Forecasting the Patterns of Demand

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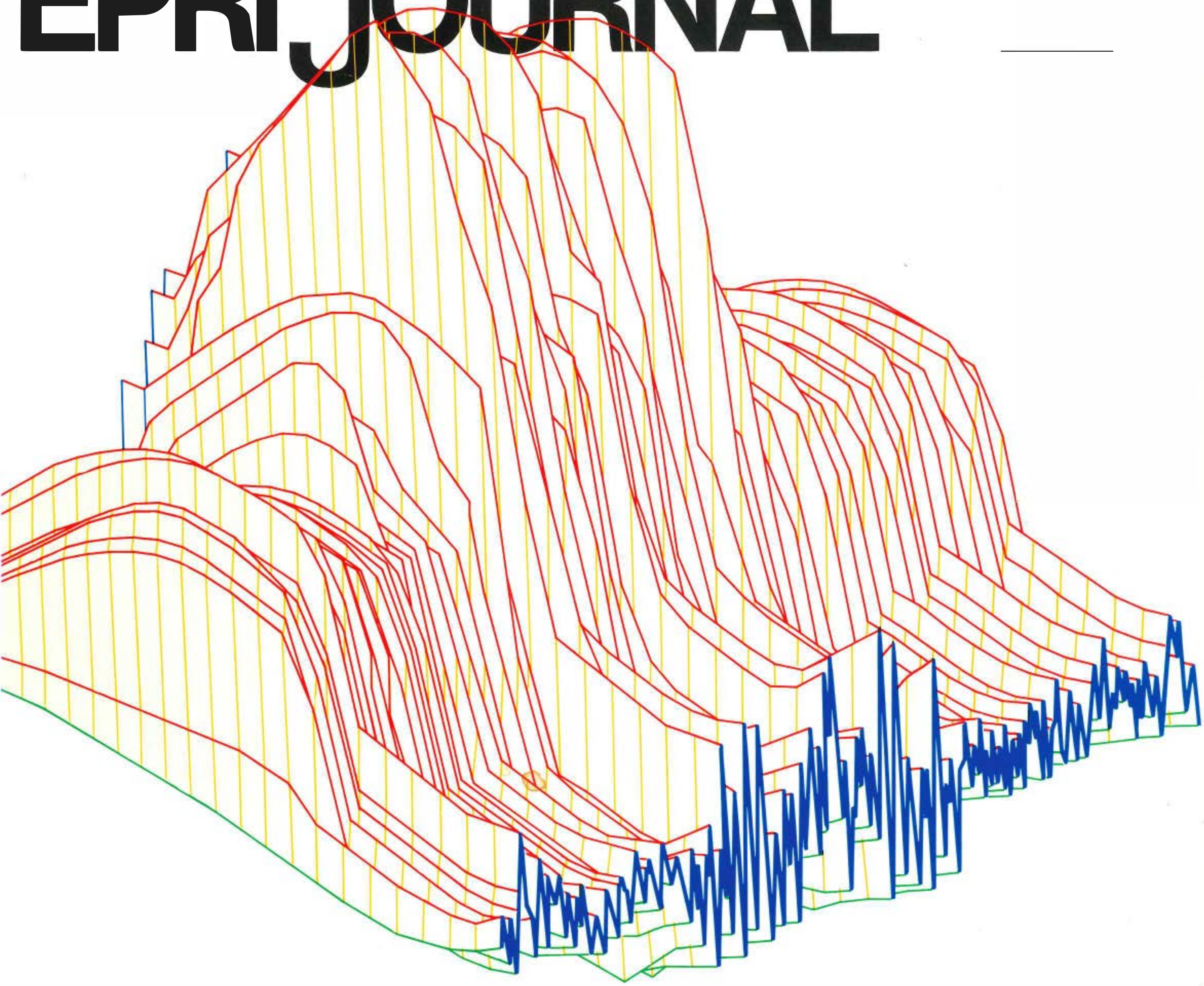

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Cover: Load shapes are now being characterized in three dimensions rather than two. Shown is an illustration of the actual system load shape of Public Service Electric and Gas Co. in New Jersey, with hour-to-hour variations along one axis and day-to-day variations along the other.

EPRI JOURNAL

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Asking More From Forecasts

Utility forecasting of energy services has entered a new era. No longer are the composite needs of utility customers adequately represented by forecasts of peak demand and total energy use. Two specific developments have changed this. First is the economic necessity for greater accuracy in forecasting, and second is the emerging potential of demand-side planning. The latter is the concept by which utilities define strategic corporate objectives in terms of their involvement in demand-side activities, ranging from conservation and load management to electrification.

Addressing these two issues of more accurate forecasts and demand-side planning requires a level of detail in prediction unimagined only a few years ago. Hour-by-hour load shape forecasts are now necessary. Furthermore, the end-use components of the load shape must be known in order to exercise planning options and to determine, say, the extent of a conservation program involving insulation financing or the most desirable rate of penetration of a load management program involving control of water heaters.

Such requirements have caused a virtual explosion of information needs. These needs include greatly expanded load and consumer research activities within utilities, as well as an increased need for utilities to reach out and exchange methods, information, and data with each other and with EPRI.

The expanded information needed to improve forecasting accuracy and load shape forecasting for demand-side planning requires the use of computers capable of manipulating large load-forecasting models. Some have criticized the industry for its continued and seemingly blind reliance on computer-generated forecasts. They seem to have missed the point. Forecasting remains an art only to the extent that the science is not fully defined. Computers are a most necessary and helpful tool to enhance the scientific aspects of forecasting and to mitigate the uncertainties inherent in it. Their use serves to support the artistry of judgment.

There are various methods of forecasting, only some of which are mentioned in this month's lead article. Each method has its own strengths and weaknesses and produces a forecast with some margin of error. To reduce the potential band of uncertainty surrounding a forecast, many utilities are adopting a multimodel approach. In this approach several models are applied to end-use sectors of the forecast or to the forecast as a whole, producing a range of results that can be evaluated and resolved by the analyst.

There is a practical limit to the quantity of data that it is cost-effective to gather and manipulate in terms of the additional insight gained by the utility planner. New techniques are under study at EPRI and elsewhere to reduce the amount of data required for a given level of accuracy, as well as to reduce the level of detail required in the ultimate forecast.

The problems of forecasting and the needs for information are well documented. EPRI and the industry are hard at work to develop tools, data, and techniques for accommodating these informational needs and to help utilities meet them in a reasonable, reliable, cost-effective manner.

Clark Gellings
Program Manager, Demand and Conservation
Energy Analysis and Environment Division

Authors and Articles

Electricity demand growth is slow nowadays, but that only makes accurate forecasts more important. If a utility is early or late with new facilities, it means a longer time with some expensive stopgap measure. **Forecasting the Patterns of Demand** (page 6), by science writer Mary Wayne, reviews comprehensive new approaches to demand forecasting that should prove more accurate; they may even allow some data from one system to be used in forecasting elsewhere.

Clark Gellings aided Wayne with technical background from the Demand and Conservation Program in EPRI's Energy Analysis and Environment Division. Named manager of the program when he came to EPRI in May 1982, Gellings was previously with Public Service Electric and Gas Co. in New Jersey for 14 years. After several years as an application engineer, he became assistant manager of load management in 1977 and was responsible for assessing the effect of load management and electricity conservation on the company's demand forecasts. He is the 1982 chairman of an IEEE working group on load management. Gellings is a 1968 electrical engineering graduate of New Jersey Institute of Technology, and he earned an MS in mechanical engineering there in 1980. He also has an MS in management science from Stevens Institute of Technology.

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Electricity and building materials will never be sold in the same package, but both are products of coal-fired power generation. Coal ash, slag, and scrubber wastes can all be used in highways, parking lots, cement, roofing, and other applications. **Marketing Coal Ash, Slag, and Sludge** (page 14), by Nadine Lihach, the *Journal*'s senior feature writer, reviews a blend of technical and market research that is aimed at giving utilities the information they need to help market more of their power plant by-products. Three members of the Heat, Waste, and Water Management Program in EPRI's Coal Combustion Systems Division contributed to Lihach's article.

John Maulbetsch has been at EPRI since 1975, managing a program that once dealt almost entirely with power plant heat rejection but now covers waste and water by-products as well. Maulbetsch was previously with Dynatech R/D Co. for seven years as director of the company's energy technology center. He holds BS, MS, and PhD degrees from Massachusetts Institute of Technology, where he was an assistant professor for three years.

Dean Golden and Ralph Komai are project managers for research in solid-waste disposal. Golden came to EPRI in February 1978 after six years with Southern California Edison Co., where he was responsible for the utility's compliance activities in water quality and waste disposal. Earlier he was with the Los Angeles Department of Public Works. Golden earned a BS in civil engineering at the University of California at Berkeley, an MS in environmental engineering at Loyola University (Los Angeles), and an MBA at the University of Southern California.

Ralph Komai has been with EPRI since May 1979, following five years as an environmental engineer with Southern California Edison Co., where he provided technical guidance in air and water quality control and in PCB and other waste disposal. He earlier worked for two years in Japan as a chemistry editor. Komai graduated in mathematics from Whittier College; he earned an MS in chemistry at California Institute of Technology and a PhD in chemistry at the University of California at Riverside.

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Pushing on a nail isn't like hitting it with a hammer. Kinetic energy is what makes the difference. **The New Bond** (page 20) describes how the kinetic energy and heat from small explosive charges are being used to create leakproof joints in the assembly of power plant steam condensers. The article was written by Carrie McKee, science writer, who drew on research sponsored by EPRI and guided by Robin Jones and Wylie Childs.

Robin Jones manages a program of research in structural materials, part of a larger effort in corrosion and materials problems conducted by the Nuclear Power Division. Before coming to EPRI in August 1978, he was with SRI International for six years as manager of its metallurgy program. Still earlier he was with Franklin Research Center for six years as a metallurgist and laboratory group leader. Jones is a graduate of Cambridge University (England) with a BA in natural sciences and a PhD in metallurgy.

Wylie Childs joined the Nuclear Power Division in August 1980 to manage research projects involving stress corrosion phenomena and fabrication techniques. He was previously with General Electric Co. for 4 years, responsible for analysis of the behavior of nuclear plant component materials. Earlier, he was successively on the metallurgical engineering faculties of Easton College (Pennsylvania) and Rensselaer Polytechnic Institute for over 20 years. Childs holds BS, MS, and PhD degrees in metallurgical engineering from Rensselaer.

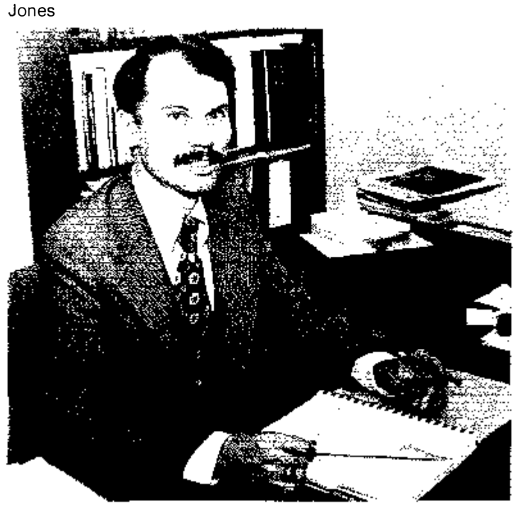
■

Recycling power plant wastes into byproduct markets is not always posible; and even when it is, there are the necessary steps of waste collection, interim storage, and (perhaps) processing for environmental compliance. **Aiding the Disposal Engineer** (page 26) reviews two EPRI manuals in which utilities find complete guidelines for the technical side of waste management. Science writer Lloyd Popish turned to Dean Golden, a project manager in EPRI's Coal Combustion Systems Division, for details on the manuals and their origin. Although Golden is now managing studies of byproduct markets for waste, much of his earlier work at EPRI, as well as at Southern California Edison Co. from 1972 to 1978, concerned waste disposal technology.

Gellings

Maulbetsch

Jones Childs



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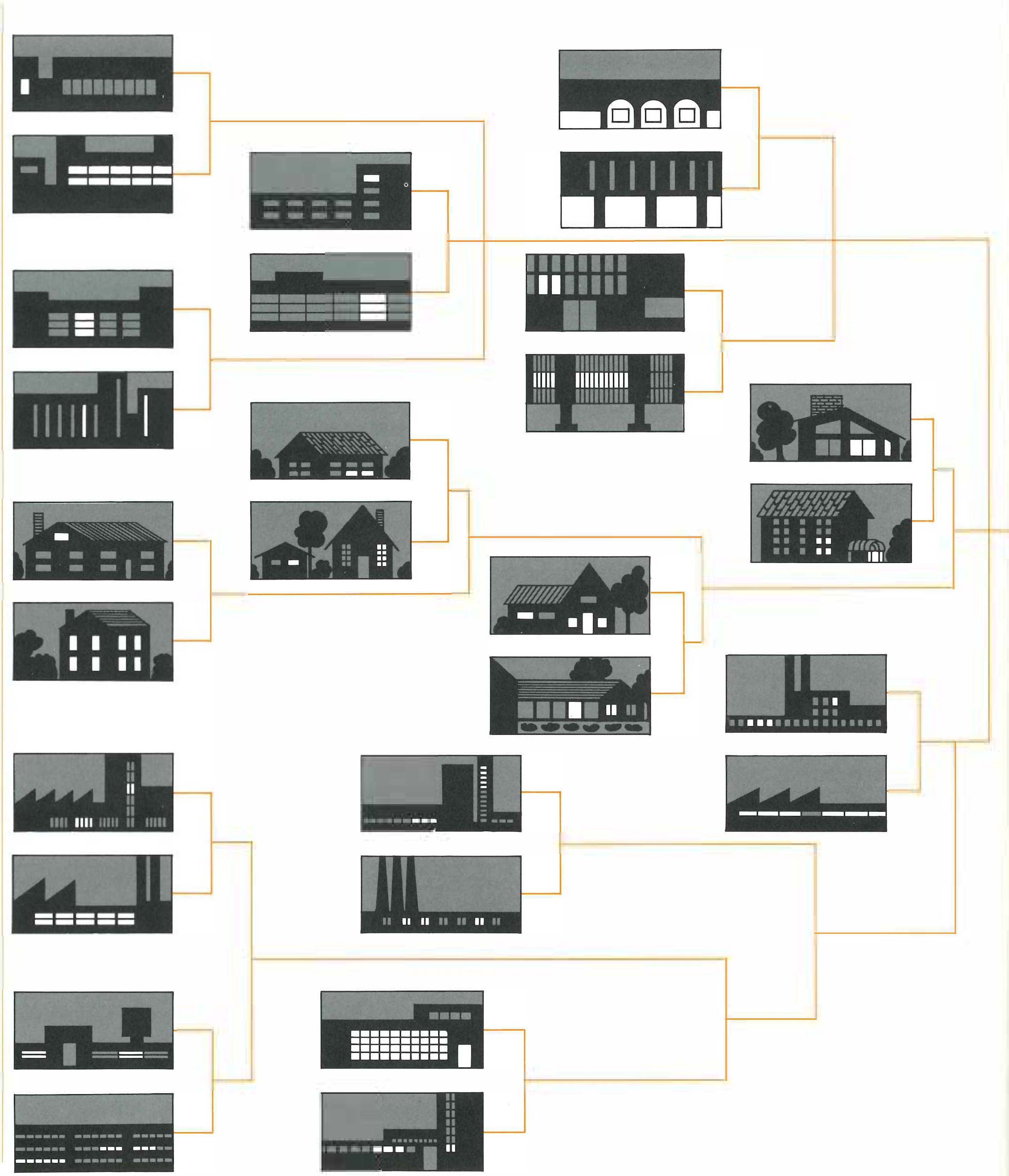
Komai



Forecasting the Patterns of Demand

The tools and techniques for forecasting utility load are evolving rapidly under the pressing need for accuracy and load management. Models that aggregate demand by end use and incorporate elements of economic behavior hold considerable promise for utility planners.

Consider that you are a utility planner struggling with the decision whether to build a new 1-GW baseload plant—what information do you need? You need a reliable forecast of the long-term demand for electricity in your service territory.

If you are trying to make immediate decisions about how much fuel to order or when to schedule maintenance, a reliable short-term forecast will be required.

If you want to know how much reserve capacity to have on hand for a surge in electricity use during an especially hot summer, the answer can come from yet another projection: a forecast of peak, or maximum, demand on the system during that time.

And if you are looking at conservation and load management as alternatives to capacity expansion, you can use a more detailed scan of the peaks and valleys of customer demand to see where such measures might be effective. What you want is a forecast of your system's load shape—by the season, the week, the day, or even by the hour.

EPRI's Demand and Conservation Program, headed by Clark Gellings in the Energy Analysis and Environment Division, is now in the midst of a major effort to develop improved methods that will assist utilities in generating more accurate forecasts for their own service areas. In addition, the aim is to see how and to what extent the data collected in one service territory may be applicable to another. Establishing the transferability of certain kinds of data for forecasting purposes can save utilities a great deal of duplication in both time and money.

The forecasting climate

Energy forecasting as a discipline has been forced to evolve at a vigorous pace over the past decade. "Back in the sixties," says Gellings, "you plotted a few points on a piece of paper and trended them out, using simple regression techniques to fit a curve. There seemed to be no limit to energy growth then." But these straight-line extrapolations of historical energy consumption trends that had served well enough for the years of steady prices and steady growth became inadequate with the onset of inflation during the late 1960s. Nor could these simple techniques cope with variations in growth rates among the different energy-consuming sectors of the economy.

Fortunately, some within the utility industry had anticipated the need for more sophisticated forecasting methods and were already at work on approaches that, for example, looked at demand and sales versus energy prices. Explicit recognition that the demand for energy was also dependent on other factors, such as income, weather, and the economy, lay behind the serious efforts that began in the late 1960s to model those relationships as a basis for forecasting. Modeling efforts accelerated when the Arab oil embargo of the early 1970s brought a sharp break in historical patterns. Clearly, knowing how much energy Americans had consumed in the past no longer offered a simple linear guide to knowing what they would consume in the future under drastically altered conditions of price and availability.

At the same time that forecasting grew more difficult, the consequences of forecast errors grew more serious. In the past, overestimates of future energy demand were quickly made right by demand growth, and the worst consequence was temporary excess capacity that was soon absorbed. Underestimates were not critical either, because turbine generators fired by cheap oil or gas could plug the gap while new baseload plants were coming on-line.

Today all this has changed. An overestimate can lead to the authorization of a baseload plant that may not be needed for several years, turning it into a financial burden for the utility that must bear the costs without offsetting revenues. An underestimate may be even worse, since it takes 8–10 years to license and build a coal-fired baseload plant and longer for a nuclear plant. Meanwhile, meeting its load may force a utility to use oil- or gas-fired turbines that are now expensive to operate, or to purchase similarly expensive power through pooling arrangements with other utilities. If a condition of undercapacity is allowed to exist, voltage reductions, localized brownouts, or even blackouts can occur.

The result is a bind for the utility planner. Squeezed between the dual threats of over- and undercapacity, the planner needs accurate forecasts more than ever. To understand how models are used in forecasting, we have to look at some of the approaches that represent today's state of the art.

Modeling assumptions

Human needs ultimately drive the demand for energy. For example, a homeowner who needs space cooling buys an air conditioner, which will consume a certain amount of electricity in a certain pattern. The retailer who sells the air conditioner uses electricity to light his store, and the appliance manufacturer uses electricity in various manufacturing processes. All this use is ultimately rooted in the individual's desire for cooling.

Economic analysis assumes that the individual's energy use reflects not only his personal needs but also his income and the level of energy prices. Individual needs are regarded as a given and held constant during the period of analysis as income and price are varied. The assumption is that demand is primarily responsive to changes in income and price.

To get from the energy consumption behavior of a specific homeowner or company to the behavior of the residential, commercial, or industrial sector as a whole, economists go through a process known as aggregating, or combining, individual consuming units. The aggregation can take a number of forms. When aggregate data are employed for large groups, the assumption is that these consumers are similar in certain important ways; if that assumption is incorrect, the aggregation step can lead

UNDERSTANDING

ELA

Price elasticity of demand is an economic concept that has gained wider currency as recent events have underscored a basic realization: When it comes to the purchase of energy, as with any other commodity, price matters. Rising prices can and do dampen the demand for energy.

Elasticity is expressed as the ratio of two percentages—in this case, the change in the quantity of electricity demanded divided by the change in price. For example,

$$E = \frac{\%\text{ change } Q}{\%\text{ change } P} = \frac{-1.0}{10.0} = -0.1$$

Note that the elasticity here is a negative number, indicating that a price rise has a negative impact on consumption. In contrast, if the relationship being explored were the responsiveness of electricity demand to a rise in consumer income, the elasticity would typically be positive. The more affluent consumer generally buys more electricity, and the same consumer may buy even more as his income goes up.

Given the probable direction (+ or −), what about the extent of a price or income impact? The number conveys the extent (0.1). And although

STICITY

the elasticity concept can range from zero to infinity, any given value must fall into one of three discrete categories. Proper terminology describes electricity demand as inelastic when the number is less than one. It is called elastic only when the number is greater than one. A special case is the unitary elastic value that is equal to one.

In the example given above (−0.1), the relationship between electricity demand and price would be termed inelastic despite the fact that demand is actually showing a response to price. "The fact that only one category of elasticity is actually called elastic leaves plenty of room for confusion," comments Braithwait.

Another source of confusion, according to Braithwait, is the mistaken treatment of elasticities as if they could stand alone, out of context. In fact, a price elasticity figure indicates what demand will do in response to price only when all other factors are held constant. "And as you go out into the future," he observes, "price is not the only thing that's changing."

Other factors, notably income and prices of other fuels, such as natural gas, will no doubt rise, mediating the electricity price impact on demand. That is why steadily rising prices will reduce demand a lot less than some expect, no matter how high prices go. So price elasticities alone, although necessary, are not sufficient for forecasting energy demand.

Further, there is no single elasticity for a given relationship, such as the price-demand relationship. To determine the price elasticity of electricity demand in a given situation, one needs to specify the place, the season, the type of customer, and a number of other variables before a sensible answer can be calculated. As Braithwait points out, no elasticity is a universal constant.

A major application of price elasticity estimates is to assess the impact of a price change on an electricity supplier's revenues. In theory, if demand is elastic (>1.00), a 20% price increase will cause the quantity demanded to fall by more than 20%, meaning that revenue will fall as well. If demand is inelastic (<1.00), a 20% price increase will bring a rise in revenues. This rise will be less than 20% unless demand is perfectly inelastic (0.00)—that is, totally unresponsive to price.

These are theoretical numbers, but history bears out the very real impact of price increases on energy and revenues. The estimated impact of alternative electricity price elasticities on the sales of a New Jersey utility showed that rather small, inelastic elasticities (−0.05 and −0.15) can make a noticeable dent in utility revenues.

In 1975 the New York Telephone Co. was granted a price elasticity adjustment to help compensate for sales lost as a result of higher rates. Since then, other utilities have applied for such adjustments with varying degrees of success. The ability to forecast price elasticities and to justify these forecasts has become a vital part of utility ratemaking procedures.

Faruqui quotes economist Paul A. Samuelson to show the changing attitudes toward price elasticity. In 1947 Samuelson dismissed elasticities with the comment, "Their importance is not very great except possibly as mental exercises for beginning students. . . " By 1981, however, his tone was different: " . . . When a regulatory commission lets a public utility raise its prices in order to cut down on losses, the elasticity of demand concept has to be crucially involved." It seems that in a climate of continuously rising energy production costs and energy prices, the elasticity concept, understood or not, will play a major role in regulatory pricing decisions. □

to flawed forecasts. Aggregation can also be applied to commodities. For example, electric resistance heaters, heat pumps, and forced-air gas furnaces may all be aggregated as space heating equipment.

Electricity is a single homogeneous commodity. But the great variety of its consumers and its end uses, from running a home TV set to melting scrap steel in an industrial arc furnace, creates a great variety of dissimilar demands. With a commodity of this sort, it is often useful to move initially in the other direction—to disaggregate, or separate, the different demand patterns and see how each one operates.

It is standard practice, then, to disaggregate electricity use by consuming sector (residential, commercial, industrial). And the current emphasis in the Demand and Conservation Program is to disaggregate it even further by end use within sectors to allow a closer look at the ways in which electricity is used. Such disaggregation allows a better understanding of the manner in which the residential demand for cooling energy, for example, may differ from the demand for heating energy or the demand for cooking energy.

One popular method for end-use forecasting is called the engineering approach, which uses so-called physically based end-use modeling. The focus is on the physical stock of energy-using equipment—for example, the projected number of electric dishwashers in American homes. Taking this number and multiplying it by a projected utilization rate yields a forecast of total electricity use by home dishwashers. This figure is then added to similarly derived figures for other major electrical appliances used in the home, from air conditioners to electric ranges, to arrive at an aggregated forecast of electricity use for the residential sector as a whole.

