Utility Capacity Expansion Model, also developed for EPRI. The report discusses further CMAS development, the exploration of theoretical and practical integration methods, and modifications to accomplish the interface between the coal supply and generation planning models and to keep CMAS to a reasonable size for computer implementation. The contractor is Charles River Associates, Inc. *EPRI Project Manager: S. D. Hu*

Effects of New Coal-Using Technologies for Electric Utilities on the Coal Market
EA-2150 Final Report (RP1221); $11.00

This report presents a revised analysis of key issues related to the effects of coal-using technologies for electricity generation on future coal markets and the utility industry. The results are compared with those of a 1979 study. The effects of new technologies on coal production, consumption, distribution, and prices are summarized. The analysis projects that new technologies will have only slight impact on coal markets. The contractor is ICF Incorporated. *EPRI Project Manager: E. V. Niemeyer*

Customer Acceptance of Direct Load Controls: Residential Water Heating and Air Conditioning
EA-2152 Final Report (RP1429-1); $12.50

This report presents analyses of 38 utility-sponsored water-heating load-control programs, 16 air conditioning programs, and 5 attitude surveys of residential customers who had no experience with load control. The data indicate that residential customers do not have inherent opposition to direct load control of water heaters and air conditioners. The contractor is Thomas A. Heberlein and Associates. *EPRI Project Managers: Ahmad Faruqui and A. G. Lawrence*

Case Studies of Innovation in R&D Planning
EA-2154 Final Report (RP1432-2); $11.00

This report describes the R&D planning systems used by four organizations (the Gas Research Institute, General Electric Co., Texas Instruments Inc., and the Air Force Systems Command). Three important characteristics of successful planning systems are discussed: documented, hierarchical objectives; evaluation criteria; and management judgment. The general findings of a literature search are also presented. The contractor is Booz, Allen & Hamilton, Inc. *EPRI Project Manager: S. S. Sussman*

ENERGY MANAGEMENT AND UTILIZATION

Opportunity and Risk Assessment: Electric and Hybrid Vehicles
EM-2068 Final Report (RP1524-1); $18.50
EM-2068-SY Summary Report; $6.50

These reports present the 1980 assessment of electric and hybrid vehicles, which was developed through a series of workshops. The assessment focuses on national objectives, transportation problems, and the potential for large-scale commercialization of the vehicles. Major opportunities and risks are identified, strategic issues for the 1980s are presented, and five recommendations for action are given. For each recommendation, coordinated programs by industry, government, and utility participants are stressed. The contractor is Purdue University. *EPRI Project Manager: J. H. Mader*

EPRI–TVA Pilot Electric Vehicle Demonstration Project
EM-2095 Interim Report (RP1136-5); $11.00

This report documents the progress made from March 1978 to June 1980 in the EPRI–TVA pilot electric vehicle demonstration project. It covers vehicle selection and acquisition, vehicle operations, data acquisition systems, early results, and future project plans. The contractor is Tennessee Valley Authority. *EPRI Project Manager: R. J. Ferraro*

Evaluation of Hybrid THR–ATR Fuel Processor
EM-2096 Final Report (RP1041-1); $9.50

This report describes a study of Toyo Engineering Corp.'s sulfur-tolerant catalysts for processing No. 2 fuel oil. It presents the results of tests carried out on the catalysts at conditions representative of a high-temperature steam reformer with a secondary autothermal reformer as integrated with phosphoric acid fuel cells. The basis of the experimental work and analysis is discussed, and the test program is described. The contractor is Kinetics Technology International, Inc. *EPRI Project Manager: E. A. Gillis*

Impact of Advanced Power Semiconductor Systems on Utilities and Industry
EM-2112 Final Report (RP1201-12); $11.00

This report examines the potential energy savings and economic benefits from the use of advanced power semiconductors and power conditioning and control systems of 200 kW and below in commercial and industrial segments of the economy. An analysis of residential applications was included for power requirements below 30 kW. Particular emphasis was placed on ac motor drives and their application as prime movers. Electric energy consumption in each end-use category was a significant factor in selecting applications for more detailed examination. The contractor is SRI International. *EPRI Project Manager: J. S. Brushwood*