Now that conservation has become a concern, physically based end-use models routinely include the energy efficiency of each appliance as an important variable in forecasting energy consumption. Because of their hardware emphasis, such models are especially well suited to looking at the impact of improved technology on energy consumption. But a straightforward engineering approach that focuses only on physical factors can miss the emergence of new end uses and miss some other very important effects, such as the impact of rising energy prices as a stimulus to conservation.

Consequently, a major trend in energy forecasting is the effort to integrate into end-use models the behavioral element characteristic of what is known as the econometric approach. (The word *econometrics* refers to the use of mathematical and statistical methods in the field of economics.) A behavioral or econometric model of electricity demand forecasts consumption in terms of consumer response to economic variables, such as price and income. It is assumed that all consumer behavior can be represented by an econometric model. A wide choice of variables can be included in such a model, from local employment levels to the gross national product.

Bringing together the physical factors and the behavioral factors in a single model allows a more comprehensive grasp of the many diverse influences that shape the demand for energy.

New models

EPRI's Demand and Conservation Program has sponsored the development of one of the first hybrid econometric end-use models to be used for forecasting residential electricity demand. It is called REEPS, for residential end-use energy planning system.

Consistent with the end-use approach, REEPS itemizes the major household appliance activities, such as space heating and air conditioning. It predicts both consumer appliance choices and energy consumption resulting from the use of appliances. These appliance purchase and utilization decisions are related to price and income variables, and the exact structure of these relationships is estimated econometrically from individual household survey data. The aim is to capture the benefits of a forecast that is detailed down to the level of individual appliance use without ignoring the important economic factors that can be critical in shaping consumer behavior.

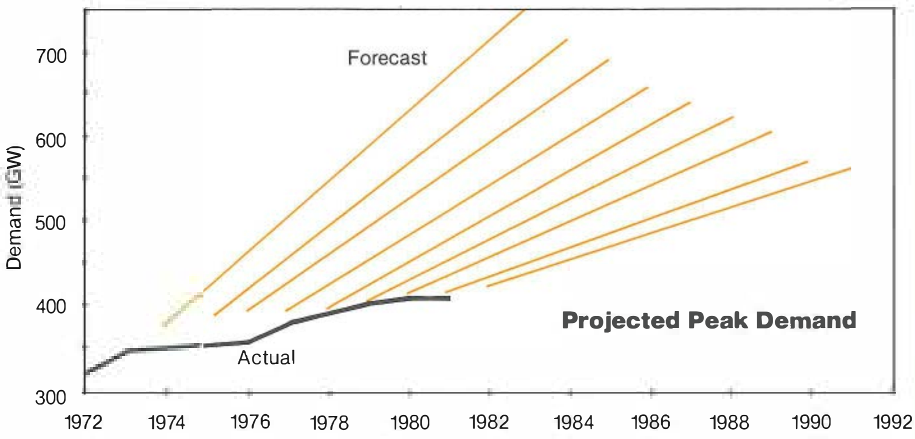
One of the innovative features of REEPS, notes Steven Braithwait, project manager, is the method used to develop forecasts. Termed microsimulation, it involves simulating the behavior of a representative sample of households for the particular region under study. Each sample household is characterized by data on socioeconomic attributes (e.g., family size, income), number and type of appliances, size and type of dwelling, and the various geographic and economic features of the region.

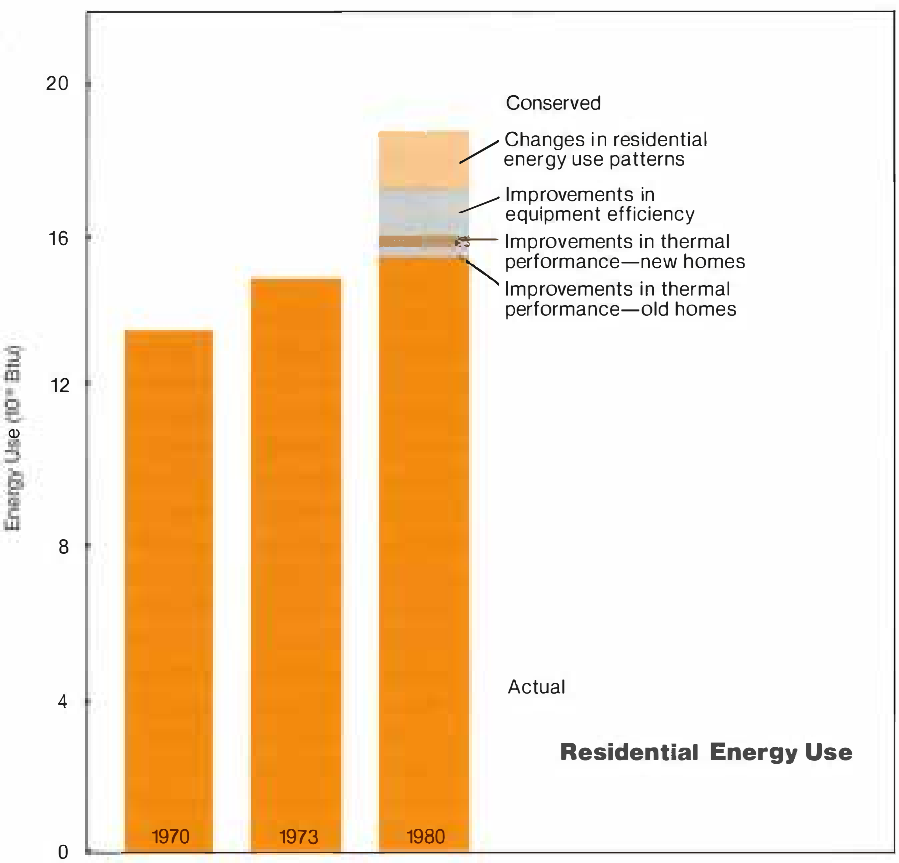
Given this setting for decision making, the household makes its appliance investment choices. These choices will depend on the household characteristics already established, as well as on weather and energy prices. For example, a high-income family is more likely than a low-income family to purchase central air conditioning, and living in a hot climate with relatively low electricity prices will reinforce this choice.

The next step is to predict how much energy a household will use, given its appliance stock. This amount will be the product of two distinct but closely related decisions.

The household first selects the appliance's operating efficiency as part of the initial purchase decision. After the unit is installed, modifying its efficiency may be difficult or impossible. But household members can still decide how intensively to use the appliance, a decision shaped by socioeconomic and geographic features of the household, as well as by the operating costs of the appliance itself. When the efficiency and utilization decisions are combined, the result is the amount of energy that the appliance will consume.

The need for greater accuracy in energy demand forecasting is evidenced by the annual reduction in the North American Electric Reliability Council's compilation of the 10-year forecasts of peak electric energy demand in the conterminous United States. This departure from the historical trend has been caused by increased energy prices, a general slowdown in the economy, and a reduction in energy use.





A study by Oak Ridge National Laboratory indicates that U.S. residential energy use in 1980 was 15.5 quadrillion Btu, up only 3% over that in 1973, despite a sizable increase in household formation and a minor increase in household income. Oak Ridge estimates that this was 3.4 quadrillion Btu, or 18%, less than what would have been consumed in 1980 if price conditions and the economy had not abruptly changed in the early 1970s. The components of U.S. residential energy conservation are also shown.

Total consumption is forecast by multiplying the individual household predictions by the relative frequency with which each household type occurs in the population and adding the results. This composite picture of the full spectrum of consuming households offers a far more richly detailed view of energy consumption patterns than a forecast based simply on the homogenized average household (as is the case in simple engineering approaches).

Because of this structural detail, REEPS is a powerful tool for examining not only the total impact of increased prices or utility conservation programs but also the impact on specific segments of the population—say, on households in the annual income range over $25,000 or on households of five or more people. The model can estimate not only how much energy is being consumed but who is consuming it and for what purpose. Further, because the model combines the advantages of the end-use and econometric approaches, it can assess both mandatory conservation effects, such as those that are built into the efficient new appliances, and the more elusive effects of conservation incentives, such as federal tax breaks, that rely heavily on consumer choice.

Initially developed for use at the national level, the model has been scaled down for application to regional or utility forecasting. Early results from the Pacific Northwest are encouraging—the relationship between purchase price and operating cost in determining household appliance investments there looks quite similar to the relationship on a national scale, suggesting that it may not be necessary to reestimate the entire model to make it fit smaller geographic units.

Transferability of analyses and data from one utility service area to another is being explored. For example, current work with time-of-day electricity pricing is examining how consumer response to these rates varies across different areas of the country. If responsiveness turns out to be about the same everywhere, or if it is different but depends on certain measurable variables, the results of a study in one service area can be applied (with adjustments if necessary) to planning decisions in another. This can save utilities considerable effort and expense. Two other projects already under way deal with transfer of data among utilities.

Time-of-day rate studies provide input to models that can forecast hourly load shapes, and a model for forecasting hourly loads systemwide over the long term is now under development. Project Manager Ahmad Faruqui points out that traditional practice has been to forecast annual sales and peak loads separately, then impose them on a suitable historical load shape, modifying the load shape if necessary. Because of recent discontinuities in historical patterns, though, such a forecast procedure has not been well suited for applications involving rapid price escalation or the emerging emphasis on conservation and load management.

In contrast, the new model builds an hourly load shape from the ground up by the aggregation of projected end-use profiles. It is explicitly designed to trace the implications of developments brought on by rising energy prices, such as new energy management strategies and end-use technologies. The model is also capable of accounting for the load shape impact of changes in sociodemographic factors, economic activity, weather conditions, and the stock of energy-using equipment.

The REEPS hybrid model and the new load shape model built on end-use profiles are representative of the kind of work that is being done as modeling grows more sophisticated and more precise.

Modeling applications

How are the new modeling methods being used to address utility forecasting needs?

The emphasis on forecasting detailed load shapes springs from the current utility priority on conservation and load management programs as an alternative to capacity expansion and to reduce operating costs. Part of the reason for this priority is the current climate of financial and regulatory constraints surrounding utility construction. Just as important, though, are continuing questions about the pace and extent of long-term load growth.

Among the many questions lingering on the long-term forecasting horizon is the impact of customer-generated electricity, especially industrial cogeneration, on utility sales. Contrary to many other forecasts, results from a model developed in the Demand and Conservation Program suggest that the impact will be small. What the results show, according to Project Manager Larry Williams, is that despite the growth in total electricity generated by industry in recent years, the percentage of industrial electricity consumption that is customer-generated is declining and will continue to decline throughout this century.

The issues here involve not only technical and economic feasibility but also the dynamics of business decision making. A follow-up model explicitly includes the inhibiting effects of risk and uncertainty on industries' decisions regarding cogeneration investments in specific installations. In Williams's view, such a model brings increased realism to cogeneration forecasting. "It quantifies risk and uncertainty," he says, "to separate the probable from the potential."

The demand impact of new electricity-based technologies is another question for the long term. There is an emerging consensus that the U.S. manufacturing sector will respond to lagging productivity and fossil fuel supply uncertainties by a market-driven program of electrification. A major gap in our understanding of the impact of this trend occurs with respect to the identification of the specific technologies likely to play a major role. The Energy Management and Utilization Division has a subprogram in place to address the hardware

TWO APPROACHES

Most energy use is modeled from one of two prevailing viewpoints: the physical or the behavioral. One approach focuses on the physical stock of energy-using equipment, while the other emphasizes economically motivated consumer choices.

A simple equation that typifies the first approach may be expressed as

$$E = S \times N \times P \times H$$

where

E = energy consumption of the appliance in kWh
S = saturation in number of such appliances per customer
N = number of customers
P = power required by the appliance in kW
H = hours of appliance use

The second approach takes the following form.

$$E = f(X, Y, Z)$$

where

E = energy sales or peak demand
X = independent variable, such as consumer income
Y = independent variable, such as the price of electricity
Z = independent variable, such as the price of competing energy sources

This equation says only that electricity demand is a function of certain other variables. Unlike the appliance-oriented equation, which will yield a numerical result, this one is just a preliminary to forecasting. Actual forecasts rely on quantification of the relationship among the variables and the value of each variable. □

issues surrounding this new area. With its help, a technical planning study is now under consideration to develop a framework for analyzing which electrification technologies will be cost-effective in industry. The long-term implications of a switch to electricity-based technologies could be substantial.

In addition to these developments on the long-term forecasting scene, the utility need for efficient cash management has created a stronger emphasis on short-term forecasting. In the 1–12-month timeframe, the applications are varied: When is the best time for scheduled maintenance? When should the new stock issue be released? On the other hand, in the 1–5-year timeframe, the most important application is rate determination.

"Using a forward test year rather than a historical test year can ease the problem of regulatory lag," Williams points out. This practice of using forecasts instead of historical data as a basis for ratemaking is becoming more and more common, and a credible, accurate forecast helps in the acceptance of this approach. Williams predicts that a new short-term forecasting model still on the EPRI drawing board will offer utilities a quantum jump in forecasting capability.

Four building blocks will go into creating the new model. The first will be adjustment of anticipated sales for weather changes, especially seasonal changes. The second will be data on the short-term impact of utility conservation programs. The third will be input on short-term price and income elasticities. And the fourth will be the use of innovative mathematical or statistical tools known as adaptive time-series techniques for the analysis of historical data on electricity use. These very powerful techniques are new in their application to energy forecasting.

Outlook for forecasting

Progress in supplying accurate, reliable forecasts has been substantial over the past decade. In contrast to the simple straight-line trend extrapolation methods of the past, today's forecasting models weigh the impact of such diverse influences as prices, incomes, weather, appliance or equipment stocks, and the sociodemographic features of the consumer.

But the energy modeler's discipline is still young. Given all the choices that go into selecting the variables to be modeled, the type of data to be used, and the statistical techniques to be applied, it is not surprising that the results generated by different models often disagree. Informed decision making based on modeling results must recognize the uncertainty inherent in the projected values of the variables assumed to determine energy demand, as well as the uncertainty in the model's representation of the structural relationships among these variables.

"We need to reduce the uncertainty in forecasting if we can," asserts Gellings, and the Energy Analysis and Environment Division is helping to develop methods to use this knowledge of uncertainty in the decision-making process. "That's one thing. The other thing is that our forecasting methods have become terribly data-intensive. Maybe there's an easier and therefore cheaper way to do it. We need to keep looking at this."

Meanwhile, models are being honed to serve a widening spectrum of specific needs. Forecasts that once tended to be global and long term have become more carefully focused, more detailed, and shorter term as the new forecasting methods have zeroed in on such emerging utility priorities as conservation, load management, rate relief, and improved cash-flow budgeting. Scaling down forecasting techniques for use in individual service territories is a part of this trend, as is the effort to establish transferability of procedures and data from one service territory to another.

The new energy modeling techniques may seem esoteric, even to many within the utility industry, but forecasting models are finding a growing range of eminently practical applications. ■

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This article was written by Mary Wayne, science writer. Technical background information was provided by Clark Gellings and the staff of the Demand and Conservation Program, Energy Analysis and Environment Division.

Utilities know the electricity market inside and out: what they sell, who they sell to, how it's sold, and how it's delivered. If present trends continue, they may become adept in another market as well, selling the by-products of coal-fired power generation—fly ash, bottom ash, boiler slag, and scrubber sludge—for use in highways, parking lots, cement, roofing, bricks, and blocks.

Altered circumstances

Many utilities have been marketing their by-products for some time. A sizable 13.3% (6.4 million tons in 1980) of all fly ash and 29.5% (4.3 million tons) of all bottom ash produced is either sold (most of it to the construction industry) or used by the utilities themselves. Whatever is left is disposed of, usually at the power plant site. But lately, new incentives have prompted more utilities to take a more active interest in the by-product business. Under the Resource Conservation and Recovery Act of 1976 and the Clean Water Act of 1977, EPA drafted tough new regulations for solid-waste storage, transportation, and disposal. The power plant wastes that once cost a few dollars a ton to dispose of may soon cost up to \$25–\$40 a ton to dispose of.

While disposal is getting more complicated, there is increasing reliance on coal to counter the economic difficulties that are confronting oil, gas, and nuclear plants, and with more coal plants, more coal combustion wastes are inevitable. Meanwhile, because of progressively stricter air quality standards, more-efficient environmental control equipment is scavenging more coal combustion wastes. Utilities are producing more and more power plant waste, and it is becoming increasingly difficult and costly to dispose of it.

Marketing Coal Ash, Slag, and Sludge

More coal-fired power plants are coming on-line, disposal regulations are tightening, and environmental control equipment is increasingly efficient. The result: more coal ash, slag, and sludge to dispose of—and a harder time doing it. Many power plant by-products are now being sold for construction material, but applied research can help utilities market even more.

One logical solution to the expanding waste problem is to turn more of the waste into a resource. Fly ash can be used for structural fill and cement; bottom ash can be used as a paving base; some scrubber sludge can be used for soil stabilization; the gypsum produced by other scrubbers can be used for wallboard. There are many other uses for power plant wastes, and at some future date, aluminum, iron, and other marketable metals might also be salvaged from ash and slag. By recovering these wastes—or by-products, depending on one's point of view—and putting them to good use, disposal costs can be eliminated or minimized, disposal permit requirements reduced, and less land devoted to disposal. Further, there can be financial returns from by-product sales.

Most utilities are already involved in by-product utilization to some extent. They frequently use coal ash in roads and structural fill at power plant sites. Some utilities, however, are more active in marketing their by-products to outside customers. Tampa Electric Co. in Florida,

Power plant by-products are used in a variety of cement products. Fly ash in particular has good cementitious qualities and is widely used in making cement and as a cement additive. Many dams (such as the Hungry Horse Dam in Montana and the Dworshak Dam in Idaho) and buildings (such as Chicago's Prudential Building and Sears Tower) include fly ash in their concrete. Bottom ash is used in cinder blocks and lightweight aggregate; boiler slag is used in concrete blocks.

for example, does not dispose of any fly ash. Whatever ash is not sold to the construction industry for use in concrete is reinjected into the furnace to produce slag, and the slag is made into sandblasting grit, aggregate, and roofing granules. Detroit Edison Co., in the fly ash business since about 1932, uses most of its fly and bottom ash for internal construction projects, sells some of it for use in concrete products, and disposes of the remainder. Houston Lighting & Power Co. sells fly ash from its coal-burning units for use in soil stabilization, ready-mix concrete, and chemical fixation of municipal waste.

Yet for every utility that actively markets its coal ash and slag, there are many more that do not. One fundamental reason why utilities and their potential customers hesitate in the marketplace is the composition of the by-products themselves. The type of coal burned, the design of the boiler used, the variations in operating conditions, and even the methods used to handle and collect the wastes can all affect product composition.

For some applications, by-product composition does not matter: gritty bottom ash controls ice on roads despite the particulars of what coal and which boiler were used to produce it. But for other applications, composition is important. In the cement business, for instance, the incorporation of certain fly ashes in concrete can produce undesirable effects, so some cement manufacturers are reluctant to add fly ash to their formulas. Even if potential customers are willing to give utility by-products a chance, established specifications (such as those set by state departments of transportation for highway construction) may not include the use of utility by-products.

Still, with proper quality control, power plant by-products can be successfully used in many applications, including cement manufacturing, and by-products are, in fact, included in numerous specifications. Many utilities with active marketing programs have quality control programs, conducted either by their own staff or by marketing agencies. At Houston L & P, for example, fly ash is sampled and tested three times a day to ensure that it meets ASTM standards for ready-mix concrete. Ash, slag, and sludge characteristics can also be controlled to some degree by tightly regulating coal, boiler, and firing conditions, and some utilities do this for by-product customers. Because the primary business of utilities is electricity generation, plants are not routinely adjusted to produce specific by-product grades, but several utilities do notify customers of varying plant conditions, such as startup and shutdown, which can affect by-product characteristics.

Utilities and prospective customers must also consider the potential effects of by-product availability on the by-product market. When a plant shuts down for maintenance or repair, its output of coal combustion by-products ceases. Any resultant shortage may be a problem for customers and could discourage them from using the by-products. It is usually not practical to adjust plant operation simply because customers are awaiting a by-product shipment, but some utilities resolve the problem by offering by-products to interested customers on an as-available basis.

Storage and transportation are additional requirements that make utilities think twice about the by-products market. If customers for ash and slag are not immediately at hand, perhaps due to a seasonal slack in the construction industry, the by-products have to be stored until buyers arrive, and storage costs the utility money. If there are no local buyers, the cost of transporting ash and slag to distant customers can make by-product utilization unprofitable. Not surprisingly, many power plants in areas of healthy construction activity (Florida and Texas, for instance) are able to sell much of the by-product they produce, while plants in economically stagnant or remote areas may have to struggle for customers.

Utilities contemplating by-product utilization also have to consider their competition. Cement companies, for example, frequently operate their own clay, sand, and gravel pits. It takes a good product at a good price to tempt a road builder or cement company from its established supplier. Yet if there is little competition for supplies, a utility may realize a favorable return for its by-products.

There are also the ever-present institutional considerations. To break into the by-products business, a utility has to develop a marketing capability distinctly different from the one it uses to sell electricity. In the midst of this unfamiliar territory, contract terms and payment schedules have to be set, product liability dealt with, and the staff to handle the utility's by-product business hired. The majority of utilities that sell by-products retain marketing firms to handle the details, as is done at Tampa Electric and Houston L & P. Other utilities have assigned their own internal departments to the job. Detroit Edison's purchasing department, for instance, is directly responsible for by-product sales, while the company's engineering and production departments are closely involved in ash management.

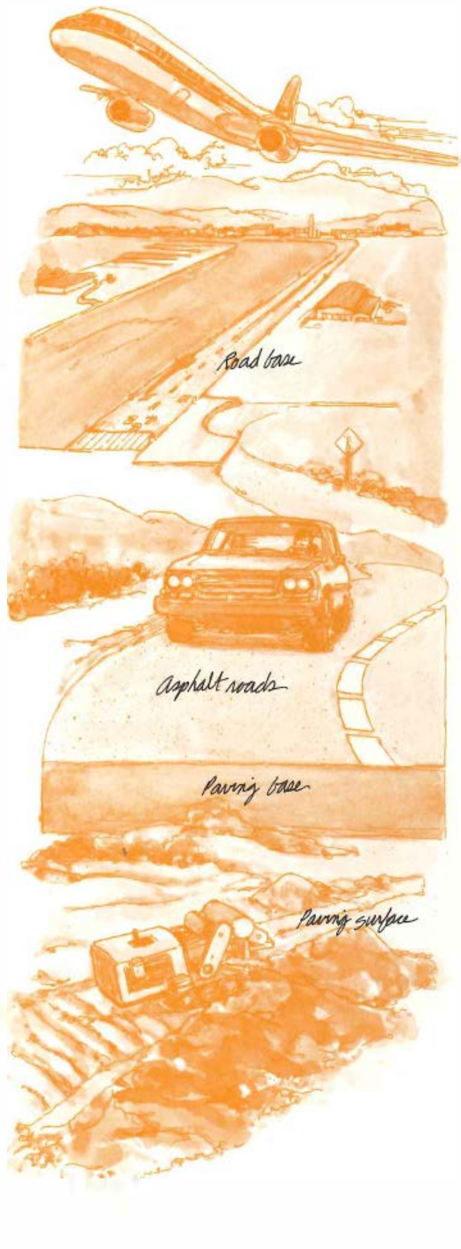
To market, to market?

There are payoffs and pitfalls in power plant by-product utilization, and a utility has to assess both carefully before venturing into this new market. About two years ago, EPRI's Heat, Waste, and Water Management Program, Coal Combustion Systems Division, decided to thoroughly document and assess the markets for fly ash, bottom ash, boiler slag, and scrubber wastes. According to Program Manager John Maulbetsch, utilities needed additional information on the quantities and characteristics of by-products, the effects of regulatory and institutional factors, the influence of marketing factors, and the impact of storage and transportation costs. Areas where further research was needed also had to be identified.

An exploratory study was carried out by contractor Michael Baker, Jr., Inc., and by early 1983 the results will be published in EPRI's by-product utilization manual. Along with basic information on the economics and technology of by-product utilization, the manual will also include a step-by-step methodology that a utility can follow to get a good estimate of whether it should consider marketing its ash and slag. The utilization manual is a companion to earlier EPRI manuals on the disposal of coal ash and sludge. Says Project Manager Ralph Komai, "Together, these manuals give each utility the basic information necessary to develop its own waste-management strategy."

The methodology in the utilization manual compares total utilization costs with existing or anticipated disposal costs that the utility would otherwise have to pay. Since the details of any utilization program largely depend on by-product characteristics, the first step in the methodology is to characterize the by-product. This requires an inventory and analysis of all large-volume by-products—their amount, type, and physical and chemical characteristics. The manual will discuss each of these categories and will include a list of standard tests for the physical and chemical characteristics required for each use. For example, ash for covering landfills probably only has to be tested for compaction and pozzolanic characteristics, while the evaluation of ash for ready-mix concrete includes tests for moisture content, water requirements, shrinkage, and certain chemical constituents.

If by-product utilization looks promising on the basis of this first broad analysis, the utility proceeds to consider its marketing options more specifically. Every likely market area must be evaluated on a local basis. The utility will have to define a realistic market area boundary, identify recent market trends, ponder market projections, collect information on conventional material requirements and prices, and locate specific potential customers. Once products have been matched with markets, effort is turned toward assessing marketing strategy: development of a pricing structure, promotion of the product, and establishment of distribution channels.



Roads, pavements, and parking lots are another category of applications for coal combustion by-products. Fly ash is used in road bases and asphalt roads; in fact, the runways and taxiways at the Newark, New Jersey, airport have fly ash in them. Bottom ash is used as aggregate in paving bases, and slag is used in paving bases and surfaces. Numerous states permit the use of by-products in highway construction.

Power plant by-products appear in many other construction applications besides cement products and roads. Fly ash, bottom ash, and slag are frequently employed as structural fill. Fly ash is also used in grout, sanitary landfill cover, and asphalt roofing; bottom ash is used in bituminous mixtures; slag is made into roofing granules. Gypsum from certain scrubbers can be made into wallboard.

When the utility has better defined its targeted market, it can begin to consider an operations plan: how the by-product is readied for marketing and how it reaches the selected market. Preparation includes by-product collection at the plant, on-site conveyance, and on-site storage. Modifications may be needed to maintain consistent by-product quality, depending on the ultimate customer. For example, bottom ash might have to be dewatered in dewatering bins before it is marketable as a de-icer. As for the by-product's final trip to market, utilities may have to allocate loading devices and carriers, as well as scales, ticket houses, quality control equipment, and laboratory facilities, to accomplish the job.

At this point in the methodology, the utility has to make a hard-nosed cost comparison. Current and projected disposal costs are weighed against utilization costs, revenues, and disposal reduction, and the utility makes the decision to dispose of, use, or sell its ash, slag, and sludge. The utilization manual will use as a case study Long Island Lighting Co.'s Port Jefferson station. The two coal-designed units at this station are currently burning oil, so no coal combustion wastes are produced at this time. But by 1987 the utility is scheduled to convert these units to coal. Accordingly, Lilco tried the methodology discussed in the forthcoming manual to evaluate by-product utilization prospects.

As prescribed, Lilco identified a number of promising by-product markets for the fly and bottom ash that the converted units will produce. The likely markets include ready-mix concrete, asphaltic concrete pavements, and ice control. The utility then followed the manual's methodology to develop an economic analysis of by-product utilization and disposal costs. The analysis covers a range of ash utilization from 0 to 95%.

Lilco found that increasing levels of utilization could considerably extend the remaining lifetime of its disposal sites—from 11 years with no utilization to 15 years with 25% utilization to more than 20 years with 50% utilization. With no utilization, annual disposal costs (in levelized 1982 dollars) would be $3,094,300; for 15% utilization, $2,903,500; for 95% utilization, $1,788,300. The cost of utilization for each year was estimated at $343,200, which includes the cost of the trucks, hoppers, and other equipment that the utility would have to invest in to carry out a utilization program.

Lilco also considered how much money would be saved by having fewer tons of waste to dispose of. For example, if the station could sell its by-products at $10 a ton and use 25%, it could save $191,500 a year (with the basic $343,200 cost of the utilization program deducted and deferred disposal costs and utilization sales revenues added in). If the by-products could be sold at $5 a ton, again at 25% utilization, $76,500 a year would be saved. But if the by-products were merely given away, again at the 25% utilization rate, the utilization program would actually cost the utility $38,500, with the cost of the utilization program exceeding deferred disposal costs.

To make utilization economically viable, the utility would have to give away about 28% of its by-products, or sell about 20% of its by-products at $5 a ton, or sell about 16% of its by-products at $10 a ton. All these numbers are strictly site-specific; each utility following the methodology will find different economics in different situations. Not only can utilities use the methodology to evaluate prospective or expanding utilization programs, but they can also use it to determine the economic success or failure of ongoing programs.

Promoting the product

If a utility decides that it should sell its power plant by-products, it is still only halfway to market. Many prospective customers may be unaware that ash, slag, and sludge are available materials with many applications. On the basis of new data, industry specifications may need to be revised to include power plant by-products. Because the utilities, the customers, and the groups that set specifications must all be convinced of the value of by-products to make further market penetration possible, EPRI's R&D is aimed at answering the questions of all these groups, and research results will be distributed to all groups as well.

Two new EPRI project-planning studies are a positive start in this direction. The first study, recently begun and due to be concluded by the end of 1982, deals with high-volume by-product applications that have low technology requirements—specifically, fly ash for use in highways, parking lots, and utility construction. According to Project Manager Dean Golden, the study will select several promising demonstration areas (those with high by-product production, low utilization, and good market potential) and then approach a utility, a prospective user, and the local state department of transportation and confer with all three to determine if a demonstration would lead to increased by-product utilization. Where this is so, such demonstrations will be considered, and EPRI hopes that through them, potential customers and state departments of transportation will recognize that plant by-products can make good building material. Where industry specifications do not include power plant by-products in various applications, new data may provide the basis to revise specifications as needed. EPRI will coordinate these efforts with the National Ash Association (NAA).

The second project-planning study, expected to begin in 1983, will consider medium-volume, medium-technology applications, including by-products used for cement manufacture, asphalt, blocks, bricks, roofing granules, and wallboard. The approach will be similar to the first study, again relying on the possibility of demonstrations, as needed, to show the applicability of these by-products. One top R&D item in this project will be concrete mixes. EPRI plans to eventually identify a representative set of perhaps half a dozen basic fly ashes, characterize them, do proportion studies of existing concrete mixes (including those with fly ash in them), and then develop guidelines for fly ash proportions in concrete. There are many knowledgeable groups involved with the cement and concrete industry, including the American Society for Testing and Materials, the Portland Cement Association, the American Concrete Institute, and the National Ready-Mix Concrete Association, and EPRI hopes to involve them in this research.

EPRI cooperates with other groups in the utilization field as it continues in its efforts to provide both utilities and their customers with the technical information they need on by-product utilization. NAA, for example, has both utilities and marketers as members and promotes ash utilization through such efforts as its Sixth International Ash Utilization Symposium, which was held in March 1982, and a workshop in fly ash utilization, which was held in November. NAA also acts as a clearinghouse for information on coal ash use. The Utility Solid-Waste Advisory Group, an ad hoc group formed by the Edison Electric Institute, has a committee on resource recovery and utilization that reviews pending regulations for potential impact on utility by-product utilization and supplies information and comment to EPA on by-product utilization. EPRI works closely with these groups in the planning of EPRI programs and in the dissemination of results.

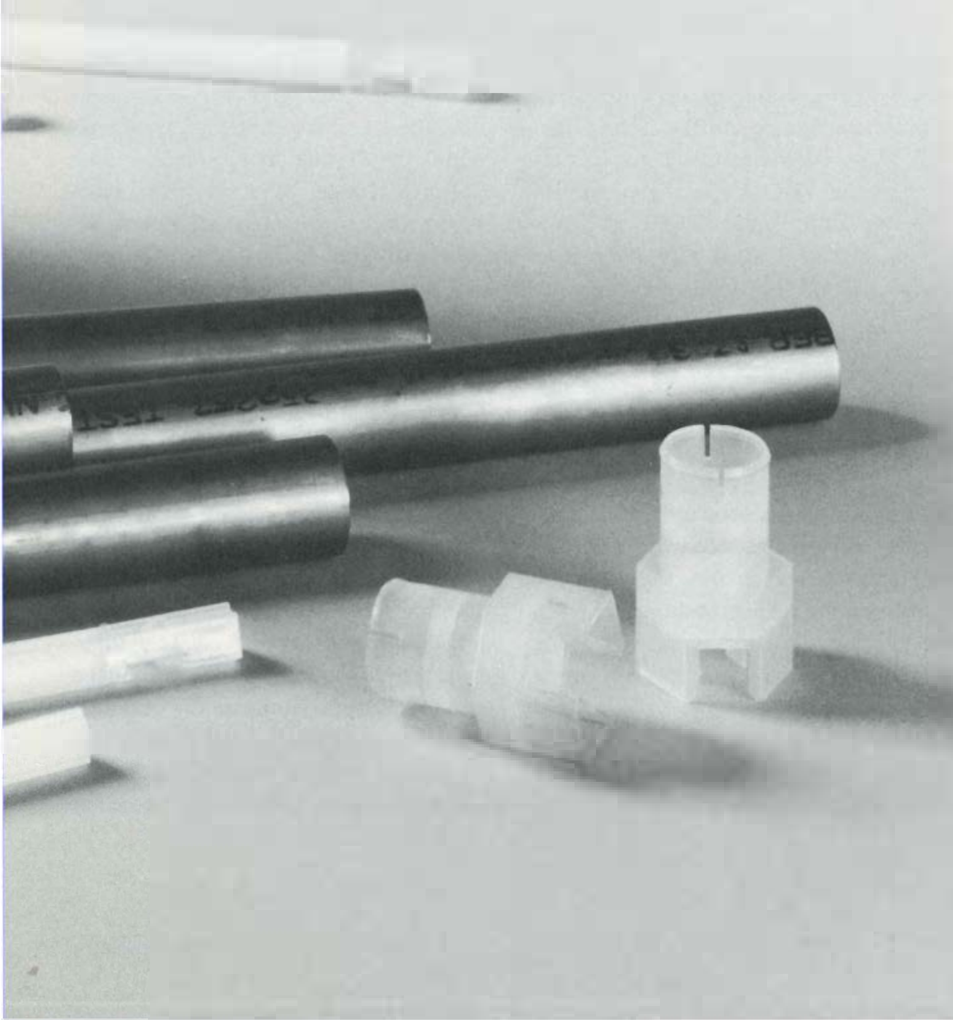
Entry into the by-products market requires thought, planning, and preparation. Many utilities need to know much more about the market before they will consider entering it, and many potential users need to become better acquainted with utilities' by-products before they will consider using them. But in many cases, a utility and a user will find each other. With continuing research and information exchange, many more utilities will have an alternative to disposal. ■

This article was written by Nadine Lihach. Technical background information was provided by Dean Golden, Ralph Komai, and John Maulbetsch, Coal Combustion Systems Division.

The construction industry is not the only one that finds coal combustion by-products useful. Fly ash makes a fine mud for lubricating oil well drilling equipment. It is also handy for FGD sludge fixation and as an FGD sorbent in power plant air pollution control systems. In winter, gritty bottom ash and boiler slag are sprinkled on roads and sidewalks to control ice; slag is also good as a sandblasting grit. And in the future, advanced techniques might permit aluminum and iron to be recovered from coal ash.

THE NEW BOND

Driving metal surfaces together at speeds approaching Mach-3 creates a bond superior to conventional welding. Using an array of charges exploded sequentially, this technique is being used to kinetically bond hundreds of tubes to a condenser tubesheet in an instant.



Somewhat like postal clerks stuffing envelopes into the mail slots of a large post office, two workers stand before the tubesheet of a power plant condenser. They are inserting not letters but explosives into each of 500 or so holes that dot the tubesheet in neat, regular rows. They work quickly, slipping the plastic cups containing explosive pellets into the holes, which open into thin-walled 1-in (25.4-mm) tubes that extend horizontally 50 ft (15 m). Within an hour 500 tubes are stuffed with explosives, ready to be detonated. The area is cleared, and in less than one noisy second the explosives expand in the tubes, bonding them to the tubesheet with 500 identical high-quality welds.

The operation is called kinetic bonding, a technique that may have found a new application in welding condenser tubes more quickly, cheaply, and effectively than conventional techniques. The new technology is being pursued in an EPRI project with the help of engineers from Lockheed Missiles & Space Co., Inc. "Several large utilities are considering using kinetic bonding as part of their condenser retubing in the next 18 months," says Wylie Childs, manager of the bonding project for EPRI's Nuclear Power Division.

With kinetic bonding, engineers at EPRI and Lockheed are combating the problem of leaking tubes and corrosion in power plant condensers and heat exchangers. The typical steam condenser is enclosed in a shell fitted at either end with tubesheets varying in thickness from 1 to 1.5 in (25–38 mm). Some 50,000 tubes, each about 50 ft (15 m) long, extend through holes in the tubesheets at each end. Cooling water from a nearby lake, river, ocean, or cooling tower passes through the tubes and cools steam that enters the condenser through an opening at the top of the shell. After cooling, the condensate is cycled for reuse.

A vital link in the power plant, the condenser ranks in importance with the boilers and the turbine itself. If the condenser tubes leak, however, the condenser becomes a source of corrosion, causing contamination of the entire plant. For when condenser tubes leak, such impurities as chlorine and sulfur compounds from the cooling water are pulled into the plant's circulating steam loop. Even in the minutest amounts, these impurities can contribute to turbine disk cracking, steam generator denting, and other costly damage.

Leaks can occur in two ways in the condenser: through penetrations in the tube walls and through poor joints between the tube and the tubesheet. Until recently, most tubes were made of brass or other copper alloy and tubesheets were of rolled brass or Muntz metal, so through-wall corrosion has been a major problem in many utilities. "With these materials," explains Robin Jones, program manager for plant structural materials in EPRI's Nuclear Power Division, "you can have the best tube joints in the world, and still get huge amounts of leakage through the tube walls." Through-wall leakage has been largely eliminated in recent years by retubing with metal alloys that are highly corrosion-resistant, such as stainless steel or titanium. The kinetic bonding project at EPRI addresses the second major source of leakage: tube-tubesheet joints.

Conventional and innovative procedures

When most power plants were built, a technique called rolling was the standard method for making tube joints. In this procedure, an air-operated mandrel mounted with from three to five rollers is inserted into the condenser tube and forced to rotate; the slight taper of the mandrel pushes the rollers out against the inside of the tube with enormous force, causing the tube to expand against the tubesheet. As a cold-working technique, rolling joins the metals mechanically by establishing a residual force/stress that holds together the tube and tubesheet rather than welding or fusing them metallurgically.

Another technique is tungsten inert gas welding. In this process, an electric arc is created between a tungsten electrode and the parts to be welded (in an inert atmosphere) to produce a strong, ductile, corrosion-resistant weld. In the past 10 years, according to Childs, this conventional welding method has become one industry standard for joining tubes to tubesheets in condensers, especially when titanium is used. This welding procedure can be done in all positions and is easily observed because no smoke or fumes block vision. Metal near the weld is only slightly distorted, and because the heat is concentrated in a small area, stresses are minimized.

An important advance over rolling, conventional welding is still not entirely satisfactory as a method of segregating heat exchanger fluids because the weld it creates is short—a mere 0.04 in (1 mm)—and is sometimes susceptible to gaseous and surface impurities. Electron-beam welding, laser welding, or other esoteric methods that use the narrow heat source necessary for longer welds require very complex equipment and procedures.

Kinetic bonding appears certain to provide a better bond than either conventional welding or rolling. It produces a relatively long bond, requires no special atmosphere, and permits bonding of materials that otherwise could not be reliably joined. With a new firing system under development at EPRI, it also permits multiple bonding of hundreds of tubes and tubesheets nearly simultaneously.

To bond two metals kinetically, a layer of explosives is placed on one metal surface, which is separated slightly from the other surface. An explosive detonation accelerates the first metal, forcing it to collide under high pressure and at high velocity against the second. Kinetic energy becomes heat, melting the thin metal surface for the millisecond during which the explosion occurs. If it goes off at the right angle and speed, the detonation ejects this molten metal in a thin jet that moves out in front of the weld. As a result of shock waves, the jet creates a rippling effect, deforming the base metal in a series of sine wave patterns. Maximum waveform amplitude produces maximum bond holding power.

Without the cleaning action of the jet, the metallurgical bond would not occur. In a brief instant, the jet removes the thin layer of oxides and other contaminants that covers the metals and hinders any welding operation. Interatomic contact is established between the metals in two ways: first, by breaking up and eliminating the surface contaminants, and second, by exerting enormous pressure on the metals and forcing them together at high velocity.

Kinetic bonding was first recognized as a potential industrial process in 1957 and was successfully developed as a cladding technique. It is used commercially to weld very simple flat and cylindrical surfaces in large-plate cladding and in welding tubes to relatively thick, sturdy tubesheets in heat exchangers other than condensers. The technique has also been used to plug faulty heat exchanger tubes in conventional and nuclear power plants.

There are difficulties, however, that have prevented its commercial use in condensers. Condenser tubesheets are thinner than the tubesheets in other heat exchangers and are therefore more susceptible to the distorting effects of the explosive charge. Especially vulnerable are the condenser tubesheet ligaments, those small areas about 0.25 in (6.35 mm) thick that remain between the holes drilled in the tubesheet. If the tubesheet is made of a soft copper-based material and the ligaments are relatively thin, the explosion can push the ligament out and shrink the size of the surrounding holes, making them more difficult to weld. The challenge is to design the explosive charge so that it makes a proper weld without also distorting the surrounding metal.

Another challenge is to position the weld exactly at the front face of the tubesheet, where cooling water is introduced into the tubes, to eliminate the potential for crevice corrosion. For it is here, and not on the side where steam is condensed, that corrosion is most likely to occur;

Hundreds of tubes can be bonded to the condenser tubesheet in one firing. After the tubes are inserted into a tubesheet where holes have been reamed to provide space for the flight of the deforming tube, an explosive package is carefully inserted into the end of each tube. (1) These plastic packages contain nitroguanidine and transfer charges positioned so the explosive wave moves from the inside out. (2) The packages are then connected by firing rails that provide the detonation path. The packages explode about 7 μs apart; as a result, each explosion makes a bond in one hole while counteracting the distortion wave arriving from an explosion in an adjoining hole. (3) At the line of impact, the kinetic energy becomes heat, melting the surface layers. A jet of molten metal moves ahead of the explosive wave, cleaning the surface and forming a sinusoidal bond.

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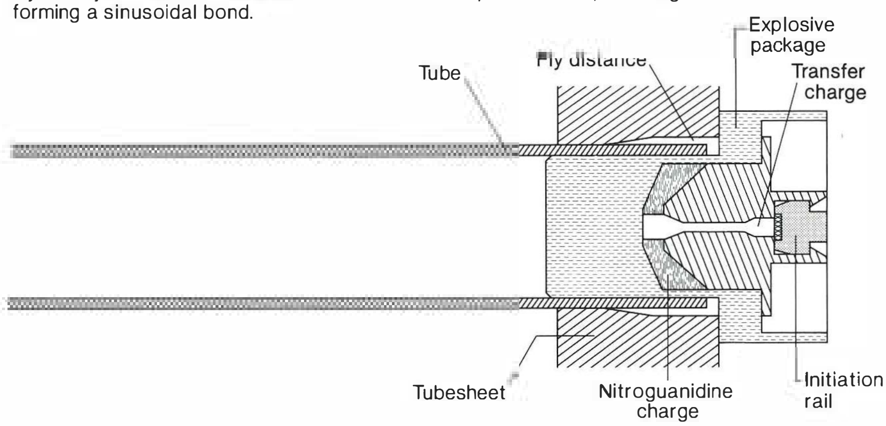

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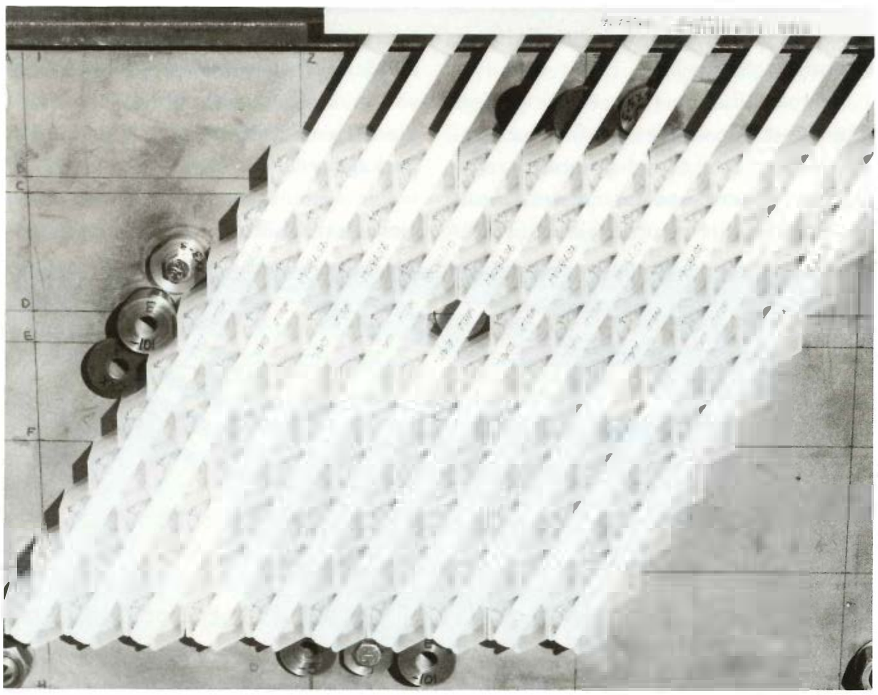

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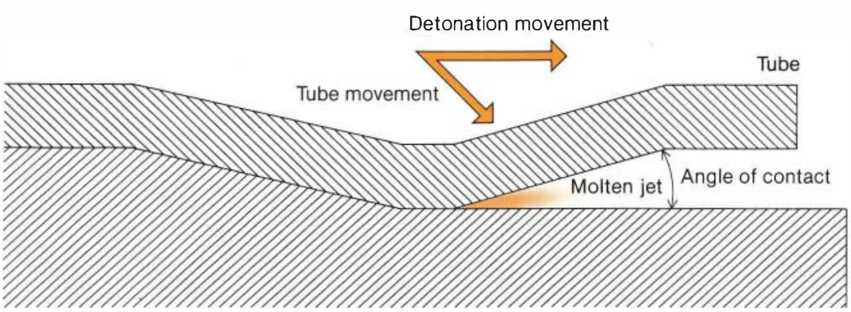


deposits that precipitate from the cooling water tend to collect at weld sites, where impurities or imperfect welds offer a toehold for corrosion. If even minuscule holes develop in the joint, the vacuum on the steam side of the condenser will steadily suck contaminated water into the plant's recirculating steam loop.

Making the bond

As with all bonding techniques, the kinetic bonding process starts with drilling of the tubes and the tubesheet. The holes are then reamed and counterbored slightly at the front face of the tubesheet so that when the tubes are inserted, a small gap remains between the tube and the tubesheet. This gap is the crucial "fly distance," which gives the detonation a chance to accelerate the tube against the hole interior for an effective bond. The tubes are then inserted into the holes so that their ends are even with or extend a few millimeters beyond the tubesheet face.

The EPRI-Lockheed design calls for a large number of identical explosive packages that fit into the condenser tubes at the tubesheet face. Each package consists of a small cup filled with approximately 3 g of the secondary explosive and a header section, which encloses the cup and holds it in place. The bottom portion of the header is cylindrical to fit into the tube, but the top portion has a hexagonal configuration so that each package will fit snugly against its neighbors on all six sides. Lines of adjacent packages are connected to one another by parallel rows of initiation rails, each of which carries a strip of secondary explosive along its length. A single firing rail is attached to all the initiation rails. When the firing rail is ignited by a single explosive cap, the secondary explosive carries the charge along the initiation rails to the explosive packages in a split-second sweep. The firing ejects the packages at the front, and there is no need to clean the tubes after firing.

The explosive package itself is made of polypropylene plastic, formed in one operation by injection molding. The explosive charge in the cup section is U-shaped; when the explosion from the initiation rail reaches the header, it is transferred straight down to the bottom of the U and then propagates out along the legs. The charge thus reverses its direction once it is in the explosive cup, and moves from about 0.25 in (6.35 mm) inside the tube outward toward the front face of the tubesheet. At a velocity of 20,000 ft/s (6000 m/s), the explosive mushrooms in each package, one explosion precisely timed to follow another as the detonation wave moves down the initiation rails. In less than a thousandth of a second, several hundred welds, each 0.25 in (6.35 mm) long, are formed between the tubes and the tubesheet.

Design improvements

The new package and ignition designs solve several problems previously encountered with kinetic bonding. For example, a single explosion strong enough to bond a condenser tube may also be strong enough to distort an adjacent ligament. But if the explosions are ignited simultaneously to avoid this distortion, they could create stress damage in the tubesheet.