Specification for Dispersed Fuel Cell Generator
EM-2123 Interim Report (RP1777-1); $11.00

This report provides a preliminary specification, general description, and performance definition for a standard 11-MW fuel cell power plant designed for electric utility dispersed-generation applications. Power rating, heat rate, fuels, operating modes, siting characteristics, and available options are defined. The general description covers equipment, typical site arrangement, auxiliary subsystems, maintenance, fuel flexibility, and general fluid and electrical schematics. The contractor is United Technologies Corp. *EPRI Project Manager: D. M. Rigney*

Electric Vehicles in Electric Utilities: National Survey
EM-2131 Final Report (RP1569-1); $9.50

This report presents the results of a national survey of electric utilities to determine their vehicle fleet characteristics, actual and potential uses of electric vehicles (EVs) in those fleets, and EV technology transfer and information needs. The methodology used in the survey is described. The contractor is O. M. Bevilacqua & Associates. *EPRI Project Manager: J. H. Mader*

Improved Beta Alumina Electrolytes for Advanced Storage Batteries
EM-2160 Interim Report (RP252-3); $9.50

This report describes an investigation of factors affecting the breakdown or degradation of sodium beta and beta″ alumina solid electrolytes used in beta batteries. Two distinct failure modes were identified: (1) the classic failure mode of beta alumina, involving cathodic plating of sodium in a preexisting surface crack, and (2) a mode that involves internal deposition of sodium. The contractor is Lawrence Berkeley Laboratory. *EPRI Project Manager: W. T. Bakker*

Workshop on the Status of Industrial Organic Electrochemistry
EM-2173 Proceedings (RP1086-9); $9.50

This report describes a workshop on the status of industrial organic electrochemistry that was held in Menlo Park, California, in April 1981. Presentations and discussions are summarized in five main topic areas: electric utility perspective, electroorganic technology status, industrial and economic factors, new concepts, and future prospects. Recommendations proposed during the workshop are also included. The contractor is SRI International. *EPRI Project Manager: B. R. Mehta*

NUCLEAR POWER

BWR Refill-Reflood Program Plan
NR-1522 Interim Report (RP1377-1); $9.50

This report provides an overview of research on BWR refill-reflood behavior, including a discussion of general strategy, brief descriptions of the experimental facilities, descriptions of the model development and qualification tasks, and planned documentation and schedule information. The contractor is General Electric Co. *EPRI Project Manager: Mati Merilo*

BWR Refill-Reflood Program: Model Development Task Plan
NP-1526 Interim Report (RP1377-1); $6.50

A plan for the development of a thermal-hydraulic system code for BWR loss-of-coolant accidents is described. Details are provided on the planned application techniques, the individual models to be developed (including the single-channel code), and the correlation development approach. The contractor is General Electric Co. *EPRI Project Manager: Mati Merilo*

BWR Refill-Reflood Program: Model Qualification Task Plan
NP-1527 Interim Report (RP1377-1); $9.50

A plan for performing assessments of BWR loss-of-coolant accident (LOCA) best-estimate models is described. Details are provided on BWR LOCA phenomena; the relevant data base and its applicability, classification, and preparation; preliminary model assessment and recommendations for improvements; and model acceptance criteria. Results of previous experiments on the void fraction distribution and level swell during a simple vessel blowdown are also presented. The contractor is General Electric Co. *EPRI Project Manager: Mati Merilo*

Control Rod Materials and Burnable Poisons
NP-1974 Final Report (TPS79-708); $21.50

A technology evaluation of the materials in control rods and burnable poison rods was conducted. This report covers designs and component design criteria, fabrication and quality control, properties and in-reactor behavior, and commercial service experience. Also, potential computer codes that could be used to model control and burnable poison elements are evaluated, and available cladding material property summaries are reviewed. The contractor is The S. M. Stoller Corp. *EPRI Project Manager: David Franklin*