Lockheed's answer was to stagger the explosions by a small fraction of a second so that one explosion counteracts the distorting effect of the one next to it. Successive explosions push the ligament from opposite sides; before the explosion in one hole has time to permanently distort the adjoining ligament, the explosion in the next tube occurs, limiting any movement of the intervening ligament. Only the ligaments surrounding the entire area being bonded suffer some distortion, unless the surrounding tubes are temporarily plugged before the process begins.

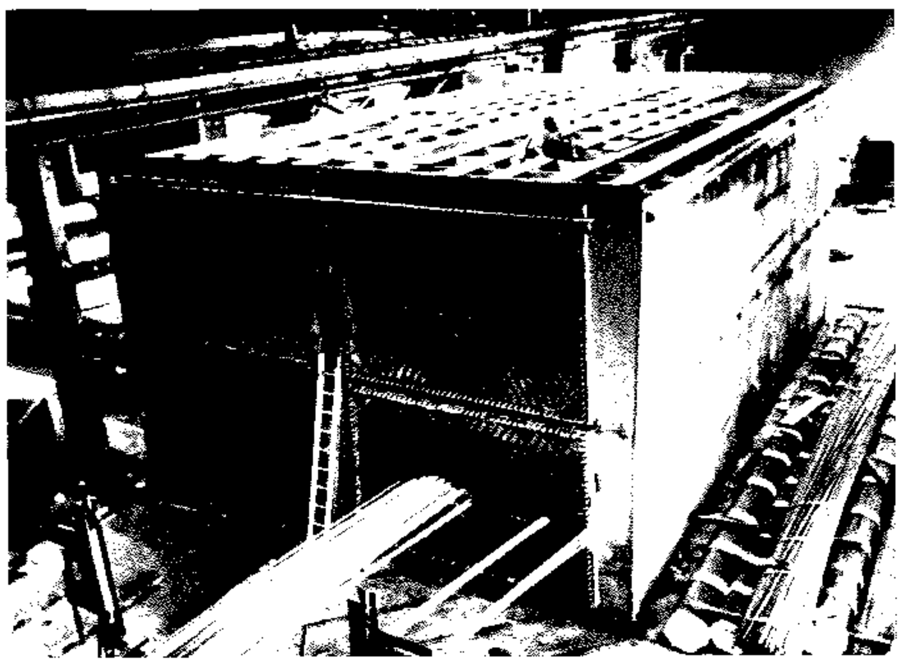
Lockheed engineers solved another technical problem by reversing the direction of the explosive detonation inside the package. Because the explosion moves from inside the tube outward, the combustion gases accelerate toward the tube opening and exert their greatest force on the water side of the tubesheet. Thus, by reversing direction, the charge makes the tightest bond where the joint is most susceptible to impurities. "It took a good deal of design work," admits Childs, "to achieve a charge that would reverse itself and move from the inside out."

Choice of materials was also critical to the process design. The polypropylene used for the explosive package and ignition rails is a widely used, inexpensive plastic that can also be readily machined to accommodate design refinements. For this project, a highly reliable explosive was needed. Nitroguanidine was favored because it is readily available, consistent from lot to lot, and extremely resistant to accidental ignition. Project engineers worked to get just the right weight, density, and geometry for the explosive to produce the best weld with the minimum amount of charge.

For the initiation train, the engineers considered Primaline, an inexpensive commercial detonating cord suitable for single detonations, but this material was quickly shown to be unreliable and difficult to handle in batches of 100 or 1000. Similar problems led engineers to reject a bridgewire initiation system and turn to Detasheet, a fairly inexpensive, waterproof material that can be easily cut into thin, lightweight strips. This explosive is readily stored and has a shelf life of at least five years.

"Project engineers have tailored the explosive charge to tube-to-tubesheet bonds in condensers," explains Childs. "In the process, they've found there is a relatively large margin of error that makes kinetic bonding much more attractive than we thought it might be. No one had been able to work with these thin tubesheets before without distorting the ligaments between the tubesheet holes. That's one of our major accomplishments."

Even if the fly distance was several times greater than it actually is, for example, the new explosive package would still make the kinetic bond. In addition, the extreme uniformity of the explosive package results in high reliability for the whole system. Managers of the project aim at a reliability rate of only one failure



Steam condensers for power plants comprise an array of some 50,000 tubes fitted at either end with tubesheets. The tubes are conduits for water from a nearby body to pass through and cool the steam. Leaks at the tube-to-tubesheet joints can open the way for contaminants to enter and corrosion to occur throughout the entire plant.

per 10,000 firings. "What we expect the failure to be is a nonignition, which is easy to detect," explains Robin Jones, "because a firing automatically ejects the explosive package; any failed packages would remain in the tubes."

Appraising the process

Kinetic bonding has other advantages over conventional welding or rolling in addition to higher reliability. The conventional welding process must be carried out in a special atmosphere of inert gas, which displaces air to avoid contaminating the weld with oxygen and nitrogen. Providing this inert atmosphere consistently is a difficult procedure, and the welding process only works for certain combinations of metals. Rolling, too, is ineffective with certain metal combinations and is difficult to use when the tubesheets are made of lower-strength metals than the tubes. Some tubing metals, such as titanium, may become brittle from excessive cold working when rolled a second time, so repairs of rolled joints can be difficult.

Kinetic bonding avoids these problems. Both stainless steel and titanium can be kinetically bonded to copper-based materials, such as aluminum-bronze, copper-nickel, and Muntz metal, from which tubesheets are still made. "If for financial reasons a utility wants to change to more durable tubes but retain its old copper-based tubesheets, it still has the option of getting a very good bond by using kinetic bonding," says Childs.

Another advantage of kinetic bonding is the ease with which it can be carried out. Unlike conventional welding, kinetic bonding does not call for specialists to make the weld. A team of two workers should be able to install at least 2000 explosive packages in a single work shift and fire the packages off between shifts. Conventional welding takes about a minute per weld, or about one work shift for 200 or 300 tubes. Comments Childs, "With multiple kinetic bonding, we have a potential bonding rate that is far higher than that of conventional welding."

Although still fairly expensive, the kinetic bonding technology developed by EPRI may soon have a cost advantage. Rolling has always been inexpensive, but conventional welding currently costs about $7 per weld, which boosts the cost of welding 50,000 tubes to about $750,000—about 5% of the cost of the condenser. Childs projects that once the explosive packages are fully tested and marketed, their total cost, including installation, firing costs, and profit margins for the manufacturer, will come to about $5 per package, less than the price of conventional welding. This cost reduction is based on projected economies of scale: The polypropylene and explosive materials cost just a few pennies per package, and wide adoption of the new technology by U.S. utilities would encourage manufacturers to develop the tooling necessary for low-cost production.

The biggest advantage of kinetic bonding may turn out to be the superior bond it produces. Rolled joints can deteriorate as the tubes expand and contract in response to normal temperature variations. Although superior to rolling, conventional welding produces very short welds that do not always remain leak-tight. Tests using kinetic bonding technology to join tubes to tubesheets have shown that this technique produces a bond that is from 5 to 10 times as long as conventional welds, which should give a much longer life.

The future of the technology

With these advantages, kinetic bonding could become an accepted procedure in assembling condensers and other heat exchangers. EPRI has demonstrated the new technology in several small-scale tests using single and multiple bonding, and it plans to test bond 1000 tube joints in a prototype within the next few months. Childs and his colleagues are now discussing use of the process for retubing condensers in nuclear plants with several major utilities. It is very possible that such a retubing will proceed within the next 18 months.

But the problems of condenser tube leakage extend beyond a few isolated plants. Jones estimates that at least half the power plants in the United States suffer from condenser failures, and these failures are costly. First, there is the direct cost of repairing, replacing, and plugging faulty tubes. It may take from a day and a half to three days of downtime to make such repairs. During this time, the plant must buy expensive power from other sources to satisfy normal demand. Unscheduled outages cost the electric power utilities in the United States several hundred million dollars each year.

Second, poor reliability of the condensers and auxiliaries in nuclear and large fossil-fired plants results in a 3.8% loss of unit availability. According to Jones, "Any factor such as condenser failure that causes several percent of downtime is a very big problem." And this 3.8% for condenser repair does not include another, hidden cost—downtime caused by corrosion or failure in other parts of the plant as a result of leaky condenser tubes.

Utilities have been working hard to avoid these costs by replacing copper-based tubes with more corrosion-resistant metals. The search for better condenser joint bonds has become the new challenge. Kinetic bonding, as Jones notes, has been made economically attractive as a way of bonding the 50,000 tubes of the typical condenser. The new technology may at long last provide utilities with a tube joint that helps to triple the life of condensers from about 10 years to the full life of the power plant. ■

This article was written by Carrie McKee, science writer. Technical background information was provided by Wylie Childs and Robin Jones, Nuclear Power Division.

Aiding the Di

Many utilities are now using manuals that guide the decisions surrounding the desi

Billions of dollars have been spent by the utilities for devices and systems to collect particulate and gaseous wastes from the stack discharges of coal-fired power plants. One way to view the effectiveness of these control efforts is by the scope of the secondary problem they have created: the annual storage and disposal of more than 70 Mt of fly ash, bottom ash, boiler slag, and sludge.

Ash and slag are by-products of the burning of coal. Fly ash is particulate matter carried off in the gas stream from a furnace; it is composed of noncombustible minerals found in coals. Bottom ash comprises the heavier ash particles that collect at the bottom of a furnace. And if removed in a molten state and quenched in water, this heavy ash is called slag. Total ash content of coal varies from 3% to 30%, depending on coal type. Typically, about 80% is fly ash and 20% bottom ash.

Sludge is the residue from various processes used to remove sulfur dioxide from flue gases. The two major scrubbing systems currently in use—lime/limestone/alkaline scrubbers and double-alkali scrubbers—employ water, in conjunction with the lime, limestone, or other chemically reactive compounds, to wash sulfur dioxide from the flue gas stream. The residue from these scrubbers is sludge—water plus dissolved and suspended solids (predominantly calcium sulfite, calcium sulfate, and, sometimes, fly ash).

It is estimated that over a projected 30-year operating life, a 1000-MW coal-fired power generating plant will produce 9.6 million yd^3 (7.3 hm^3) of fly ash and bottom ash (based on operating at 70% average capacity, burning 2.6 Mt/yr of coal with 12% ash, a fly ash–to–bottom ash ratio of 80/20, and 99% efficient fly ash collection). This is enough to cover 1000 acres with a 6-ft (1.8-m) layer of waste material.

As part of its solid-waste disposal program, EPRI has developed several manuals expressly designed to bring together information that will help utility engineers and cost analysts with disposal systems application. The manuals will be especially helpful to those individuals who may lack training and experience in the chemical and civil engineering aspects of waste management.

The emphasis in the manuals is on practical methods the engineer can use to select, design, and operate economical and effective disposal systems that conform with applicable regulations and that promise reliable performance over the long term. These are workbooks in every sense of the word—they pinpoint and analyze decision-making factors, specify and assess technical and cost criteria, and discuss probable ramifications of governmental regulations.

The *Coal Ash Disposal Manual* (CS-2049, prepared by GAI Consultants, Inc., Monroeville, Pennsylvania) is a comprehensive reference work that covers all aspects of the removal and eventual disposal of fly ash and bottom ash. It includes site selection criteria; the physical, chemical, and engineering properties of

P P L I C A T I O N

posal Engineer

d operation of solid-waste disposal systems. Some have documented cost savings.

ash; and the design of conceptual systems. Economic analyses and examples are presented in detail, including a description of a computer program, ASHDAL, which was developed to calculate the levelized annual cost of various ash disposal alternatives. The different kinds of utility ownership, capital requirements, operating costs, land acquisition costs, and system maintenance costs are also discussed. Some success in using the manual has already been documented. Carolina Power & Light Co. credits the *Coal Ash Disposal Manual,* as well as other EPRI leachate studies and reports, with helping to resolve a ponding problem, and it anticipates levelized annual savings in revenue requirements of $2.1 million.

EPRI's *FGD Sludge Disposal Manual* (CS-1515, prepared by Michael Baker, Jr., Inc., Beaver, Pennsylvania) presents comprehensive processing and disposal guidelines for utility operators of lime, limestone, alkaline fly ash, and double-alkali wet scrubbers. Sludge composition and quantity, disposal system alternatives, site selection criteria, the computer cost-estimating program SLUDGECOST, the design of disposal areas, and regulatory requirements are discussed in detail. Case histories summarize the experience of some utilities in making site selections and in obtaining necessary permits. A prominent architect-engineer firm made an economic evaluation of the sludge manual and concluded that its proper use at a 500-MW (e) coal plant could save the operating utility $1.5 million per year. In this same vein, the Tampa Electric Co. projects annual savings in revenue requirements of $124,000 as a result of using the *FGD Sludge Disposal Manual* to select the "most economical and best engineered" disposal system for its Big Bend 4 plant. (A new edition of the sludge manual will be released soon; it has been renamed the *FGD By-Products Disposal Manual,* to reflect the added coverage of dry scrubber waste management.)

The *Manual for Upgrading Existing Disposal Facilities* (CS-2557, prepared by SCS Engineers, Long Beach, California) provides step-by-step instructions for the utility engineer who must upgrade existing waste disposal sites to bring them into conformance with newly applicable governmental regulations.

EPRI's principal objective in compiling and presenting the information contained in the disposal manuals was to make it useful to the utilities in general and to utility engineers with system design responsibilities in particular. That its objective was achieved is evidenced by widespread and continuing utility interest and by the successful application of the manuals in solving practical waste disposal problems in ways that fulfill regulatory obligations and save money. ■

This article was written by Lloyd Popish, science writer. Background information was provided by Dean Golden, Coal Combustion Systems Division.

Banking on Energy Development

Helping to raise the standard of living in developing countries is the aim of the World Bank, an international financial institution that channels funds for economic development programs from the developed to the developing countries of the world.

Recognizing that electric power can stimulate economic growth, the World Bank is engaged in a significant program of energy development loans to assist the developing countries of the world. Increased availability of electric power is crucial to these countries, where today only 25% of the inhabitants have access to electricity. And in some areas, this figure drops to a mere 4% of the population.

Partly because of the imbalance in electricity availability, the World Bank devotes about 26% of its total loans to energy development, or $3.4 billion for the fiscal year that ended June 30, 1982. As this amount indicates, the World Bank recognizes the impact that high energy costs have on the economies of the developing countries. It therefore makes financial resources available to countries classified as developing—those with a per capita gross national product (GNP) below $2650 (1980 dollars).

The current emphasis on energy loans is a logical extension of the original purpose of the World Bank, which is headquartered in Washington, D.C. With the objective of improving economic productivity and thus the standard of living in the developing world, the World Bank was established in 1945 as the International Bank for Reconstruction and Development (IBRD). With its capital subscribed by 144 member countries, of which the United States is the largest contributor (21%), IBRD finances its lending operations primarily through its own borrowings on capital markets, retained earnings, and loan repayments. IBRD loans are specifically directed toward those developing countries considered to be in more advanced stages of economic and social growth, such as Indonesia and Brazil, and are generally repayable over a period of 17–20 years with an interest rate commensurate with IBRD's cost of borrowing.

To direct assistance toward those even less financially secure than the IBRD countries, the International Development Association (IDA), an affiliate of the World Bank, was created in 1960. IDA countries must have an annual per capita GNP of less than $731 (1980 dollars), such as Bangladesh and Pakistan. There are close to 50 countries that are eligible for IDA credits, which are usually repayable over a 50-year period at no interest, except for a small surcharge. Over 80% of IDA loans go to nations with an annual per capita GNP of less than $360.

There are also "blend" countries that may apply for financing from either IBRD or IDA. India, for example, is unique in this regard because it has received both IBRD loans and IDA credits. As one of the largest industrialized nations in the world, it is considered credit-worthy by IBRD on the basis of its balance of payments. However, India is also one of the poorest nations in per capita GNP and under this criterion is eligible for IDA credits as well.

Assisting Energy Growth

The World Bank's emphasis on energy development has increased appreciably

Fish Davis

over the years—from 14.8% of the bank's total loans in the 1976–1978 period to 25.8% in 1982. Of the 44 new energy projects approved for FY82, 21 involved electric power and received loans totaling $2.1 billion; 14 entailed oil and gas for loans of $539 million (8 projects for predevelopment work and 6 for development). In addition, 3 coal projects were approved for $227 million, and 6 were approved in other project areas, including refinery conversion and energy conservation, for $460 million.

A relatively new program area, oil and gas, involves World Bank–financed projects in predevelopment work, as well as in exploration. In selecting projects to spur this development, the World Bank seeks to identify potential sites for predevelopment (including technical assistance, geologic and geophysical surveys, and exploratory or appraisal drilling), development, and production.

Since its inception, the energy program has financed 18 petroleum projects in 16 developing countries. Nine projects involve predevelopment work; the other 9 are for production activities. The projected economic rate of return on oil and gas development is high—between 30 and 50%.

In Argentina and Peru, World Bank–financed predevelopment work includes seismic surveys to create opportunities for exploration by a domestic oil company or in cooperation with one from another country. By financing geologic and geophysical surveys in developing countries, the bank seeks to generate accurate information to attract international risk capital for exploration or to enable national oil companies to initiate well-prepared drilling programs. In exploring coal options, the bank has sent engineering missions to interpret and review the coal sectors in 10 developing countries.

Electric Power Projects

Of all the energy development programs, those related to electric power receive the greatest amount of financing—about two-thirds of the energy budget in FY82. "If you look at the 100 or more countries that make up the developing world by the bank's criteria, the investment needs in electric power over the next 10 years are on the same order of magnitude as the U.S. investment program in electric power—somewhere around $500 billion. So you can see that we have a major problem ahead of us," emphasizes James Fish, power adviser in the World Bank's Energy Department.

There are currently about 150 electric power–related projects under World Bank supervision throughout the developing world. And from FY1981 through FY1985, the bank plans to lend about $13 billion for energy projects, of which about 58% will be devoted to electric power.

In the past, the World Bank has placed funding priority on projects concerning the generation, transmission, and distribution of electric power. To improve its transmission and distribution network, in 1981 Indonesia received bank financing amounting to $170 million. Construction work will include some 1210 km of overhead lines, 1336 substations, and a large number of transformers. The loan also included financing for consultants to find ways to enhance the use of coal for power generation. The World Bank has made 10 power development loans to Indonesia, totaling $1.1 billion.

In 1978 the bank's funding moved in the direction of distribution and rural electrification. For example, the bank loaned the Philippines $60 million toward a $160.5 million rural electrification project to provide about 500 towns and 8540 villages with reliable electric power. The objective of the Philippine government is to bring electricity to the entire Philippine population by 1990. The project is directed toward construction of new transmission and distribution lines; radio communication and other equipment; and electric motors, pumps, and machinery for load promotion. The project will benefit 5.3 million people and create about 12,000 jobs in the Philippines.

The World Bank's power loans have been concentrated on hydroelectric power projects, which take advantage of indigenous resources to reduce reliance on imported oil. In 1980 the bank approved a $125 million loan to assist Honduras in the financing of the El Cajon hydroelectric power project. The total cost of the plant is estimated to reach $582.7 million, and because of its regional interest, it has attracted cofinancing from several sources, including the Inter-American Development Bank and the Venezuelan Investment Fund. It is expected that the plant will produce 1051 GWh of energy in a dry year and 1348 GWh as an average annual output.

In the future, the bank plans to promote financing for projects aimed at improving efficiency and loss reduction. "Increasing the efficiency of existing plants becomes a key objective, particularly as the generating capacity matures in these developing countries," Fish states.

Project Selection Cycle

Requests for project support can originate from a developing country or from the bank itself. But no matter the origin, and whether for an IBRD loan or an IDA credit, the proposed project is subject to a comprehensive review process called a project cycle. The cycle consists of six stages: identification, preparation, appraisal, negotiation and approval, implementation and supervision, and post-project evaluation. From inception to completion, a project's life is usually about 11 years.

Of primary importance is the financial soundness of the requesting country. "The borrowing entity must be financially viable and capable of carrying out the project. We evaluate the borrower's past, present, and future financial position. The project is also examined in the context of the country's total economy. We try to look at what the sector needs are and where the money will be most beneficial," explains John Davis, World Bank financial energy adviser. And to ensure financial security, loans and credits are usually made directly to the government concerned; if the loan is on behalf of a private organization, the loan is guaranteed by the government.

Whether a hydroelectric power or a rural electrification development project, the bank maintains a close watch on each and every project it finances. "Every six months or so, the bank sends in its own experts to review the progress of the project. That is what is meant by supervision—to see if the project is being executed on the basis of the loan agreement," adds Fish.

Energy Affiliate

Each one of these project cycle stages is important to ensure that the project contributes to the country's overall economic growth. It is precisely this relationship between energy development and economic production that compelled the World Bank to expand its operations by offering assistance in energy planning and the financing of oil and gas exploration. Yet even this additional lending support appears to fall short of meeting the volume of investments required to adequately develop the energy potential of these nations.

In 1981, therefore, the member countries of the bank discussed the possibility of creating an energy affiliate to the World Bank to be supported as a separate international organization. But because of current budgetary constraints in many member countries, including the United States, it became difficult to gather support for another international lending agency. One solution to this problem was to turn to private sector investment and cofinancing arrangements with both public and private sources. For example, the bank currently has collaborative projects with Union Oil Co. in Thailand, with Chevron, Inc., in the Sudan, and with Phillips Petroleum Co. in the Ivory Coast.

Fish points out that the World Bank cofinances many projects with other international organizations. "We often look to cofinance with our brother or sister institutions—for example, the Inter-American Development Bank, the OPEC Fund, the Asian Development Bank. But many of these organizations are in the same situation we are in terms of funds being reduced. Overall, the total amount of official international aid is declining in terms of needs, so we are investigating private commercial bank cofinancing for some of these projects."

Although the available funds for energy development loans are limited, the World Bank is doing its best to assist the developing world. Fish explains, "We maintain dialogues with the countries that are active borrowers to give us a general view of their requirements. The projects grow out of that kind of dialogue. But one must realize that we are in an increasingly residual position when the amount of dollars we have available is compared with sector needs. This is especially true in the electric power area. We have an enormous requirement for electric power projects. I think a minimum program over the next four years, if we had the finances, would entail another 170 projects. Ten years ago we were able to finance up to 30% of the developing countries' electric power needs. In the next five years, however, we will be fortunate if we can contribute 5%. This means that we have to pick and choose among the projects and carefully determine the amount of our participation." ■

This article was written by Ellie Hollander, Washington Office.

Energy Conference Celebrates 10th Year

ET '83, the largest international trade fair of its kind, highlights America's energy technology progress with a wide array of information, hardware, and services.

Over 7000 people are expected to attend the 10th annual Energy Technology Conference and Exposition, to be held February 28–March 2, 1983, in Washington, D.C. Popularly known as ET '83, the event has been certified by the U.S. Department of Commerce as the only international trade fair in the field of energy for 1983.

As in past years, EPRI will cosponsor the conference with the Gas Research Institute, the American Gas Association, and the National Coal Association. EPRI President Floyd Culler will deliver the traditional state-of-energy message that kicks off the conference. Another featured speaker will be Ulf Lankzke, chairman of the International Energy Agency, based in Paris, France.

The emphasis during 1983 will be on technology transfer and on providing an independent forum for information exchange and interaction among all segments of the energy community. The 200 speakers participating in the three-day program will address some 65 conference sessions and workshops that cover all aspects of energy technology. Some of the subjects on the agenda include cogeneration, load management, fluidized-bed combustion, utility rate design, transmission and distribution systems, small-scale hydro, nuclear power, fuel cells, wind, solar, photovoltaics, and environmental controls.

The event will be oriented toward hardware and real-world applications that mirror how the energy industry has evolved and matured over the last 10 years. The concurrent exposition will feature more than 300 exhibit booths displaying energy hardware, research, and services of interest to utility executives, industry and government representatives, builders, and architects.

EPRI staff members are organizing the following sessions: Wayne Seden, Practical Approaches to Technology Transfer and Commercialization; Fritz Kalhammer, Use of Advanced Technology to Improve Industrial Productivity; James Calm, Commercial/Residential Heat Pumps; William Blair, Electric Load Management; and Michael Tinkleman, Cost-Benefit Analysis of Energy Options. A number of other EPRI representatives will be on the program as speakers in their particular fields of expertise. Serving on the ET '83 Program Committee are R. L. Rudman and Michael Tinkleman; Christine Lawrence is the publicity liaison.

The event is managed by Government Institutes, a private publishing and educational organization. Advance programs, registration materials, and exhibitor information for ET '83 are available from Martin Heavner, Government Institutes, P.O. Box 1096, Rockville, Maryland 20850; (301) 251-9250. ■

Software Center Moves to Dallas

EPRI's Electric Power Software Center, located in Santa Clara, California, since its founding in 1979, has moved to Dallas, Texas, where it is now being operated under contract to EPRI by University Computing Co. (UCC). The center's services—providing software distribution for EPRI-related computer codes—continue as before.

Software packages, including source code, test cases, test case output, and documentation, are available under EPRI license. EPRI member utilities pay distribution fees for the software through their annual membership contributions to EPRI. In addition, the Electric Power Service Bureau has been established to permit users access to EPRI-licensed codes through UCC's computer facilities. Again, membership contributions include the surcharges for this service, and EPRI member utilities are also eligible for discounted rates on computer time.

A list of EPRI computer codes now available can be found in the quarterly *EPRI Guide.* To request a computer code, write or call the Electric Power Software Center at 1930 Hi Line Drive, Dallas, Texas 75207, (214) 655-8883. ■

TMI-2 Cleanup Research

A cooperative research effort to restore the damaged TMI-2 nuclear plant to service (and to learn from and document that experience) is making progress. The effort is cosponsored by EPRI, General Public Utilities Corp., DOE, and the Nuclear Regulatory Commission. "The timely, efficient recovery from this accident, with its potential for requalifying the unit for service, is probably the single most important thing the nuclear industry can do," says Adrian Roberts, EPRI program manager for the research effort.

As part of the research, EPRI and DOE are studying how well various components in the plant functioned during the accident. That is, did they do what they were supposed to do? Were they designed too conservatively, or not conservatively enough? Did they survive? EPRI's role is to assess the performance of various mechanical components, such as pumps, valves, control rod drive mechanisms, and parts of the polar crane. DOE is examining instrumentation and electrical equipment. A complete report will detail results of these tests when all results are available.

Decontamination is another major work area shared by participants in the R&D program. EPRI is funding efforts to decontaminate the reactor coolant system and auxiliary system, while DOE is responsible for studies on decontaminating the containment building.

"We're getting some real-time, direct-benefit information of use to the industry," comments Willis Bixby, manager of DOE's TMI Site Office. "We concentrate on getting the lessons learned here at TMI directly back to the people who can use them—the industry; they, in turn, will improve whatever deficiencies may be present. This is a unique opportunity to develop new technology for accident recovery through on-line, learn-as-you-go R&D. When we're faced with a technical problem, we don't have two or three years to come back with a solution." ■

EPRI Releases New Film

EPRI's Communications Division recently released a new 16-mm film focusing on the human side of research and development. Called *Windows in Time: Research Today for Energy Tomorrow,* the film looks at the men and women who devote their lives to R&D.

In the film, five scientists engaged in

Chinese Delegations Visit EPRI

In October EPRI hosted two delegations of scientists and engineers from the People's Republic of China. The 16 guests included representatives from the PRC's Electric Power Research Institute, as well as officials from various PRC ministries and planning agencies. One group participated in briefings with staff members from the six EPRI technical divisions, while the other discussed HVDC issues with Electrical Systems Division personnel.

energy research introduce viewers to the contemporary world of R&D and discuss the importance of their work to society. The five are seen at work in their laboratories and in the field, where they talk about their research and their lives as researchers. The film explores the motivations, frustrations, and rewards inherent in their work. The message is that there are still many questions to be asked and much to be discovered.

The five scientists featured in the film are William Fairbank, a physicist at Stanford University; Richard Swanson, a pioneer in high-efficiency photovoltaic cells, also at Stanford; Pat Finnegan, with NASA's wind research program; William Podolney, vice president and general manager for fuel cell operations at United Technologies Corp.; and Melvina Farcasiu, a scientist at Mobil Corp. specializing in coal and heavy petroleum research.

The film was produced for EPRI by Bill Stokes Associates of Dallas, Texas. It was written by Marshall Riggan, produced by Don Stokes, and directed and edited by Peter Meyer.

Aimed at general audiences, *Windows in Time* is available free on loan from Modern Talking Picture Service, 5000 Park Street North, St. Petersburg, Florida 33709; (813) 541-6661. Sales information can be obtained from Jeffrey Iavecchia, EPRI, (415) 855-2928. ■

MHD Process Component Dedicated

A key component for the development of magnetohydrodynamics (MHD) was dedicated early this fall in Butte, Montana. The $1.5 million component, an inverter, changes the direct current (dc) generated by the MHD process into alternating current (ac), the form used to supply most of the country's electricity needs. Officials from EPRI presided at the ceremony, with participation from DOE, Mountain States Energy, Inc., and The Montana Power Co.

Funded by EPRI, the inverter was designed and built by Westinghouse Electric Corp. as part of a $40 million DOE test center, the Component Development and Integration Facility. CDIF is operated by Mountain States under contract to DOE to test individual parts of the MHD process. Hosted by Montana Power, the facility is located in Silver Bow County, five miles south of Butte, Montana.

MHD has the potential of generating electric power with up to 50% efficiency compared with the 35% efficiency of current coal-fired steam turbine power plants. Because MHD generators are so efficient in burning coal and other fossil fuels, the plant shows promise of emitting far fewer pollutants than conventional combustors. Thus, commercial-size plants envisioned for the future may not need costly auxiliary scrubbers.

High efficiencies rely on a configuration in which the same fuel is used to generate power through two separate processes. Electricity is first generated directly by the MHD process when extremely hot gases produced by burning fossil fuels at high temperatures are directed through an intense magnetic field at velocities close to the speed of sound. These hot gases are then used to produce steam to drive a turbine and generate electricity. This dual use of fossil fuel is known as a combined cycle.

At the dedication, EPRI President Floyd Culler said EPRI's work on the inverter is part of an overall development program in which cooperation has resulted in a balanced, continuing exploration of MHD technology. He commented, "Inverters that can switch dc power to ac are available from manufacturers today, but they have not been designed and built on the large scale necessary for commercial, full-sized use in an MHD power plant. This inverter represents a significant step in that direction." ■

CALENDAR

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

DECEMBER

15–17
4th Symposium on Electric Utility Load Forecasting
Dallas, Texas
Contact: Larry Williams (415) 855-2415

JANUARY

18–19
Residential Passive Solar Buildings Energy Analysis
Baltimore, Maryland
Contact: Gary Purcell (415) 855-2168

20–21
Seminar: Load Management Strategy Testing Model
Atlanta, Georgia
Contact: Victor Niemeyer (415) 855-2744

27–28
Seminar: Load Management Strategy Testing Model
Scottsdale, Arizona
Contact: Victor Niemeyer (415) 855-2744

FEBRUARY

1–3
Workshop: Hydro Operation and Maintenance
San Francisco, California
Contact: Charles Sullivan (415) 855-8948

15–17
VIPRE–RETRAN Meeting
Charlotte, North Carolina
Contact: Joseph Naser (415) 855-2107

MARCH

22–24
2d Conference on Fabric Filter Technology
Denver, Colorado
Contact: David Eskinazi (415) 855-2918

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

HEBER GEOTHERMAL DEMONSTRATION PLANT

The Heber project has reached full strength and is making excellent progress. The design of a 45-MW (e, net) binary-cycle power plant has been essentially completed and procurement of the hardware is under way (RP1900). The project schedule calls for groundbreaking late this year and turbine roll early in 1985. Following startup, the demonstration program will span approximately two years, after which it is anticipated that the plant will be converted to commercial operation by the participating utilities. The plant will be constructed at Heber geothermal field in the Imperial Valley of southern California.

Project significance

Of the known geothermal hydrothermal resources in the United States, approximately half are in the moderate temperature range of 150–210°C (300–410°F). If developed, this represents approximately 10,000 MW (e) for 30 years. A major portion of this potential will remain economically marginal unless the binary-cycle technology is fully developed. The primary reason for this is that binary cycles have an inherently higher resource utilization efficiency (more Wh/lb brine) than flashed-steam cycles, giving a significant advantage when the resource temperature falls into or below the moderate range (Figure 1). A second reason is that binary-cycle technology is close enough to maturity to be considered an attractive option. The purpose of the $122 million Heber project is to scale up the binary-cycle technology and demonstrate its performance capability, economic viability, and environmental acceptability for use in the commercial development of the moderate-temperature geothermal resources. When completed, the results are expected to give the industry an economically competitive, directly applicable option for development of resources in the temperature range of 163–210°C (325–410°F), possibly higher, and to establish performance characteristics and economic trends for binary cycles in general.

Industry first identified the need for such a demonstration plant during EPRI-sponsored workshops in 1974. Details of the project were first formulated in 1976, following completion of feasibility studies and assessment of representative geothermal sites. The first iteration of design optimization was completed in 1978, which later served as the starting point for the current phase of the project.

Project participation

In September 1980 EPRI and the other cofunders agreed to proceed with the project to completion. The power plant, excluding geothermal fluid production facilities, is being cofunded by EPRI, DOE, San Diego Gas & Electric Co., Imperial Irrigation District, California Department of Water Resources, Southern California Edison Co., and the state of California. DOE is contributing 50% of the funding, and EPRI is contributing 10%. The balance will come from the other participants. SDG&E is the second largest contributor and is the lead utility, as well as the project manager. Better than 80% of the funding required for the plant appears to be assured at the present time, and confirmation of the balance is expected in future years well before it is needed by the project.

The geothermal fluid production facilities will be developed entirely with private funding by Union Oil Co. of California and Chevron USA, Inc. The heat will be supplied to the plant under a purchase agreement. Once the plant has removed the heat from the geothermal fluid, the fluid will be returned to the field operator for reinjection into a suitable part of the reservoir formation. Power from the plant will be delivered to Imperial Irrigation District's electric grid and IID will provide power for plant startup. Cooling water will also be supplied by IID.

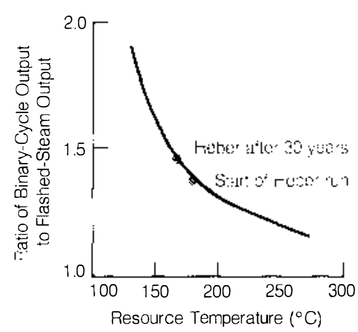


Figure 1 Binary cycles have the advantage of producing more Wh/lb of brine than flashed-steam cycles. This is expected to result in lower fuel cost. The shaded area represents the temperature range of approximately half the known geothermal hydrothermal resources in the United States.

Plant design features

The geothermal wells are sensitive to sudden changes in temperature and flow, and the plant must operate in unison with the reservoir. For this reason, the plan is to operate the plant as a baseload unit to minimize production problems.

The overall design approach is essentially the same as that defined by earlier EPRI studies (RP580). The power cycle is based on a simple organic Rankine cycle with supercritical boiling. The working fluid will be a mixture of 90% isobutane and 10% isopentane. The working fluid vapor will enter the turbine at 152°C (305°F) and leave the turbine at about 52°C (126°F). The actual temperature will depend on ambient atmospheric conditions. The hydrocarbon boiler is a brine-to-hydrocarbon heat exchanger of conventional tube-in-shell counterflow design, with the hydrocarbon flowing on the shell side of the exchanger. The heat exchangers have been sized so that the plant can produce at full capacity with any geothermal fluid temperature from 182°C down to 163°C (360–325°F). This allows for a possible reservoir temperature decline that might occur during the life of the plant. The amount of temperature decline will depend on the rate at which the total field is developed. The geothermal fluid will exit the heat exchangers at 68°C (154°F), or possibly a few degrees higher. The heat exchangers will consist of two trains of four modules each, and the condenser will be divided into two units. Conventional wet-cooling towers will be used.

One significant revision to the design has been to incorporate an unconventional but desirable cooling strategy. Because organic Rankine cycles are sensitive to cooling temperatures, the cooling approach is to design the plant for maximum capacity when the ambient air temperatures are low, operate the system at constant cooling-water flow throughout the year, and let the power output float, depending on the time of day and year. This approach yields the maximum average annual power per dollar invested. Several other changes have been made in the areas of heat exchanger, condenser, and other equipment arrangements to improve operability, increase reliability, and reduce cost. The capacity of the brine return pump was increased to be compatible with the current understanding of reservoir and brine flow characteristics. The wells serving the plant are expected to produce about 3.4 million kg (7.5 million lb) of brine per hour at approximately 182°C (360°F) at the time of plant startup. The temperature is expected to decline by about 17°C (30°F) by the end of a 30-year plant life, assuming the reservoir will be developed to produce at full capacity. If not, the temperature decline should be less. The primary measures of power plant performance include net power to the grid; gross heat rate, which sizes the cooling tower; overall thermal efficiency as a matter of interest; and specific brine rate, which is an indirect measure of resource utilization efficiency. Table 1 is a summary of the annual average expected performance.

Table 1
ESTIMATED ANNUAL AVERAGE PERFORMANCE

Performance Parameter	Gross Power	Net Power to Grid
Capacity	65 MW (e)	45 MW (e)
Heat rate	23.7 MJ/kWh (22,500 Btu/kWh)	32.5 MJ/kWh (30,900 Btu/kWh)
Thermal efficiency	15.6%	11%
Brine rate	49 kg/kWh (107 lb/kWh)	69 kg/kWh (147 lb/kWh)
Availability	82% (potential for improvement)	

Schedule

The purchase order for the turbine generator, the longest lead item, was issued in May of this year. The turbine will be a dual-flow axial-type machine rated to produce 70 MW (e) at full load. This represents a scale-up of approximately 3 to 1 from the prior state of the art. More than 90% of the preliminary engineering and design for the plant is now complete, and the piping and instrumentation drawings have been approved by the Sponsors' Technical Committee (Figure 2). A total of 72 equipment specifications must be prepared. As of August 1982, 27 of these were complete and 23 requests for quotation had been issued; the bids received are being evaluated. Site preparation for the plant will start late this year. Production drilling will commence in February 1983. Construction will start in August 1983 and will be completed in October 1984, at which time brine will first be delivered to the power plant to start the checkout procedure. Turbine roll will occur a few months later. The demonstration program will start in August 1986 and run for approximately two years. *Program Manager: Vasel Roberts*

WIND TURBINE R&D

Results from major wind turbine field experiments during the past few years have been encouraging and have significantly improved the understanding of future R&D requirements for evolving a viable utility power generation option. This generation option could ultimately be of significant value as a fuel saver in windy areas with ample site availability. However, significant improvements in cost and performance, relative to the current state of the art, are still prerequisites for any potential widespread use of wind turbine technology. Continuation of a well-paced R&D program in the next few years will be necessary if the goal of evolving a generation technology that is cost-effective, technically sound, and available for widespread deployment as early as the 1990s is to be realized.

Historical perspective

The rapid tempo of wind turbine R&D during the past few years has been established by the federal program in a series of progressively more-advanced wind turbine experiments. Both horizontal-axis and vertical-axis machines have been under development. The premier field experiments in the federal program during recent years have been the four MOD-0A wind turbines. These machines have produced a wealth of performance information. From a historical viewpoint, the MOD-0A program is widely regarded as the most successful horizontal-axis wind turbine

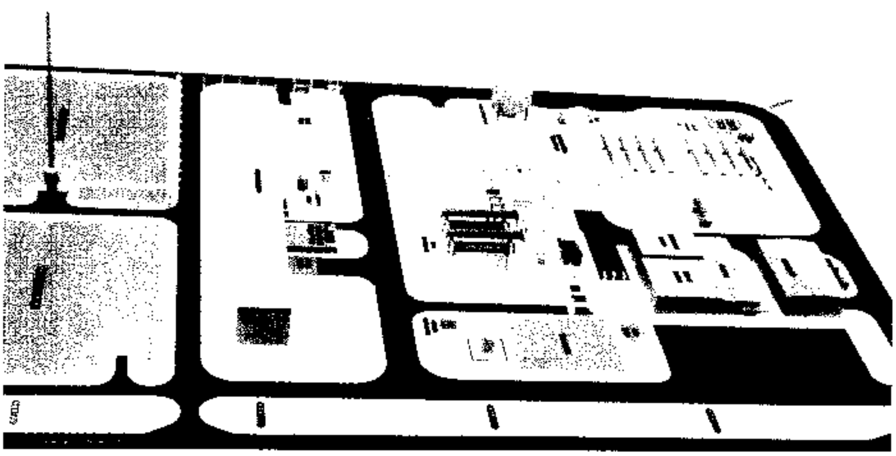


Figure 2 The model of the Heber binary-cycle plant that will be used for construction is already taking shape at the facilities of Fluor Engineers and Constructors, Inc., in Irvine, California. The model will be transported to the site to support construction in mid 1983.

R&D program to date. This program was managed by NASA, Lewis Research Center, for DOE. These machines are each rated 0.2 MW for an 18.3 mi/h (29.4 km/h) wind speed at 30 ft (9 m) above ground level. The machines are located in Hawaii, New Mexico, Puerto Rico, and Rhode Island. As of June 30, 1982, they had collectively produced nearly 3700 MWh of energy in over 38,000 hours of synchronized operating time. Although last to be installed, the unit in Hawaii has produced the most energy to date. This wind turbine's relatively good performance stems from the excellent wind resource availability in Hawaii and from the fact that this unit incorporated a number of improvements over the three other MOD-0A machines.

The MOD-0A machines are currently the only experimental wind turbines for which there is a long-term history of performance in applications to bulk energy supply in actual utility systems. NASA has attained all its primary objectives in this program, and the machines have been shut down. Although the ultimate disposition of the MOD-0A machines has not yet been decided, the more advanced, megawatt-scale MOD-2 machines are now the premier federally sponsored wind turbines. However, before leaving the program, MOD-0A's page in the history of wind turbine R&D warrants additional recognition. The program's major achievements were associated with verifying the durability of new low-cost rotor blade concepts; validating analytic codes; clarifying the requirements for wind turbine compatibility as a bulk power source in utility networks; and providing baseline data on control concepts, component reliability, and overall machine performance. Thus, the design work on more-advanced machines has benefited significantly from insight gained in the MOD-0A program. The field experiments with these early research machines have laid groundwork and set precedents for activities in the burgeoning test programs of more-advanced wind turbines.

Current state of the art

The current state of the art in horizontal-axis wind turbine R&D is represented by the 2.5-MW MOD-2 and the 4-MW WTS-4 (Figure 3). The MOD-2 was developed by Boeing Engineering and Construction under a DOE-funded program managed by NASA, Lewis Research Center. Five MOD-2 machines have been recently constructed by Boeing. Three of these machines were constructed under DOE sponsorship at the Goodnoe Hills site near Goldendale, Washington, with support and cooperation of the Bonneville Power Administration. The fourth MOD-2 was constructed for the U.S. Bureau of Reclamation near Medicine Bow, Wyoming. The fifth unit was constructed for the Pacific Gas and Electric Co. at a site in Solano County, California. This fifth MOD-2 has a cut-out wind speed of 60 mi/h (97 km/h) as opposed to 45 mi/h (72 km/h) in earlier units.

The WTS-4 is a competing horizontal-axis wind turbine design developed by Hamilton Standard, a division of United Technologies Corp. The first prototype was recently constructed near Medicine Bow by Hamilton Standard for the U.S. Bureau of Reclamation. A number of other U.S. industrial sponsors are designing or developing prototype horizontal-axis utility-scale wind turbines, but none of these efforts has progressed as far as the MOD-2 or WTS-4. The largest known machines, under design at this time by General Electric Co. and Boeing, are the MOD-5A and MOD-5B, with expected ratings in the range of 7.0–7.5 MW. The five MOD-2 machines and the WTS-4 are on the threshold of test programs to evaluate their performance and their operation and maintenance requirements. These test programs are also expected to identify key R&D activities for advancing the state of the art and developing machines with cost and performance characteristics that are suitable for widespread applications.

The state of the art in vertical-axis wind turbines is represented by the 17-m, 0.1-MW Darrieus machine developed by Sandia National Laboratories (Figure 4). At this time,

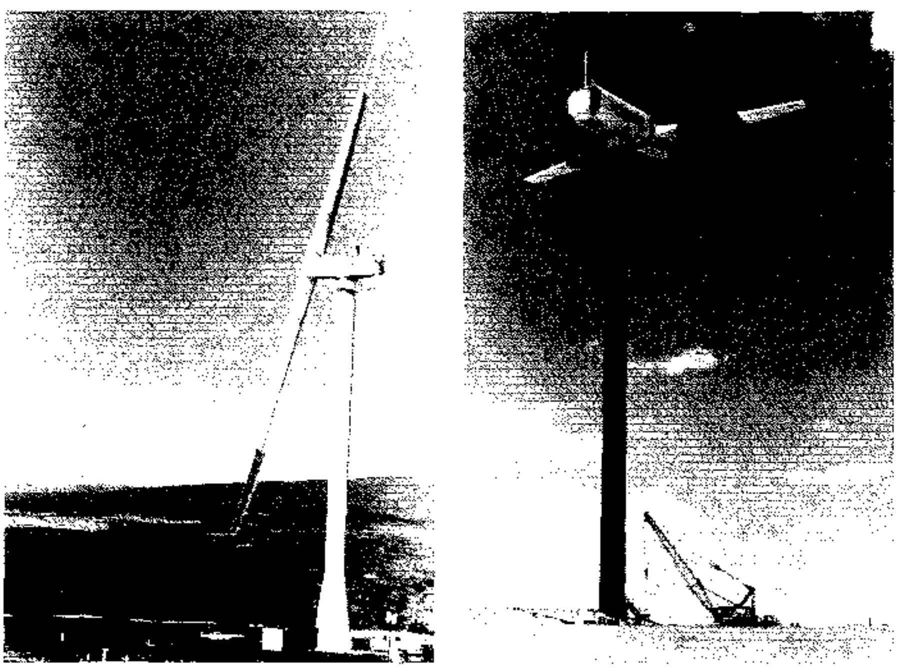


Figure 3 MOD-2 (left) and WTS-4 (right) horizontal-axis wind turbines. The characteristics of these machines are described in the December 1981 issue of the *EPRI Journal*, pp. 28–29.

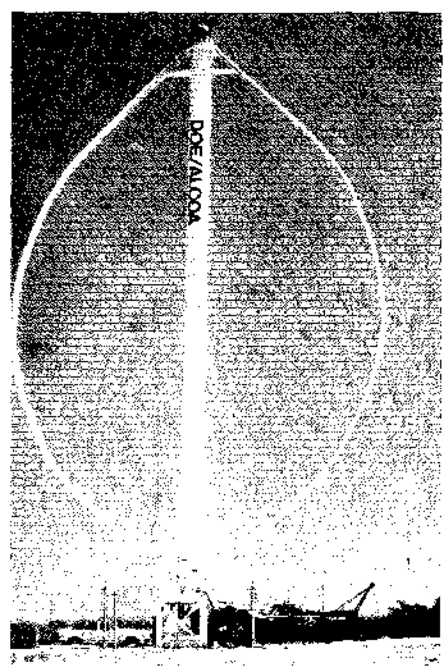


Figure 4 Darrieus vertical-axis wind turbine machine.

the technology development and long-term testing of vertical-axis machines have not progressed as far as those for their horizontal-axis counterparts, and the prospects for vertical-axis machines in utility applications are not as well understood. However, some small vertical-axis machines have been successfully deployed in other applications, such as pumping water.

Experts in the field of wind power believe it is desirable to develop the largest feasible multimegawatt machines for most utility applications (especially for typical good sites with large open land areas and uniform wind flow). However, some special situations are also expected in which unusual site topography or some siting constraint would mandate use of submegawatt wind turbines. For example, the terrain could be so rough that it would not be possible to transport and construct a multimegawatt machine. However, the following general advantages are expected to result in a lower cost of energy from the larger machines when the technology matures.

- Increased energy capture and better site use
- Lower operation and maintenance costs
- Better safety and security
- More practical coordination, control, and dispatch of units in a generating station

Another illustration of the advantages of larger unit sizes is provided by Table 2. The number of units required for a generating station with a modest 100-MW rating grows rapidly as unit size is reduced. For units with submegawatt ratings, the required number of units becomes unwieldy and perhaps unrealistic. It is noteworthy that the largest multimegawatt units under development produce a relatively small amount of power on an individual unit basis; even these units will have to be deployed in substantial mass-produced quantities to make a significant contribution to world energy supply.

Table 2
UNIT REQUIREMENTS FOR A 100-MW GENERATING STATION

Machine	Rating (MW)	Number of Units
Advanced	~7	14
WTS-4	4	25
MOD-2	2.5	40
Typical currently available submegawatt	0.05	2000

Utility industry activities

Utility participation in wind power development is essential if the technology is to make a significant contribution to overall energy supply. Economies of scale, distances between good wind turbine sites and most population centers, space requirements, and maintenance demands make utilities the logical primary market. In general, wind power's greatest potential value is in displacement of fuel consumption during windy periods, rather than displacement of planned generation capacity. Under normal operating circumstances, a utility would preserve its most expensive fuels, typically oil or gas, during windy periods. Utilities that have high dependence on these costly fuels and are in or near windy areas are promising early markets for wind power development. Because wind is intermittent, little or no credits for capacity displacement are likely to be realized from the installation of wind-powered generating stations. However, if the cost of wind turbines declines enough, the fuel displacement value of the technology may be sufficient to result in its economic viability independent of credits for capacity displacement.