Assessment of Inspectability of LMFBR Designs
NP-2021 Final Report (RP1704-4); Vol. 1, $33.50; Vol. 2, $18.50

Volume 1 provides a comprehensive review of the inspectability of specific portions of loop- and pool-type LMFBR (1000-MW [e]) designs selected by EPRI. The requirements for normal, contingency, and post-repair inspections, the intrinsic characteristics of the designs, environmental aspects, and available inspection techniques formed the basis for assessing design inspectability in terms of accessibility, feasibility, practicality, and costs. Changes and additions that would be required at a minimum to make the designs inspectable are identified. Volume 2 presents appendixes that contain detailed procedures, manpower and man-rem requirements, and costs associated with the evaluations. The contractor is Rockwell International Corp. *EPRI Project Manager: Joseph Matte III*

Additional Pool-Swell Experiments on a 1/11.7-Scale Mark I Pressure-Suppression Model
NP-2058 Final Report (RP693-1); $12.50

The dynamic response of a Mark I pressure-suppression system during the early air-discharging phase of a postulated loss-of-coolant accident was studied by means of scale-model experiments. Details are provided on split and vent pipe orifice tests, pool-swell dynamics as a function of vent resistance distribution, an investigation of downcomer pressures, and tests in support of parallel analytic efforts. The contractor is SRI International. *EPRI Project Manager: C. W. Sullivan*

Three-Dimensional Pool-Swell Modeling of a Mark I Suppression System
NP-2061 Final Report (RP693-1); $26.00

This report—a revision of an earlier report, NP-906—presents scale-model test results on the dynamic response of a Mark I pressure-suppression system during the early air-discharging phase of a postulated loss-of-coolant accident. Tests yielding quantitative data on the vent-clearing process, pool swell, and loads on the torus and ringheader are described. The report also discusses scaling considerations, the model and instrumentation, and the results of other exploratory tests. The contractor is SRI International. *EPRI Project Manager: C. W. Sullivan*

Two-Phase Natural Circulation Experiments in a Test Facility Modeled After Three Mile Island Unit 2
NP-2069 Final Report (RP1731-1); $11.00

A series of natural circulation experiments was conducted in a test facility configured after the primary and secondary cooling systems of Three Mile Island Unit 2. Details are provided on the test facility, the instrumentation, and the effects of various operating parameters. Two modes of natural circulation are described: in one the heat is removed via reflux condensation and in one it is removed via two-phase natural circulation in the primary loop. The contractor is SRI International. *EPRI Project Manager: J. P. Sursock*

Evaluation of Oconee Steam Generator Debris
NP-2082 Final Report (RPS136-2); $12.50

Debris samples from operating steam generators at the Oconee power station were examined to determine the nature and source of the debris and its relationship to observed erosion and corrosion damage within the tube bundle. To evaluate the source of the debris, samples of mill scales from various operations in the steam generator manufacturing process were obtained and analyzed. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: J. P. N. Paine*

Inferred In-Core Flow Velocity Profiles During the First Fuel Cycle at Hatch-1
NP-2083 Final Report (RP1754-2); $9.50

This report presents inferred data for fuel channel steam velocities and boiling in the bypass region outside the fuel channel boxes. These results were processed from previously recorded in-core neutron noise data. The methodology of inferring velocity and bypass boiling by using BWR neutron detector noise is discussed. Data acquisition and reduction are described, and some analysis to aid in the interpretation of the inferred data is provided. The contractor is Oak Ridge National Laboratory. *EPRI Project Manager: B. A. Zolotar*

Fundamental Developments for Quantitative Acoustic Emission Measurements
NP-2089 Interim Report (RP608-1); $20.00