EPRI program

In the next two years, EPRI's wind power program will emphasize participation in key test and evaluation programs for state-of-the-art wind turbines in partnership with cosponsoring utilities and wind turbine developers. The overall objective of EPRI's wind power program is to develop a viable generation option for use by the utility industry as a fuel saver in diversifying future generation expansion. Participation in the key wind turbine test programs will support attainment of this objective by enabling EPRI to accomplish the following.

- Maintain a firm understanding of the status and outlook for wind turbine technology
- Define key follow-up R&D activities for advancing wind turbine technology in terms of improved performance and lower cost
- Develop a technical information base

As a follow-up to these test programs, EPRI cosponsorship of advanced wind turbine R&D programs in subsequent years will be the next step toward attainment of the stated overall objective.

In parallel with the near-term test programs and follow-up advanced machine development, EPRI will continue an existing broad technology assessment activity to maintain a perspective on key complementary wind turbine research efforts throughout the world. This broad-based information will be a vital factor in planning, executing, and evaluating the new activities. Utility-scale horizontal-axis wind turbines are currently under test in Denmark and Sweden. Additional programs are being planned in France, the Netherlands, the United Kingdom, and West Germany. A major effort to develop vertical-axis machines is taking place in Canada.

Outlook

Although the rapid wind turbine technology advances achieved during the past few years are good reasons to be enthusiastic about the long-term promise of wind power generation, the job is far from complete. Significant improvements in cost and performance, as may be achieved through additional technologic advances, are needed to make wind power competitive in widespread utility applications. EPRI's planned emphasis in the next few years on key test programs with follow-up development of advanced machines is expected to help maintain the momentum established by the DOE program in recent years. This EPRI activity will also provide both coordination of key individual test programs and an efficient means for direct involvement of the utility industry in the wind turbine research process. If this process is carried to completion and its objectives are attained, wind power could begin making a contribution to our domestic generation system prior to the end of this century. Wind power is not going to play as large a role as coal or nuclear power in our future energy supply, but it is one of a blend of technologies that collectively should make a contribution. *Project Manager: F. R. Goodman, Jr.*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

DIAGNOSTIC MONITORING OF ROTATING EQUIPMENT

Fossil plant rotating equipment failures account for 30–50% of plant outages. Forced outages—sudden and sometimes catastrophic events—have the most severe effect on plants. However, rotating equipment usually deteriorates progressively, not suddenly, so on-line diagnostic monitoring endeavors to provide the early warning necessary for scheduling maintenance and avoiding unexpected failures. EPRI research is directed toward developing packaged computer-based diagnostic systems that rely on a variety of early warning signals, including vibration spectra, acoustic emission bursts, and eddy-current distortions.

In the next 20 years, the utility industry will have to maintain the integrity of power generation and supply with only a limited number of new plant additions. Financial constraints on new plant construction, canceled and deferred nuclear plant orders, and the uncertain growth rate of electricity use emphasize the necessity of enhancing existing plant availability. Many fossil fuel units are approaching the limits of their design lives (typically 30–40 years), and extending plant operating life without reducing availability presents a challenge.

In this climate the techniques for detecting incipient failures are beginning to flourish. Advances are being made in diagnostic monitoring for all areas of the power plant, but the degree of sophistication of the techniques is not uniform. Some monitoring techniques—vibration signature analysis, for example—are well developed and can be incorporated into utility maintenance procedures in the very near term. Others, such as on-line eddy-current monitoring, require further development and field qualification before application in aging fossil fuel plants can be confidently carried out.

On-line turbine monitoring

One of the most serious of all plant failures is a fracture of the turbine generator shaft system (Figure 1). This precisely balanced train of shafts and rotors usually exhibits no more than a few mils peak-to-peak vibration at each bearing location. Any deviation of shaft vibration beyond set limits requires immediate investigation and correction. Worldwide research efforts have been directed at developing early warning systems for turbine generator failures by monitoring the vibration spectrum (up to about 250 Hz) and detecting changes in spectral peaks.

Turbine shaft, disk, or blade failure can be catastrophic, extensively damaging the turbine generator, shutting the plant down for long periods, and possibly threatening the safety of plant personnel. The causes of such failures include water induction, hard-particle erosion, and chemical corrosion; all are the subjects of EPRI projects for on-line monitors.

Water induction—water backed up into the turbine from the steam lines to the feedwater heaters—can be detected with a novel ultrasonic device, which senses the presence of water droplets or slugs. Westinghouse Electric Corp. has developed such a sensor (RP637) and has installed the monitoring system at Boston Edison Co.'s New Boston station.

Hard-particle erosion of turbine components, caused by exfoliation of calcium deposits in boiler superheater or reheater tubing, may be detectable by laser-Doppler techniques, which are being explored by General Electric Co. (RP1648). A major area of concern is corrodent deposits in low-pressure turbines. A unique device has been developed to monitor the buildup of corrosion deposits while the turbine is on-line. Consolidated Controls Corp. is studying the use of a 14-MeV neutron generator to produce gamma rays from neutron-corrodent collisions (RP1409). The number and energy of gamma rays monitored indicate the degree and type of corrosion.

Another severe and persistent problem

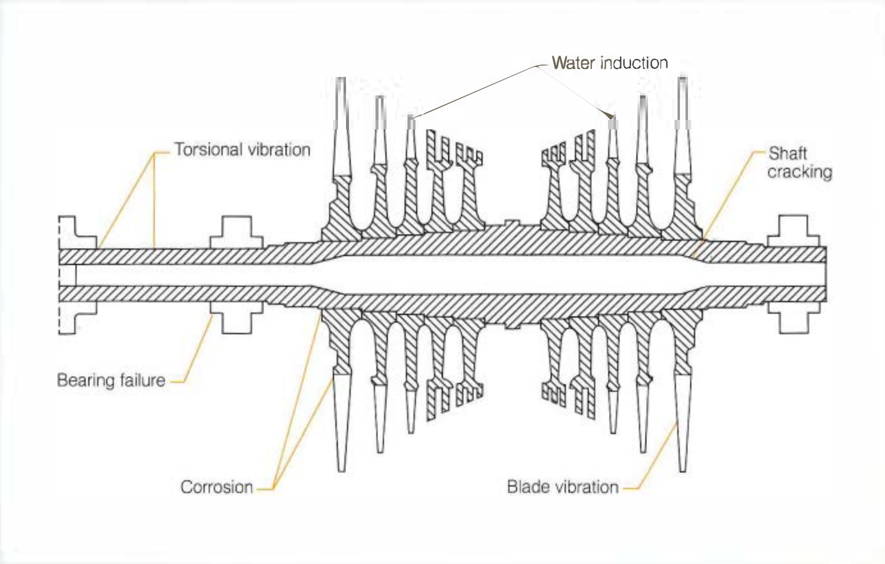


Figure 1 On-line monitoring points for a typical low-pressure turbine configuration. This area, the turbine generator shaft system, must be closely watched for deviations from vibration limits.

in large power plants is the failure of low-pressure turbine blades. The mechanisms and causes of blade failure are complex and interrelated. Turbine blades fail as a result of combined mechanical stress and the effects of the environment to which they are subjected. Failure usually occurs as high-cycle fatigue, exacerbated by corrosion effects. The problem of detecting cracks in advance of failure while the turbine is running appears severe, yet this may be achieved by a unique approach developed by the Franklin Research Center, which uses only a single stationary sensor for each turbine stage (RP1854). This blade-monitoring system is based on an acoustic-Doppler procedure that tracks the individual blade vibrations above background noise levels. When validated, this development could have a major impact on plant reliability.

Shaft crack detection

Shaft and disk cracking is of continuing concern, the potential effect being severe in terms of cost and downtime. Three on-line monitoring techniques may have potential for early warning of such failures. None is yet available to the utility industry as a packaged system, but all show great promise. All three may be needed in any comprehensive crack-monitoring system to ensure validity of the diagnosis.

Vibration signature analysis has already demonstrated its ability to detect large transverse cracks during turbine rundown. This technique may be capable of picking up such abnormalities during full-speed, full-load conditions. General Electric is investigating this possibility (RP1862).

Acoustic emission (AE) monitoring studies by Rockwell International Corp. on four turbines at TVA have established background noise levels and attenuation paths through the turbines for AE bursts up to 1 MHz in frequency (RP1266-14). Data relating material cracking to acoustic emissions have been taken by Science Applications, Inc. (RP734-3). Much additional study is needed before this technique will become viable for crack detection. However, such failure modes as bearing deterioration, blade rubbing, and rotor unbalance all appear to be easily detected by AE monitoring. Work at TVA is continuing under RP734-5.

The use of eddy-current monitoring devices is well established as an off-line nondestructive evaluation (NDE) method. RP1894, with General Electric as contractor, represents the first attempt to develop on-line methods using eddy currents. If the eddy-current sensor can transmit to and receive distorted signals from a cracked, rotating component, it will have unique advantages over the two preceding methods. Of the three methods described here, this is the only one that will "look at" the actual flaw, making detection of flaw initiation and growth unambiguous.

Predictive maintenance by vibration signature analysis

Vibration signature analysis appears to offer utilities a valuable incipient failure detection method for turbines, pumps, and fans. Monitored incidents suggest that such failures as blade rubbing, unbalance, oil whip, steam whirl, and bearing failures can be readily identified by this method. The procedure should be adaptable to predictive maintenance procedures and will increase plant availability by reducing forced outages.

For more than two years, Rockwell International monitored the Brayton Point plant at New England Electric Co., observed component failures, and identified sensors, methods, and algorithms suitable for predictive maintenance based on vibration signatures (RP734-1).

EPRI is now introducing vibration signature analysis systems into the utility indus-

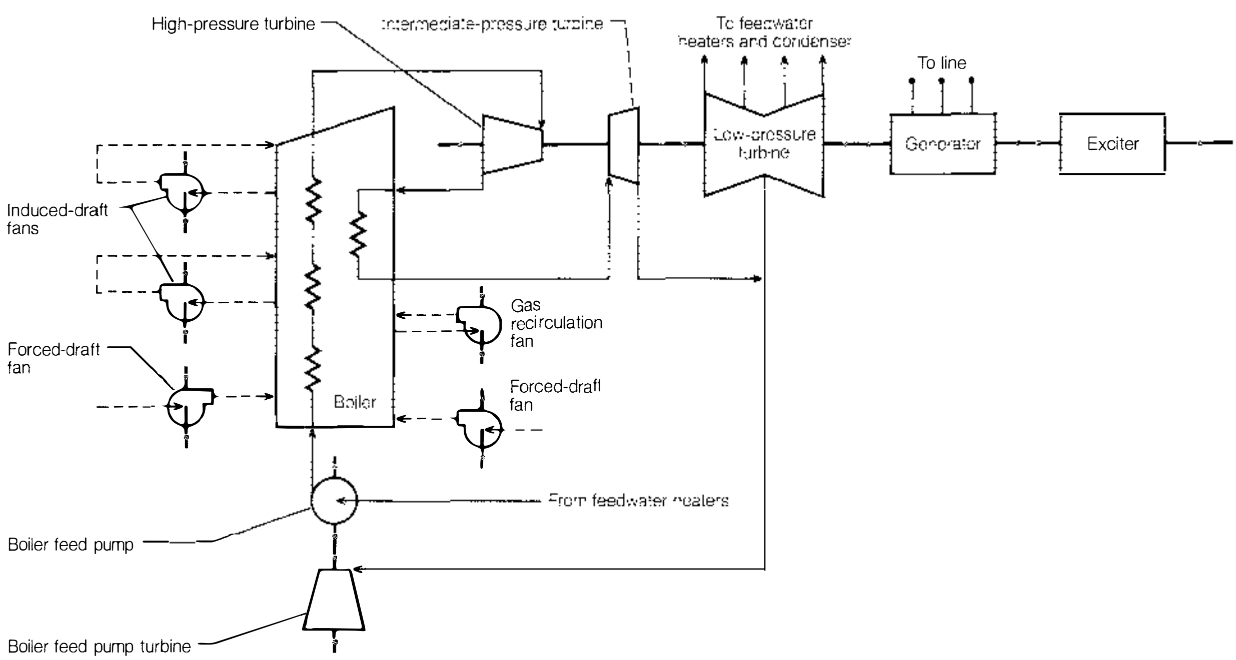


Figure 2 Equipment monitored at United Illuminating Co.'s New Haven Harbor station. Vibration sensors are located on each of the 22 bearings (color) shown in this diagram. The dashed line is the air path; the solid line is the steam path.

try. The first such system (Figure 2) is being developed as a prototype at United Illuminating Co.'s New Haven Harbor plant (RP1864-2). This system uses, as a baseline, statistical data showing how vibration responds to normal plant variations of load, speed, and so on. Abnormal signature variations can then be identified and diagnosed from a fault table, which is generated and periodically updated, by using data from equipment operating failures.

A more advanced system, which employs dynamic models of the rotor-bearing system for each item of rotating equipment, is being developed and installed at Philadelphia Electric Co.'s Eddystone plant (RP1864-1). It uses dynamic models to predict an abnormality at one location on the rotor train on the basis of observed vibration behavior at select sensor positions (Figure 3). Such systems can be adapted to minicomputers, making the overall system modest in cost. Both predictive maintenance systems are based on continuous sensing of vibration amplitudes and frequencies, with data being recorded and analyzed at periods of minutes, hours, or days, depending on prevailing vibration trends.

Both the New Haven Harbor prototype and the more advanced system are guided by utility advisory committees. Members of these two committees are chosen for their interest in vibration signature analysis and in utility maintenance procedures. Membership selection ensures that the ultimate products are designed to be usable by utility personnel, are cost-effective, and are applicable to the most vulnerable equipment and the most likely modes of failure.

A related project is being carried out by Battelle, Columbus Laboratories at Pennsylvania Electric's Homer City plant (RP734-4). In this project the axial draft fans' antifriction bearings are being monitored with accelerometers. The goal is to provide an early warning system for detecting incipient bearing failure.

The application of vibration signature analysis systems throughout the industry should have a major effect on fossil fuel plant availability. Across-the-board application of these techniques is estimated to enhance plant availability by at least 2%, which is worth more than $400 million a year to the industry.

These systems should make operators more aware of operation and maintenance factors that influence component integrity and provide utility engineering personnel with valuable diagnostic information.

Although many of the techniques are in early stages of development, several others have already demonstrated their usefulness in detecting failures and helping utilities schedule their maintenance more effectively. Savings in outage time and repair costs have already amounted to millions of dollars, and operating practices should improve even more as utilities begin to understand, accept, and rely on the new diagnostic systems. Progress in this direction has been greatly aided by rapid advancements in computation and display capability, and significant changes in control room layout and data information flow are likely. *Project Manager: Anthony Armor*

ENTRAINMENT IN WET STACKS

The use of wet flue gas desulfurization (FGD) systems on power plants has resulted in the widespread use of stack gas reheat systems to improve dispersion and to protect downstream equipment from corrosion. Stack gas reheat systems are expensive and often ineffective in preventing the corrosion of downstream equipment. An alternative to the reheating of flue gas is the use of wet-stack systems. The disadvantage of wet stacks is the danger of corrosion and liquid discharge. The objectives of this analytic and experimental work were to generate new information on the factors that most affect stack operation, such as stack diameter, flue gas velocity, and the flow of condensed liquid on typical liner materials.

A field survey of operational wet-stack installations was conducted to determine the most common design and operational parameters leading to stack liquid discharge. The mechanisms by which the liquid droplets are produced and the size distribution of the droplets were investigated and evaluated. Critical velocities, reentrainment rates, and droplet size distributions were determined for seven different stack liner materials and construction tolerances. Special configurations for wet-stack design, such as the use of a choke to improve plume dispersion of the cold gas and problems associated with use of a choke that can contribute to stack liquid discharge, were evaluated both analytically and experimentally. Based on the understanding of the behavior of the liquid droplet sources obtained, stack liquid discharge control methods and concepts (including specific designs) were developed.

The sources of liquid in a wet stack include mist eliminator carry-over, condensation caused by adiabatic expansion along the path of the duct, and condensation on stack surfaces. This liquid can be reentrained by the shear of the gas flow. The amount and the droplet size distribution of the reentrained liquid were measured and found to be functions of the gas velocity and liner surface materials.

The primary source of liquid in stacks following FGD systems is carry-over from mist eliminators. There is some carry-over of droplets during normal operation, and the amount increases during washing cycles and partially plugged operation. There are no reliable published data describing the efficiency of mist eliminators as a function of gas velocity, liquid load, and number of passes. The quoted efficiency and carry-over are much lower, 0.02–0.2 gr/ft^3, than the limited field data indicate, 0.17–2.0 gr/ft^3. Note: All measurements are actual, not standard, cubic feet.

Thermal models of heat transfer in stack, the condensation analysis, show that the potential grain loading from heat transfer in wet stacks is 0.02–0.07 gr/ft^3 at 20°F (−70°C) ambient temperature and 0.01–0.04 gr/ft^3 at 60°F (16°C) ambient for four selected typical stack liner materials, insulation, and shell configurations. These grain loadings cannot be neglected but contribute only 5–20% of the total potential liquid grain loading in wet-stack systems.

The adiabatic condensation of the gas

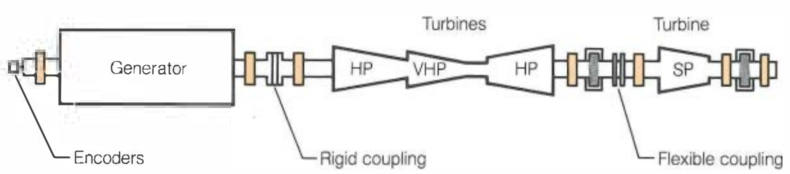


Figure 3 Diagram of high-pressure turbines and generator at Philadelphia Electric Co.'s Eddystone plant. Displacement probes and radial accelerometers are located in the journal bearings (color); axial accelerometers are in the thrust bearings (gray). Encoders record data from a 1-per-revolution sensor and a 64-per-revolution sensor.

stream occurs in the stack from the pressure drop with elevation. Fine droplets and particles in the gas flow act as condensation sites. An example calculation shows that the adiabatic condensation produces a grain loading equal to zero at the bottom of the stack ($\Delta p = 0$), and 1.2 gr/ft³ grain loading at the top of a 1000-ft (300-m) stack ($\Delta p =$ 13 in H_2O). This value is near a maximum limit for tall stacks.

Droplet size distribution and reentrainment

The total liquid loading from mist eliminator carry-over and condensation in typical wet stack installations may range from 0.7 to 3.5 gr/ft³. The amount of this total grain loading that may result in droplet fallout in the plant vicinity is a strong function of the droplet size distribution.

Few data are available documenting the droplet size distribution leaving the mist eliminator. The limited available field data show a mass mean droplet diameter in the range of 100–200 μm. In typical power plant duct designs, droplets in this size range are too large to negotiate the gas flow paths, and they will ultimately contact a solid surface. Only a portion of the very fine droplets, less than 10–50 μm, will follow the gas stream lines. However, these droplets are only 10–20% of the total liquid load.

Adiabatic condensation is a major source of liquid droplets produced in the stack, but it generally produces only small droplets, even with available condensation sites. Only 5–15% of the droplets in the range of 20–200 μm are expected to deposit in the stack. Therefore the majority of the liquid droplets produced by adiabatic condensation will be discharged from the stack and are small enough to be carried by the plume.

Droplets produced by reentrainment are typically in the range of 200–2000 μm, but can be larger than 6000 μm. There are two basic mechanisms of producing liquid droplets by reentrainment: the shear force caused by the gas flow and the dynamic pressure of the gas flow at local flow disturbances on the liquid surface.

Prior to this work, very little was known about the entrainment of water droplets from typical liner materials. Because of the high inertial forces experienced by liquid droplets in the 90° turn at the stack bottom and condensation by cooling along the total height of the stack liner, a liquid film is formed. A significant advance in the state-of-the-art knowledge is the effect of surface roughness and gas velocity on the reentrainment of droplets from liner materials. This work also provides useful design information heretofore unavailable to designers of wet-stack systems.

Two other parameters important for wet-stack design are the critical entrainment velocity and the flow reversal velocity. These two parameters dictate the gas velocity level for the onset of entrainment and the gas velocity at which all the liquid present on the stack liner is dragged upward. These velocities set limitations on wet-stack designs to prevent reentrainment of liquid films and thus stack liquid discharges.

Test results showed that the critical velocities range from 30 ft/s (9 m/s) for ⅛-in (3-mm) radial tolerance brick liner surface to 70 ft/s (21 m/s) for very smooth surfaces, such as Inconel. Large surface discontinuities strongly affect the value of critical velocity. The critical velocity for a zero radial tolerance brick liner surface is reported as 60 ft/s (18 m/s), twice that of the ⅛-in (3-mm) configuration. The stack diameter would have to be increased by 40% to prevent the onset of entrainment.

Quantitatively, reentrainment rates ranged from 3.3×10^{-5} to 7.2×10^{-3} (gal/min)/ft². For a 20-ft (6-m) inner diameter, 300-ft (90-m) stack, this would result in grain loadings of 0.03–8.3 gr/ft³. For all liner materials tested, virtually all the droplets ranged from 50 to 700 μm at all reentrainment velocities. The mass mean droplet diameter measured for all liner materials tested was in the range of 300–600 μm.

Effect of design on droplet discharge

Designing stacks and operating them at the above velocities would result in a low rate of droplet discharge. However, downwash at high wind velocities and insufficient plume dispersion from low discharge velocities represent undesirable stack performance, which can lead to droplet fallout near the stack or ice buildup near the top of the stack.

Good dispersion of the stack discharge usually requires a stack discharge velocity of 75–100 ft/s (23–30 m/s). This can be achieved with a choke on the top of a lower velocity stack. The low gas velocity ensures low reentrainment from the liquid deposited on the liner surface, and the choke reduces the occurrence of the downwash and improves dispersion.

Some droplets entrained in the gas flow will deposit on the choke surface. Depending on local gas velocities in the choke, the liquid deposited can result in stack liquid discharge. The magnitude of this liquid discharge is a function of the choke geometry, gas velocity variation through the choke, droplet size distribution, and the spatial variation of the different size droplets.

A typical mass mean droplet diameter of 300–500 μm could be expected to be reentrained into the gas flow. For a typical choke design with a 2:1 area contraction and a stack gas velocity of 60 ft/s (18 m/s), near the upper limit for wet-stack design, only those 500-μm droplets in the outer 35% of the stack cross-section area will impinge on the stack surface. Droplets up to 250 μm diam will pass through the choke surface. Although this is not a large fraction, liquid tends to be dragged to the lip of the choke and reentrained as much larger droplets.

Liquid collection in chokes was evaluated. The operation of two collectors was observed at stack velocities of 30 and 60 ft/s (9 and 18 m/s) and corresponding choke velocities of 60 and 120 ft/s (18 and 37 m/s). The estimated capture of the liquid film in the two collectors was 60 and 75%. Further development could improve this performance.

Future improvements

Liquid collection in chokes is only one of many concepts and methods that can be used to control stack liquid discharge. Many concepts, in various stages of development, are discussed in the final report, which is now available (CS-2520). Common factors in these concepts include promoting maximum deposition and separation of the liquid, providing protected drainage and collection of the liquid, and minimizing reentrainment by gas shear and turbulence.

Future EPRI work in this area will focus on reducing the liquid loading to wet-stack systems and further development of control concepts. Other problems associated with wet stacks following FGD systems, such as corrosion, are being addressed in ongoing research. The elimination of reheat following an FGD system can save about $6 million per year for a typical 500-MW plant. With this economic incentive, most future designs are expected to use wet-stack systems. *Project Manager: Charles Dene*

COAL CLEANING

The Coal Cleaning Test Facility (CCTF), located in Homer City, Pennsylvania, began operation in October 1981. The facility was designed and constructed by Roberts & Schaefer Co. (RP1400-5) and is operated by Kaiser Engineers, Inc. (RP1400-6). Test plans development and data analysis are provided by Science Applications, Inc. (RP1400-11).

At facility startup, initial attention was given to bias testing the 54 automatic samplers that are installed at strategic points in the

CCTF processing systems. The solids and slurry samplers are representative of available state-of-the-art equipment; however, modifications to the sampling equipment have been required to make it sufficiently accurate for process testing. Results of the sampler validation work will include sampler performance-testing methods, bias test results, data analysis procedures, and guidelines for selection and installation of solids and slurry samplers. While samplers are being validated and modified, sampling is being performed manually according to proven, standard methods.