The results of a project to develop quantitative acoustic emission (AE) measurements are detailed. AE sensor and system calibration work—including work on a new piezoelectric AE sensor—is described, and current AE test practices are analyzed. The report also covers a theoretical framework, specific theoretical solutions, new processing techniques, and verification of the theory and analysis methods in glass and steel. The contractor is the National Bureau of Standards. *EPRI Project Manager: J. R. Quinn*

Nuclear Unit Operating Experience: 1978 and 1979 Update
NP-2092 Final Report (RP771-4); $12.50

This report presents an analysis of recently available 1978 and 1979 performance data for 62 nuclear units 400 MW (e) or larger. The results are compared with similar information published in an earlier report (NP-1191). Capacity, availability, and equivalent availability factors are presented by commercial year for individual nuclear units. Capacity factor loss is used as the principal index for comparison and as the parameter for determining trends in problems and component performance. The contractor is The S. M. Stoller Corp. *EPRI Project Manager: J. M. Huzdovich*

Carbide Dissolution and Precipitation Kinetics of Inconel 600

NP-2093 Topical Report (RP1708-1); $6.50

This report presents the results of tests to define the tube-processing parameters required to ensure that Alloy 600 tubing responds consistently and favorably to thermal treatment as a means of preventing stress corrosion cracking in steam generators. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: C. E. Shoemaker*

Input-Motion Specification for Nonlinear Seismic Analyses of Soil-Structure Systems

NP-2097 Final Report (RP810-9); $12.50

This report provides a brief assessment of some rational approaches to specifying input motions within a nonlinear analysis framework; consideration of nonlinear deconvolution and of the incident wave approach is included. A program of one-dimensional analyses using the STEALTH-1D seismic and SHAKE computer codes was conducted to illustrate certain points in the assessment, and the results are presented. The contractor is Civil Systems, Inc. *EPRI Project Manager: Y. K. Tang*

On-Line Power Plant Signal Validation Technique Utilizing Parity-Space Representation and Analytic Redundancy

NP-2110 Final Report (RP1541); $12.50

The feasibility of using advanced sensor validation concepts for a representative nuclear plant application was evaluated. The report describes a technique that applies parity-space representation and analytic redundancy to detect and isolate failures of sensors and other components in PWR feedwater and steam generator subsystems. Testing and evaluation efforts are described, and the application of the technique to a disturbance analysis and surveillance system is considered. The contractors are Combustion Engineering, Inc., and The Charles Stark Draper Laboratory, Inc. *EPRI Project Managers: R. M. Kanazawa and A. B. Long*

Investigation of Stainless-Steel-Clad Fuel Rod Failures and Fuel Performance in the Connecticut Yankee Reactor

NP-2119 Final Report (RP1758-1); $9.50

A detailed poolside and hot cell examination program was conducted to determine the cause of failure of batch-8 fuel in the Connecticut Yankee reactor and to identify differences between that fuel and previous batches that had operated without failures. The hot cell work consisted of detailed nondestructive and destructive evaluation of fuel rods from batches 7 and 8. The results indicate that the batch-8 failure mechanism was stress corrosion cracking that began on the cladding's outer surface. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: Howard Ocken*

Uncovery Boiloff Transients in a 3- × 3-Rod Bundle

NP-2121 Final Report (RP341-2); $9.50

This report summarizes a study of uncovery boiloff transients in a 3- × 3-rod bundle, including the core uncovery test data. Two sets of experiments were conducted: one using different wet front positions with the same input power density to the rod bundle and one using the same wet front position but with different input power densities. The instrumentation, test procedures, and uncovery test conditions are described. The contractor is the State University of New York at Buffalo. *EPRI Project Manager: R. B. Duffey*

Effects of High Temperature and Flow Blockage on the Reflood Behavior of a 4-Rod Bundle

NP-2122 Final Report (RP1118-1); $14.00

The results of an experiment to quench both deformed and undeformed 4-rod Zircaloy tube bundles are summarized. The report details the experimental procedure, apparatus, and quenching temperatures. It also presents quench front location and velocity data. The contractor is the University of California at Los Angeles. *EPRI Project Manager: R. B. Duffey*