A formal report on CCTF sampler validation will be available early next year. This report will be of interest to utilities that operate bulk coal-sampling systems for monitoring coal quality at power plant locations. The slurry-sampling test results will also be of interest to utilities and coal suppliers that operate coal-cleaning plants. When the slurry samplers and an on-line slurry ash and sulfur analyzer are demonstrated, the means for on-line process control will be available to cleaning plant operators. The CCTF sampler evaluation and validation program will result in improved coal quality monitoring and control capabilities for utilities and coal producers.

Instrumentation and coal cleanability

Extensive instrumentation is installed on the coal-processing systems to monitor cleaning-system conditions during test runs. This instrumentation is coupled to a digital computer that performs data logging, plant startup, operation, shutdown, and alarming. Considerable effort is required to maintain instrumentation accuracy and debug the computer software because accuracy, rather than relative measurements, is required at CCTF. The computer and all instrumentation calibrated to date have performed satisfactorily. Emphasis is being placed on completing instrumentation verification tests, developing process control strategies, and demonstrating automated on-line control of cleaning operations.

A key CCTF objective is to characterize the cleanability of U.S. steam coals. The effectiveness of coal cleaning on any given coal is chiefly dependent on raw coal characteristics. Other factors, such as mining conditions and end-use specifications, will affect the choice of cleaning process and the economics associated with a cleaning option. If a utility is considering coal cleaning to improve quality, reduce variability, or increase power plant availability, processing the selected coal through CCTF reduces the risk of design deficiencies and unanticipated operating problems. Because CCTF contains conventional, commercial coal-cleaning processes, realistic predictions of full-size plant performance can be made after testing a coal at CCTF. Predictions of fine-coal cleaning process performance based on data generated from a CCTF test program are more accurate than those generated by traditional methods.

A great deal of interest has been expressed in this facet of CCTF by the utility industry. Utilities that have used CCTF to predict fine-coal cleanability (Table 1) include Pennsylvania Power & Light Co., Union Electric Co., The Cincinnati Gas & Electric Co., Pennsylvania Electric Co., and British Columbia Hydro & Power Authority.

Interest in using CCTF to predict cleaning performance has also been shown by the Tennessee Valley Authority, Northeast Utilities, Central Illinois Light Co., and several coal companies, and discussions on work details are continuing. A coal supply for all of 1982 and early 1983 has been secured as a result of the interest shown by these utilities.

Detailed test plan

Coal cleanability characterization is one of three major areas covered in the 1983 CCTF

Table 1
CCTF 1982 COAL CLEANABILITY CHARACTERIZATION TESTING

Test Run	Test Period	Coal Supplier	Major EPRI Objectives	Coal Supplier Benefits
820226	March	Pennsylvania Power & Light Co.	Evaluate water-only cyclone circuit performance	Flowsheet performance data to improve coal-cleaning plant Btu recovery
820701	July	Pennsylvania Power & Light Co.	Evaluate Deister table flowsheet performance	Flowsheet performance data to improve cleaning-plant coal quality and Btu recovery
820308	August	Pennsylvania Electric Co. and New York State Electric & Gas Corp.	Evaluate heavy-media cyclone flowsheet performance	Design data for Homer City commercial plant first-stage heavy-media cyclone circuit
820802	August and November	Union Electric Co.	Characterize Illinois No. 6 cleanability	Investigate deep cleaning to reduce slagging at Labadie Power Plant and (as a result) increase plant capacity
820816	September and October	The Cincinnati Gas & Electric Co.	Compare individual-seam cleaning and combined-seam cleaning	Data to establish optimal coal quality specifications
820910	September and October	British Columbia Hydroelectric Power Authority	Demonstrate cleaning of subbituminous coal Investigate dewatering problems associated with subbituminous coal	Flowsheet data to decide whether or not to clean Application of water-only cyclones to cleaning high-clay-content, low-rank coal
821116	November and December	Pennsylvania Electric Co. and New York State Electric & Gas Corp.	Develop improved ash liberation testing techniques Investigate heavy-media cyclone geometry versus performance	Coal supply comparison Data for performance comparison of competing heavy-media cyclone designs

test plan. The other two are development/demonstration and performance prediction validation. The detailed test plan, developed by Science Applications, Inc. (RP1400-11), has been reviewed by the Coal Quality Program and CCTF committees and will be issued as a formal report late this year after review by the Technical Advisory Committee.

By definition, a coal's cleanability will have been characterized (quantified) when a specific set of CCTF tests have been accurately performed on the coal. The tests include laboratory tests (e.g., float-sink analysis, mineral matter liberation tests, chemical analysis, batch flotation tests), CCTF flowsheet tests, and refuse characterization tests. Test results will allow utilities and others to determine the performance of commercial coal-cleaning flowsheets on a specific coal; the top size to which a coal should be crushed to maximize recovery at a given quality; the relationship between yield and quality obtainable in commercial flowsheets; and methods for avoiding coal and energy losses in the cleaning process.

Tests required to determine actual coal cleanability fall into two categories: characterization of raw coal and its mineral matter liberation, and flowsheet tests. Raw coal liberation behavior will be quantified at top sizes of 1¼ in, ¾ in, ¼ in, and 28 mesh. Seven flowsheet tests are currently proposed for each cleanability characterization.

- Two heavy-media cyclone flowsheet tests with complete performance analysis of all unit operations and complete characterization of clean coal and refuse
- Three heavy-media cyclone flowsheet tests with complete characterization of flowsheet clean coal and refuse
- One water-only cyclone flowsheet test with detailed performance analysis of all unit operations and complete characterization of clean coal and refuse
- One Deister table flowsheet test with detailed performance analysis of all unit operations and complete characterization of clean coal and refuse

The proposed flowsheet tests are considered to be a minimum and will be evaluated before any revisions are made.

The following projects have been identified for 1983 development/demonstration.

- Testing an on-line continuous coal-water slurry sulfur and ash analyzer
- Application of the slurry ash-sulfur analyzer to slurry samplers bias testing
- Demonstration of the feasibility of on-line control of water-only cyclones
- Low-gravity separation of fine coal in heavy-media cyclones
- Demonstration of commercial slurry flow-rate measurement instrumentation
- Demonstration of sludge level control in high-capacity coal refuse thickeners
- Demonstration of clay removal in low-rank western coals
- Demonstration of multistage flotation circuits

CCTF performance prediction validation consists of comparing the performance of a commercial coal-cleaning plant as actually observed and as predicted from CCTF coal cleanability characterization data. Three levels of validation, each with increasing sophistication and complexity, will be evaluated: Level I—prediction of yield and quality at a selected commercial coal-cleaning plant by predictive techniques developed at CCTF; Level II—computation of all commercial plant flow-streams from CCTF raw coal quality and cleanability data and confirmation of these predictions by actual sampling in the commercial plant; Level III—actual testing of a coal sample from a cleaning plant in a duplicate CCTF flowsheet.

Each level of validation serves a different function, although all prove the soundness of the data and methodologies used at CCTF. Level I testing validates the basic yield calculations technique, and Level II testing validates the methods of determining performance of each unit operation under plant conditions. Level III validation pinpoints the differences between CCTF operation and commercial operation, and it determines the extent and nature of these differences.

In addition to the above activities, in 1982 CCTF produced 100 tons of low-ash coal (less than 3% ash) for use in coal-water slurry development demonstration projects. CCTF has also been used for performance testing of fine-coal and fine-refuse dewatering in a belt filter press. These two activities demonstrate the flexible nature of CCTF, a valuable element in a changing and advancing coal-cleaning technology. *Project Manager: Clark Harrison*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

OVERHEAD TRANSMISSION

Transmission line grounding

The final report and computer programs describing improved methods for the design of transmission line structure grounding are available for distribution (EL-2699). Volume 1 describes analytic methods, measurement techniques, and design methodology related to transmission line grounding. Volume 2 contains an extensive set of charts for the design of typical structure grounds. Safe Engineering Services is the contractor.

A software package is available that will analyze grounding designs for a wide variety of structure designs in nonuniform soil. The four programs in the Grounding Analysis of Transmission Lines (GATL) package are as follows.

- LINPA, calculates the self- and mutual impedances of transmission line conductors
- RESIST, interprets earth resistivity measurements
- GTOWER, analyzes the performance of transmission line grounding systems
- PATHS, calculates the distribution of fault current in the transmission line

The two volumes of the final report and the GATL computer programs form an integrated package that meets the widely varying needs of researchers and designers. The report also serves as a comprehensive reference document for engineers with little or no grounding experience.

A short course describing the results of the project and hands-on use of the analysis techniques will be held at EPRI in Palo Alto, May 24–26, 1983. *Project Manager: John Dunlap*

Substation grounding

A more accurate method for analyzing the performance of substation grounding grids is now available to EPRI member utilities (EL-2682). Compared with the popular IEEE Guide 80 method, the new method results in improved accuracy over a wide range of grid configurations and soil resistivities. The contractor, Georgia Institute of Technology, developed a technique that includes the effects of grounding sources other than the substation grid. This technique is a major result of the project. For example, transmission line structure grounds are an additional grounding source if they are connected to the substation via the overhead ground wire. The performance of the substation grid cannot be accurately determined unless all the grounding sources are taken into consideration.

Two forms of analysis have been developed: one consists of simple equations and/or charts that serve as a quick method for analyzing typical grid configurations in uniform soil. The other, which is much more versatile, uses computer programs. Complex grid configurations in nonuniform soil can be analyzed by the software package Substation Grounding Analysis (SGA).

Two programs compose SGA. One is substation maximum earth current computation (SMECC) and analyzes the current distribution among grounded structures inside and outside the substation. SMECC calculates the location and magnitude of the maximum fault current and the maximum rise of ground potential within the substation grounding grid. The second program, substation grounding systems (SGSYS), analyzes the performance of the grid, given the total fault current present. SGSYS calculates the total resistance of the grounding system; step, touch, and transfer potentials; a voltage profile along any line across the substation; and body currents.

Results from these new methods have been compared with measurements made during staged fault tests on a Georgia Power Co. substation, and close agreement was observed. Also, comparisons with scale-model tests have verified the accuracy of the methods developed.

Even though the computer programs perform complex analyses, users will find them relatively simple to input and easy to use. *Project Manager: John Dunlap*

EHV compact transmission line design

EPRI has just completed a project that resulted in phase-to-phase switching surge flashover specifications for compact transmission line designs through 500 kV. This work (RP1492) is an extension of the phase-to-phase flashover work done RP1202 for systems rated through 138 kV (final report, EL-1550).

In the new project, phase-to-phase flashover tests were completed for line dimensions that might apply to compact ratings through 500 kV (24-ft [7-m] conductor-to-conductor spacings) and the effects of varying weather, altitude, types of conductors, line hardware, line length, and height were assessed.

The project was divided into four segments: physical modeling, transient network analyzer (TNA) studies, phase-to-phase flashover testing, and statistical analysis. Advanced statistical methods were used throughout the project to maximize the efficiency of the analyses. The data analyzed included those obtained from the previous study (RP1202), as well as those gathered in this project, for a combined total of over 18,000 test shots.

The significance of this work is that the more accurate results obtained will permit line design engineers to use much less conservative assumptions on both standard and compact line designs. The final report should be available in January 1983. *Program Manager: Richard Kennon*

POWER SYSTEM PLANNING AND OPERATIONS

Advanced concepts application

The EPRI Power System Planning and Operations Program is completing its fourth year of sponsoring a series of projects (now totaling 17) that develop and test new ideas having application in power system engineering. These projects were designed to arrive at new modeling, computing, and analysis techniques. The research topics sponsored were chosen during open solicitations to universities. Three separate contracts under RP1764 that will be completed in 1982 are reported here.

At the University of Pittsburgh, researchers are studying the effect of the way different computers store data internally on the performance of a basic power system planning and operations analytic tool: the power flow program (RP1764-2). Theoretically, when a computer rounds off numbers internally, the total error from this rounding-off can increase the error substantially because of the enormous number of intertwining calculations in a power flow program. Preliminary results indicate this is true. The practical impact and result is a caution that hand-held calculators and personal computers may not be sufficiently precise to do power flow calculations.

In another contract, University of Washington researchers are designing and testing methods of using computer-aided design (CAD) techniques to design and analyze transmission protective systems (RP1764-6). Data requirements, data storage techniques, and computerized methods for automatically coordinating transmission overcurrent and distance relays have already been developed. The protective scheme for an 11-bus, 15–transmission line test system from Puget Sound Power & Light Co. is now being evaluated by using these methods.

Researchers at Purdue University are expanding and generalizing the conventional balanced single-phase power flow program so that it will accommodate the effects of harmonics caused by such nonlinear loads as rectifiers, dc drives, battery chargers, and fluorescent lights (RP1764-7). Harmonics in power systems cause higher losses and, if severe, can cause insulation degradation and equipment overheating and failure. A prototype computer program to analyze the propagation of harmonics up to 2000 Hz is being written and tested, and it will be available from the Electric Power Software Center in early 1983. Typical nonlinear load data required for program use are also being collected. *Project Manager: James Mitsche*

Human factors in dispatch control centers

A recently completed project studied the electric power dispatch control center environment, where power system dispatchers are expected to perform their duties with a minimum of errors (RP1354). The work on this project was divided into three phases, including a survey of design practices now used in dispatch control centers, a list of needs, and recommended changes.

The results of this research project are presented in a six-volume report, *Human Factors Review of Electric Power Dispatch Control Centers* (EL-1960), which includes a summary of the survey results, a compilation of operator needs, and a list of information management and presentation needs.

Phase 1, the survey of human factors in dispatch control centers, focused on the interface between the operator and the system being monitored and controlled. During this phase, 13 dispatch control centers were visited and a total of 48 system operators were interviewed. Volumes 1 and 2 present the results of these site surveys.

The major part of the work in Phase 2 was concerned with the activities within the real-time dispatch domain. The effects of response time, the disruption of the system operator's thought process by time delays, and the inconsistency of response times were studied. Recommendations were made in Volumes 3 and 4 for the timeliness of data, information, and computer system response to operator actions.

The study looked at tools to implement information management and presentation that are on the horizon. Some new tools are barely emerging; others are being considered for a second or third time. New technologies, such as CRT display tubes, flat-panel displays, large-screen systems, and voice recognition and synthesis, were analyzed for future or potential applicability. Volumes 5 and 6 present the practical aspects of system composition from an information management and presentation standpoint, with the operator as a system component. *Project Manager: Charles J. Frank*

UNDERGROUND TRANSMISSION

Thermal stability of soils

Experience shows that a moist soil surrounding a cable undergoes a drying process that occurs in two distinct stages. The first stage consists of a gradual decrease in moisture content, accompanied by a slight increase in thermal resistivity. This stage is characteristic of a thermally stable soil.

The second stage commences when the soil reaches a critical moisture content; the time to reach this stage is called the initial drying time. This thermally unstable stage is characterized by a greatly accelerated drying rate and a rapidly increasing soil thermal resistivity. A matter of concern to utilities is just how stable a given soil is and under what conditions it becomes unstable.

The results of a recently completed research project (RP7883) show that the soil type, soil density, initial moisture content, cable diameter, and cable heat rate per unit length are the most influential factors affecting the soil stability. The first phase of this work involved a detailed analytic model that mathematically simulated the complex process of heat transfer and moisture migration in soil. The second phase consisted of an experimental verification of the predictions provided by the analytic model. Numerous tests were made with thermal probes embedded in reproducible soil samples, and experimental measurements were made in a large tank by using full-size cables as heat sources.

It was found that small laboratory thermal probes could be used to measure initial drying times and that this single value can be scaled up to provide a drying time for any reasonable cable diameter. This technique will allow the cable engineer to operate the system below thermal instability levels and use the full capacity of the system at the same time. This project thus provides cable engineers with an analytic technique that allows them to rate their cable systems with a great deal more confidence than before. *Project Manager: Thomas Rodenbaugh*

Paper-film laminates for pipe-type cables

An advanced three-part laminate insulation system of cellulose paper, polypropylene film, and paper (PPP) for underground cable was described in the November 1980 *Journal*. A prototype 765-kV cable, insulated with this laminate, is in its final year of successful life-testing at the Underground Cable Test Facility, Waltz Mill, Pennsylvania (RP7812).

In a contract with Phelps Dodge Cable & Wire Co. (application of PPP to 138–550-kV pipe-type cables) two prototype cables rated 230 kV and 345 kV have been developed and tested (RP7880). After further testing, trial demonstrations will be recommended with host utilities during 1984.

The laminate concept achieves a combination of the best properties of a polymer film with the quality and service reliability of impregnated-paper insulation. Major material benefits have been achieved by this approach, and these are illustrated in the cable cross sections in Figure 1. The center cross section shows a 345-kV PPP-insulated pipe-type cable readily accommodated in an 8-in (203-mm) pipe, whereas on the right, a 345-kV cable with conventional paper-insulated conductors (3.5 in [89 mm] diam each) requires a 10-in (254-mm) diam pipe. On the left is a 230-kV PPP-insulated cable installed in a 6-in (152-mm) diam pipe that is normally used for 69-kV paper-insulated cables. At the higher voltage, both of the PPP-insulated cables represent a tripling of capacity by uprating the voltage two levels in the same size pipe.

This two-level uprating applied to existing underground pipe structures could defer new cable routes and new construction for underground cable, and costs about one-half those of new circuits could be saved. If all the underground transmission needs rated 138–345 kV for the United States forecast through 1988 are constructed with PPP insulation (431 circuit miles), studies have indicated potential savings of nearly $48 million.

Work on the current project is progressing favorably. Materials studies with two candidate laminate and three dielectric fluids (two polybutenes and a blend of polybutene and alkylbenzene) have indicated excellent stability and compatibility. Cable model tests (using miniature cable samples) have been conducted under accelerated voltage and temperature conditions, and the expected high dielectric strengths and very low dissipation factors have been confirmed. Tests have shown a 75% increase in breakdown strength with increased pressure, a favorable factor for pipe-type cables, which operate at 15–20 atm (1.5–2 MPa).

Two prototype full-scale, reduced-wall cable samples, one rated 230 kV and one 345 kV, have been designed, manufactured, and tested. An analysis of the results indicates that the cable designs and performance levels can be achieved up to impulse withstand levels of 130 kV/mm (3.3 kV/mil). However, special care and procedures must be exercised in precision manufacture to obtain the quality necessary for high-stress cables. Further prototype samples are to be manufactured with improved conductor and insulation structures. Before final prototype designs are recommended in 1983 for trial demonstrations with host utilities, all test data will be analyzed and evaluated by industry experts and advisers.

Two small but important supplementary test projects have been funded—Pirelli Cable Corp. (RP7876-18) and Sumitomo Electric Industries (RP7876-20)—for basic PPP materials tests for ac and impulse breakdown, and these results should be reported in early 1983. *Project Manager: Stephen Kozak*

Thermomechanical bending of pipe-type cables

The laminar structure of oil-impregnated paper-insulated cables is largely responsible for the cables' high dielectric strength. As many as 200 individual paper tapes (0.875–1.5-in [22–38-mm] wide) are precisely applied in a designed overlay pattern, presenting multiple radial barriers in series with the oil-filled butt spaces. When this overlay pattern is disarrayed significantly, an area of reduced dielectric strength results, characterized by wider-than-normal butt spaces and a higher-than-normal number of radially aligned butt spaces. Such an area is known as a soft spot because of its spongy feel under finger pressure. More recently, soft spots have been measured with special hardness testers.

Soft spots can result from either improper tape application or excessive bending during manufacture, test, or installation. Most of the problems related to these operations have been effectively eliminated by application of modern taping theory, practices, and equipment and by rigorous quality control of handling and installation activities.

However, over the last several years, another mechanism of soft spot formation has surfaced in commercial 345-kV cables and experimental 550-kV cables with 1.025-in (26-mm) and 1.340-in (34-mm) insulation thicknesses, respectively. On these cables, irreversible migration of the paper tapes has occurred where the cable flexes during thermal expansion and contraction of the conductor during load cycling.

The commercial (345-kV) problems to date have been confined to early design cables and in joint casings where the cables are intentionally offset to permit splicing. Soft spots at 345-kV have also occurred where oversized casings permit large lateral movement to accommodate both cable migration and expansion.

As a countermeasure, additional special supports (spiders) are now installed on the cables within the joint casing, effectively immobilizing the splice so that thermal expansion must be absorbed within the line pipe. The objectives of a current project (RP7873) are to examine the cables' bending behavior within the line pipe and, through experimental and theoretical analysis, evaluate the mechanism(s) by which soft spots develop. This project is cofunded by the Empire State Electric Energy Research Corp. and is being conducted by Power Technologies, Inc. (PTI).

Accelerated mechanical tests are being done in a three-conductor, 20-ft (6-m) sample length thermomechanical bending (TMB) machine where thermal expansion/contraction is simulated by a hydraulic cylinder pushing/pulling against the three cables at one end. Figure 2 shows a 345-kV cable installed in a 12-in (305-mm) line pipe (oversized).

The testing to date has used cables ranging from 2250-kcmil copper conductor through 3750-kcmil aluminum conductor; insulation thicknesses from 0.620 in (15.7

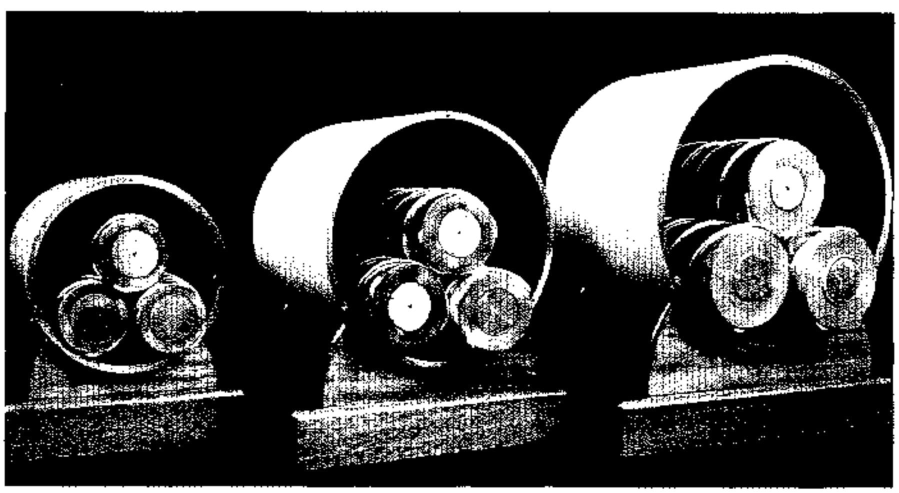


Figure 1 Cross sections of 345-kV and 230-kV high-pressure oil-filled cables insulated with standard paper and paper-film laminates. The cable on the right is a conventional paper-insulated cable in a 10-in (254-mm) pipe, while the same cable with paper-film laminate is comfortably housed in an 8-in (203-mm) pipe (center), and a 230-kV paper-laminate-insulated cable is in a 6-in (152-mm) pipe (left).

Figure 2 Test apparatus demonstrates that thermomechanical bending of underground cable under load is both sinusoidal and helical; soft spots that develop in the insulation can be observed during this type of test. If predictable trends develop, cable designers will be able to recommend steps needed to prevent soft spots from developing.

mm) through 1.250 in (31.75 mm); skidwire materials of zinc, stainless steel, and polyethylene; and pipe diameters of 8, 10, and 12 in (203, 254, and 305 mm). Through this testing, it has been observed that a soft spot does not always develop at the minimum radius bend. Rather, it may develop close to an area where the cables are sliding against the pipe and bending during the compressive part of the cycle corresponding to thermal expansion.

The cables bend within the line pipe in a sinusoidal and helical configuration, but measurements indicate that no rotation of the individual cables about their axis occurs during this bending.

A single-conductor test apparatus was designed and built in which the cable can be tested in one plane rather than the helical configuration in the three-conductor machine. Thus far the result of testing in one plane supports the theory that both friction against the pipe and cable bending are required to develop a soft spot. The single-conductor testing is a very reproducible test method with excellent correlation to actual field behavior of the cable when looking at only one bend.

The testing to date has been on unused cables manufactured within the last few years, except for two tests on cables manufactured and installed in 1973 and removed from service in 1981.

Present tests on modern constructions indicate that the force against the pipe wall and the bending radius will be relieved by another bend before the critical compression and bending radius are reached. Pirelli Cable Corp., a subcontractor for this project, is testing certain of these cable constructions in a 65-ft-long (20-mm) TMB machine. The first tests confirm that the cables will continue to form new bends until the pipe is filled with bent cable. Both the Pirelli machine and the PTI machine simulate past Waltz Mill test facility observations very well. It is believed the bending patterns, especially at small increments of pushing, are very similar to those found in field installations. The specification and testing of TMB-resistant cables based on study results are included in the scope of the project. *Project Manager: John Shimshock*

DISTRIBUTION

Development of a fail-safe surge arrester

A project to develop a nonfragmenting failure mode surge arrester is nearing completion (RP1470). Thus far, we have been successful with 10-kV conventional and metal oxide types, and metal oxide types up to 27 kV are undergoing final design iteration and test.