Plant Materials Program Progress Report: June 1980 to May 1981

NP-2125-SR Special Report; $15.50

This is the first annual progress report of the plant materials subprogram, which was organized to address corrosion-related materials problems in LWRs. Included are an overview of materials problems with a high impact on plant availability; a review of the status and goals of R&D work addressing these problems; and details on significant progress in relevant technical areas, including intergranular stress corrosion cracking of austenitic steels and nickel-based alloys, environmentally assisted cracking of carbon and low-alloy steels, and improved fabrication technology. *EPRI Project Manager: R. L. Jones*

Radiation Effects on Organic Materials in Nuclear Plants

NP-2129 Final Report (RP1707-3); $11.00

This report presents the results of a literature search for data concerning the radiation resistance of organic materials and for information on the synergistic effects of radiation and other environmental stresses. An overview of radiation effects and an extensive list of organic materials in order of increasing resistance to radiation damage are included. The contractor is the Georgia Institute of Technology. *EPRI Project Manager: George Sliter*

Simulation of the Winfrith SGHWR X-Trip Blowdown Experiment Using RELAP–UK and RETRAN–UK

NP-2140 Final Report (RP1439-1); $12.50

This report describes calculations made with the thermal-hydraulic codes RELAP-UK Mk IV and RETRAN to model the behavior of the Winfrith steam-generating heavy water reactor during a controlled depressurization experiment. The results of the simulations are compared with each other and with the data obtained during the X-trip reactor experiment. The contractor is the Atomic Energy Establishment (U.K.). *EPRI Project Manager: L. J. Agee*

Static Strain Analysis of TMI-2 OTSG Tubes

NP-2146 Topical Report (RPS176-1); $9.50

The data reduction and analysis of strain gage measurements made in tubes of a once-through steam generator at Three Mile Island Unit 2 are documented. Changes in tube axial stress and axial load are computed for each transient condition, and these values are plotted against other parameters (time, temperature, or percent power) to fully define the tube stress and load changes occurring as a result of the transient. The results are compared with design predictions and used to assess tube buckling and fatigue susceptibility. The contractor is Babcock & Wilcox Co. *EPRI Project Manager: D. A. Steininger*

Corrosion-Product Transport in PWR Secondary Systems

NP-2149 Topical Report (RP404-1, RP704-1); $12.50

Corrosion-product concentration data for the secondary systems of 10 PWRs were obtained by employing integrating sampling techniques. On the basis of these data, mass transport relations were developed for iron, copper, and nickel and were used to evaluate how such parameters as blowdown, condensate polishing, operating pH, and oxygen ingress affect corrosion-product transport and the buildup of sludge in steam generators. Several generic system designs were considered for minimizing corrosion-product input to generating equipment. The contractor is NWT Corp. *EPRI Project Manager: G. W. DeYoung*

PLANNING AND EVALUATION

Alternative Nuclear Technologies

P-2073 Final Report (TPS78-817); $12.50

This study estimates and compares the times required to reach initial commercial deployment for certain selected nuclear power technologies and fuel cycles as alternatives to LWRs and the current once-through uranium fuel cycle. The study determines where each nuclear alternative stands in its development and postulates the events required for it to reach the stage of initial commercial-cycle deployment. The contractor is International Energy Systems Corp. *EPRI Project Managers: W. H. Esselman and Chaim Braun*

R&D STAFF

2¼Cr–1Mo Steels for Coal Conversion Pressure Vessels

RD-2143-SR Special Report; $6.50

This report summarizes results from various studies on the use of 2¼Cr–1Mo steel in coal conversion pressure vessels. Under the projected operating conditions, degradation of the steel's mechanical properties by temper embrittlement, hydrogen embrittlement, and hydrogen attack is a major concern. The significance of these mechanisms is reviewed here in light of experimental results from recent EPRI projects and other results published in the literature. *EPRI Project Managers: Ramaswamy Viswanathan and R. I. Jaffee*

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