In this project, the contractor (General Electric Co.) first determined that relatively simple modifications of surge arrester housings would eliminate the very small percentage of cases in which arrester failure was accompanied by housing breakup.

The modifications were first tried on 10-kV arresters (both conventional silicon carbide and metal oxide types) and were found to be effective over a wide range of currents and durations. For the final proof test series, arresters with built-in defects were tested at seven available fault current levels, ranging from 200 A for 125 cycles to 20,000 A for 12 cycles.

To cover the complete range of arresters used on distribution circuits, the same technology was applied to 27-kV arresters. However, it was found that the modifications required for the 27-kV silicon carbide arrester were neither economical nor practical because of its length, so work was discontinued on this arrester.

The 27-kV metal oxide arrester is much shorter than the conventional 27-kV model, and tests on modified designs indicate that we will ultimately be successful in being able to produce fail-safe metal oxide arresters up to 27 kV. This means that distribution systems up to and including 35 kV can be protected with arresters that resist fragmentation.

It has exactly the same protective characteristics, and it is just a little bit larger than the original 10-kV model. One utility has already ordered over 20,000 of the new variety. Other ratings will undoubtedly be made available as the demand grows.

This project is scheduled for completion in March of 1983, and a report will be available thereafter. However, the fragmentation-resistant arrester is already available in the 10-kV rating. *Project Manager: Herbert Songster*

Line clearance

Trees that grow near distribution circuits must be trimmed periodically to keep them clear of the wires; this causes one of the largest single budget items in distribution maintenance and operations. EPRI has already completed one project that addresses problems relating to line clearance, that of developing tree growth retardants (RP214). This was reported in the July/August 1981 issue of the *Journal,* and two reports have been issued: EL-1112 and EL-2569. The project demonstrated that tree growth retardants injected into the tree trunk extended the period between trimming efforts as much as three years.

Another project, started last year, has the broad objectives of designing and producing prototype equipment capable of lowering the costs and improving the efficiency, safety, and flexibility of tree trimming operations (RP1780). There have been only two significant items of equipment introduced in the past 40 years to improve these operations—the lightweight power chain saw and the aerial ladder, or bucket truck. Specific objectives for Phase 1 of this project are to document techniques, methods, and tools used; develop concepts for improved new cutting tools; develop new concepts for improved or new positioning equipment; and analyze and evaluate these new concepts to identify those with the greatest potential for further development.

Researchers in this Phase 1 study have identified five concepts that, with the development and commercialization of the necessary hardware, have the potential for increasing the efficiency of tree-trimming operations. These concepts include the following.

- Pantograph-type linkage, a support for powered pole saws and pruners at the bucket level on aerial lifts
- Mobile platform lift, similar to those used in the orchard industry
- Boom-mounted tool, replacement for the bucket on existing lift trucks and operated from the truck
- Servo-assisted pole saw, for trimming from the ground in back lot locations
- Cut-bundle-chip vehicle, a mechanized vehicle for continuous tree-trimming operations

These concepts, more completely described in the final report (EL-2599), give excellent direction for effective follow-on work in the development of new equipment. *Project Manager: Robert Tackaberry*

ROTATING ELECTRICAL MACHINERY

Torsional fatigue strength of large turbine generator shafts

The goal of a recently completed project (RP1531-1) was to develop an analytic method for accurately predicting the fatigue life of specific turbine generator shafts; this was to be validated by tests on large-size shaft sections (5 in, 127 mm, in diameter) of various alloys and configurations, such as notches and slots. This information was to be made available to the utilities in such a form that it could be used in planning future expansions on their specific power generation systems, modifying existing system operating practices if and where required, and quantifying the fatigue damage sustained by a turbine generator shaft during a torsional transient.

The final product of the project is a digital computer program. The program contains a fatigue damage algorithm verified by large-specimen testing. The work under this project was reported to utilities in a seminar held in Denver, Colorado, July 15–16, 1982.

The project has produced extensive torsional fatigue data on turbine generator rotor material specimens up to 5 in (127 mm) in diameter. The effects of high- and low-cycle fatigue, material damping, size, notch geometry, and loading sequence have been evaluated experimentally. The data and analysis have served as a basis for the development of a computer model for the assessment or prediction of torsional fatigue damage in turbine generator shafts. *Project Manager: D. K. Sharma*

Improved motors for utility application

This project addresses the need to improve the reliability and efficiency of powerhouse auxiliary drive equipment through advanced concepts and design techniques. Efficient, cost-effective electric generation is directly dependent on the reliability, availability, and maintainability of this auxiliary equipment.

Powerhouse auxiliary drives (e.g., fans, pumps, compressors) account for a significant percent of the total energy consumption in the United States. Improvements in electrical drive efficiency would decrease total energy consumption, thus increasing the available generation capacity.

The overall objectives of this project were to evaluate the present reliability of powerhouse motors, to identify and develop new technologies and manufacturing techniques to improve reliability and efficiency, and to study the application of powerhouse motors to determine if new modes of operation would improve reliability and efficiency (RP1763-1). The first goal was the identification and documentation of current reliability issues associated with powerhouse auxiliary motors. Information obtained from the Industry Assessment Study (IAS) was to be the basis for establishing improved specifications and identifying needed developments.

The IAS has been completed and results are being published by EPRI in a two-volume report (EL-2678). In this study, failure data on power plant motors were collected from utilities that represented most classes of generating equipment (oil, coal, nuclear) and varieties of climate, geographic location, and operating conditions. The IAS data base covers a total of 4797 motors. Fifty-six utilities participated in the survey, and a total of 132 generating units were represented. The actual data collection from utilities was done by Booz, Allen & Hamilton, Inc., and the names of motor manufacturers and participating utilities are known only to EPRI and Booz, Allen & Hamilton. The data gathered will be the basis for improved motor specification and identification of needed developments for power plant motors. Volume 1 of the final report is the statistical and engineering analysis of the IAS data by General Electric, the prime contractor on the project. Volume 2 is the data and analysis by Booz, Allen & Hamilton, the subcontractor to General Electric. The analysis in this volume focuses on motor reliability. The two volumes are complementary.

The scope of IAS includes generating units rated 150 MW and larger; the motors are those rated 100 hp (74.6 kW) and larger, at 440 and 575 V, and all motors with voltage ratings 2.3 through 13.8 kV. Out of 4797 motors in the survey, a total of 872 motors failed (some more than once), with a total of 1227 failures reported. The failures were categorized by motor components: 41% of the failures were bearing-related, 37% were stator-related, 10% were rotor-related, and the remaining 12% were due to miscellaneous causes. Bearings and stators are thus the failures occurring most frequently.

The results of IAS were presented at an EPRI workshop in St. Louis, Missouri, September 24–25, 1981. The data analysis has identified three broad areas for further research on the subject of improvements: motor data collection and operation, motor technology, and motor application (RP1763-2). Motor technology improvement efforts include work on bearings, stator windings, and squirrel cage rotor windings. Motor application improvement efforts include studies on bus transfer; conveyor, pulverizer, and fan drive; and the impact of harmonics on motors.

As part of IAS, a separate survey was undertaken to identify any experience utilities have had with vacuum switching devices for the control and protection of generating station motors. The survey results are in Volume 1, but when interpreting them, one should keep in mind that the vacuum switchgear survey data base was relatively small.

Overall, this report presents important and useful information on motor failure modes and failure causes from a motor technology viewpoint, and it gives insight into utility application and operating practices. *Project Manager: D. K. Sharma*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

OIL IMPORT INTERRUPTIONS: IMPACT ON ELECTRICITY SUPPLY

An important short-term uncertainty faced by the United States today involves oil supply disruptions. As demonstrated in 1973–1974 and 1979, oil import interruptions can follow from a variety of events not easily foreseen. This is particularly troublesome because of the importance of oil in ensuring a reliable electric power supply. In a letter to the North American Electric Reliability Council (NERC) in 1980, DOE urged the electric utility industry to make coordinated efforts in energy emergency planning. To provide information for such industry contingency planning, EPRI—in cooperation with an advisory group from NERC—has sponsored a study examining the effects of oil import interruptions on the costs and reliability of service in the electric utility industry (RP1153-3).

The study examined alternative national policies for allocating scarce oil supplies among electric utility regions during an emergency. It also examined certain utility industry strategies that could reduce electricity outage costs, namely, the use of utility-held oil inventories and the interregional transfer of electricity. The examination of costs was limited to electric reliability regions, and the findings are not intended to provide insights into the operations of individual utilities.

The methodology employed is similar to that of a previous EPRI study on electricity demand uncertainty (EA-1446). In that study the Baughman-Joskow Regionalized Electricity Model (REM) and decision analysis techniques were used to analyze the effect of demand growth uncertainty on optimal capacity expansion plans from the viewpoint of customers. REM, a model that links supply, demand, and regulatory and financial behavior in a single integrated framework, was modified to accommodate NERC load and capacity projections. The model had been assessed favorably by the Massachusetts Institute of Technology in a previous EPRI project (EA-1071).

In the present study REM was used to estimate the costs and electricity outages associated with various oil supply disruption scenarios, and a sequential decision analysis model was constructed to explicitly incorporate uncertainties about the occurrence and nature of disruptions. Five oil import interruption scenarios were considered (Table 1).

Alternative national policies

The study first examined two possible national policies for coping with oil shortages following an import interruption and compared their effects on the cost and reliability of electricity service. The alternatives considered were (1) reliance on market forces, and (2) federal allocation of oil supplies and price controls. The first policy implies higher prices and a voluntary reduction in fuel oil consumption without incurring electricity outages. The second implies lower prices and an equal percentage reduction in fuel oil consumption for all utility regions.

The effects of these policies can be summarized under the categories of outage costs and fuel oil costs. The major findings regarding outage cost effects are as follows.

- Outage costs per unit (i.e., the value placed on an unserved kilowatthour during utility service interruptions) will be an important determinant of the total costs associated with the alternative policies.

- Total outage costs (i.e., per-unit outage costs times unserved energy) can be very high with federal allocation and price controls.

- For oil import interruptions of long duration, reliance on market forces is preferable because outage costs are avoided.

- With federal allocation of oil supplies, any rationing scheme implemented by utilities to curtail consumer electricity use will be a

Table 1
OIL IMPORT INTERRUPTION SCENARIOS

	National Utility Fuel Oil Shortage		
	Amount (10^6 bbl)	Percent of Base Case Consumption	Price of Crude Oil ($/bbl)
Case 1	22	5	41
Case 2	40	9	46
Case 3	65	14	55
Case 4	77	17	60
Case 5	123	27	82

Note: The projected base case (1981) fuel oil consumption by utilities is 460×10^6 bbl. The base case oil price is $35/bbl. Oil prices are derived from the Baughman-Joskow Regionalized Electricity Model.

critical determinant of the amount of the outage costs.

The major findings regarding the effects of the policies on fuel oil costs are as follows.

- The higher fuel oil prices resulting from shortages in world oil supply will add 3–15% to the electric utilities' national fuel bill if reliance is placed on market forces.
- The electric utilities' national fuel bill will rise 1–7% if the federal allocation and price control policies examined in this study are adopted.
- The projected national average electricity cost increases may not reflect regional electricity cost increases. For instance, regardless of the oil allocation policy adopted, the Northeast will experience electricity cost increases nearly three times the national percentage increase because of its dependence on oil-fired generation.

Table 2
TOTAL SOCIAL COSTS OF ALTERNATIVE OIL ALLOCATION POLICIES
(1981 $ million)

	Reliance on Market Forces	Federal Allocation and Price Controls	
		Priority Curtailment	Nonpriority Curtailment*
Case 1	1,500	1,500	14,000
Case 2	2,600	2,700	25,000
Case 3	4,500	4,700	40,900
Case 4	5,600	5,700	48,700
Case 5	10,000	10,400	77,100

*A value of $1.00/kWh is assigned to unserved energy.

A comparison of the total social costs (the sum of outage costs and fuel costs) of the two national policies is shown in Table 2. The impact of federal allocation and price controls is dependent on the rationing scheme adopted by utilities to curtail consumer electricity use. Two different rationing schemes were considered in this study: priority curtailment and nonpriority curtailment. The former assumes that utilities could curtail service to lowest-marginal-value users first; in the latter a $1.00/kWh outage cost is assigned to service loss.

Utility actions

The study then investigated the value of certain utility actions that might reduce outage costs if federal allocation and price control policies were adopted.

Given a set of subjective, but not unreasonable, assumptions about the likelihood of oil supply disruptions of various magnitude and duration, the results show that utility oil stockpiling and drawdown are very effective means of offsetting the adverse economic effects of disruptions. For instance, the analysis found that the use of existing inventories (as of January 1981) could reduce the total cost of the disruptions to electricity consumers by about 80%.

Under a wide range of assumptions, the optimal inventory size was found to be between 20 and 120 days of normal consumption supply. This result is particularly sensitive to two factors: (1) the value of an unserved kilowatthour during electric utility service interruptions, which depends on the rationing scheme adopted to curtail electricity use, and (2) aggregate economic conditions outside the electric utility sector. However, a detailed investigation of these two factors was outside the scope of this project.

A brief analysis of interregional electricity transfer revealed that it is currently being used to near maximum potential because it is an economical source of energy; thus it would probably offer little relief during oil supply interruptions.

A more detailed discussion of this study can be found in the final report (EA-2464). *Project Manager: Hung-po Chao*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Director

FEEDWATER HEATER FLOW TESTS

All modern large steam power plants use a process of regenerative feedwater heating to increase overall thermodynamic efficiency. Several problems have contributed to the unreliability of nuclear plant feedwater heaters. One of these, identified at an EPRI workshop in March 1979 (WS-78-133), is the effect of tube-side (water-side) flow on the erosion and corrosion of tube inlets. Tube inlet erosion is a gradual wastage of metal on the inside of a tube along the first several inches from the inlet end. It is associated with the relatively high turbulence of the water coming into the tube from the heater's inlet channel. To gain an understanding of water velocity and turbulence effects on in-tube erosion—an understanding necessary to improve flow characteristics in feedwater heater channels and tubes—Joseph Oat Corp. has developed and tested scaled mock-ups of feedwater heaters with typical channel and nozzle configurations (RP1722).

The typical closed feedwater heater is a shell-and-tube heat exchanger (Figure 1). To provide for the feedwater inlet and outlet nozzles, three basic shapes of channel sections are used: cylindrical, elliptical, and hemispherical. The channel configuration, along with the location of the feedwater inlet nozzle on the channel, plays a larger role in determining the flow characteristics near the tubesheet face and inside each tube.

Erosion is most prevalent in carbon steel tubes in feedwater heaters, particularly those in high-pressure service. Reducing the fluid velocity somewhat mitigates erosion. However, lower velocities reduce the rate of heat transfer and thus increase heat exchanger costs. Even with lower design velocities, high localized velocities can be produced by turbulence and vortices. The current Heat Exchange Institute standards for closed feedwater heaters allow a maximum feedwater

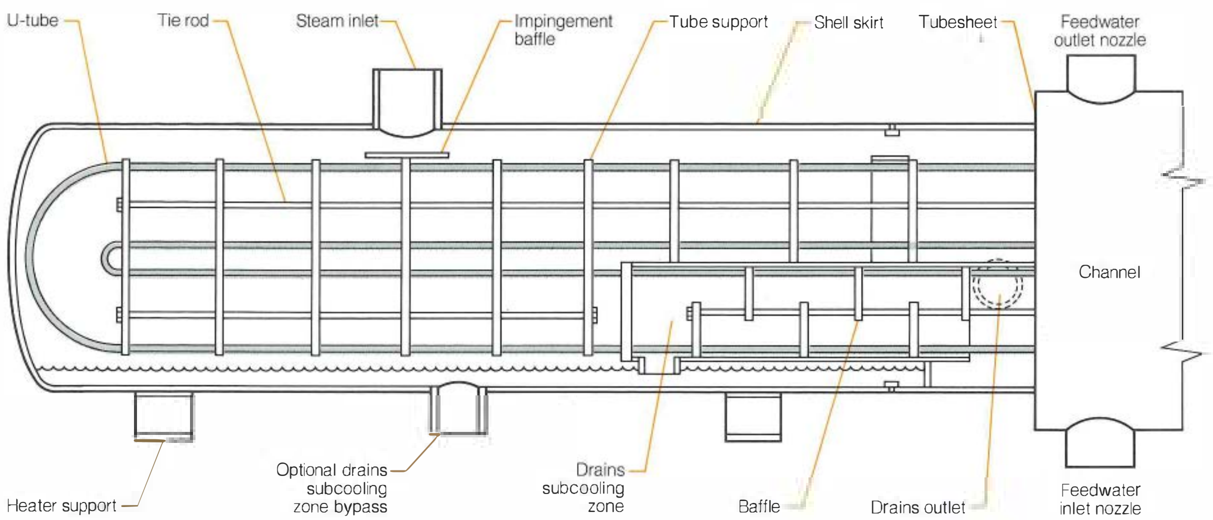


Figure 1 Typical two-zone (condensing and subcooling) feedwater heater. EPRI has sponsored scale-model flow tests to study the effects of water velocity and turbulence on tube inlet erosion for various channel and feedwater inlet nozzle geometries.

velocity of 8 ft/s (2.44 m/s) for carbon steel tubes; 8.5 ft/s (2.59 m/s) for admiralty brass and copper tubes; 9 ft/s (2.74 m/s) for copper-nickel tubes; and 10 ft/s (3.05 m/s) for stainless steel, Monel, and Inconel tubes.

Feedwater velocity and turbulence effects created by inlet channel configurations are not yet completely understood. This has resulted in differences between foreign and domestic feedwater heater manufacturers, and even among domestic manufacturers, concerning the acceptable range of feedwater velocity for a given tube material. The objectives of this EPRI-sponsored effort are to determine the tube erosion effects of in-tube and inlet channel velocities and turbulence for various typical geometries; to examine flow improvement devices for mitigating erosion, reducing pressure drop and turbulence levels, and distributing flow evenly for a more effective use of each tube; and to provide a supplement to existing guidelines for the specification and procurement of feedwater heaters.

In this work scaled Plexiglas models of feedwater heater inlet channel sections (scaling factor of 3.67) were constructed so that flow characteristics could be both seen and measured. Provisions were made in each model design to accommodate various methods of flow improvement (e.g., flow straighteners, guide vanes, and baffles) and various off-design conditions (e.g., plugged tubes). Three inlet configurations were modeled: a cylindrical channel with the inlet nozzle situated 90° from the heater centerline; a hemispherical channel with the inlet nozzle situated 45° from the heater centerline; and a hemispherical channel with the inlet nozzle situated parallel to the centerline. Plexiglas tube sections were also used so that in-tube velocity profiles could be measured.

The test loop consisted of a 2300-gal/min ($0.145\ m^3/s$), 60-hp (45-kW) pump; the three Plexiglas feedwater heater inlet channel models in series; a cool-water holding tank; a 1-μm filter for water clarity; and a flowmeter (Figure 2). To determine flow profiles, average velocity measurements were made at several points along the face of the tubesheet in the inlet channel section and along the internal diameter of selected tubes. Velocities were measured by a laser-Doppler velocimeter. This technique can accurately and instantaneously determine localized velocities at any point in the flow, thus permitting highly turbulent flows and flow reversals to be measured. The major advantages of the device are that no probe (which may disrupt the flow) and no calibration are required. From instantaneous local velocities measured at any given point over a given time period, mean velocity and turbulence intensity (a dimensionless ratio of the standard deviation of the velocity distribution to the mean velocity) can be calculated. Mercury manometers were used to measure pressure drop across each model.

Initial experiments were conducted at various flow rates corresponding to average tube fluid velocities typically experienced in power plant feedwater heaters (4.5–9.0 ft/s; 1.37–2.74 m/s). However, preliminary results showed that within this normal flow-rate operating range, the Reynolds number was sufficiently high that velocity distribution and turbulence intensity remained constant. (Mean velocity changed proportionally with the flow rate.) Consequently, all further experiments were run at the same flow rate.

The results from testing the three basic channel geometries have established a baseline for comparing flow improvement methods. Without flow improvement aids, the hemispherical channel with the feedwater inlet nozzle situated 45° from the heater centerline gave the lowest pressure drop and turbulence level of the three channel configurations. The cylindrical channel configuration showed the highest turbulence and pressure drop.

Flow instabilities in the inlet channel result in unstable, highly turbulent flows at the entrance of and inside the tubes. It is important to reduce turbulence intensities because rapid changes in flow velocity and direction result in sharp pressure fluctuations, which may cause cavitation. To reduce the potential for erosion at the tube entrance, the flow velocity profile should be oriented along the tube axis. The remainder of the test program was scheduled to attempt to achieve this through the use of various flow-straightening devices and perforated face plates. The program was also scheduled to investigate the effects of tube protrusion past the tubesheet surface, plugged tubes, and inlet nozzle location.

The future of this work is uncertain, however, in light of recent developments. The original carbon steel tubes in virtually all nuclear plant feedwater heaters are being replaced by tubes or tube inserts made of stainless steel, which provides effective protection against erosion. In the interim, erosion of carbon steel can be mitigated through

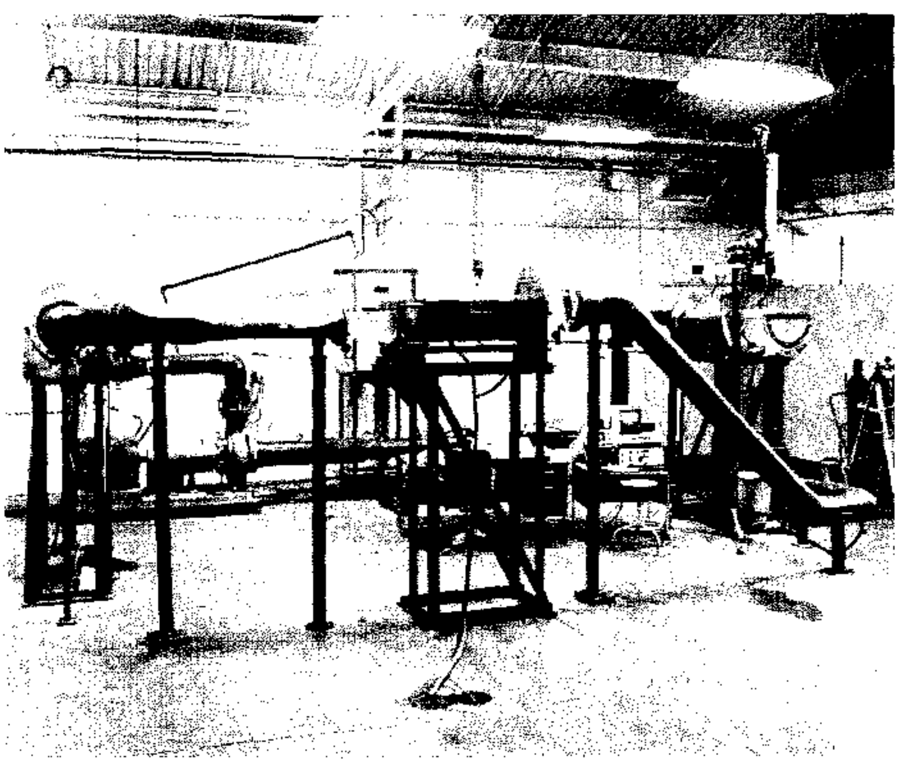


Figure 2 Feedwater heater flow test system. The three inlet channel scale models are connected in series. Above the model with the cylindrical channel configuration (far right) can be seen the laser-Doppler velocimeter, which can measure localized fluid velocities instantaneously and unobtrusively.

proper control of pH, dissolved oxygen, and turbulence (flow distributors have already been developed and successfully used). Thus it may not be necessary to continue research on tube inlet erosion. A detailed report summarizing all project work completed to date is being prepared. A review of this report will determine whether further research is required and cost-effective. *Project Manager: Norris Hirota*

MITIGATION OF IGSCC IN BWR STAINLESS STEEL PIPING

The objectives of the intergranular stress corrosion cracking (IGSCC) research program of the Boiling Water Reactor Owners Group are to extend the service lifetime of austenitic stainless steel piping systems in BWRs and to minimize outage time for repairs and inspections. This major four-year program (1980–1983) is jointly sponsored by EPRI and the owners group, which at this time includes 22 utilities in the United States and 11 in other countries. The program is divided into three tasks: problem resolution, remedy development, and remedy application. This article reviews the status of remedy development.

Pipe-cracking remedies—engineering solutions for the mitigation of stress corrosion cracking—are logically divided into three categories. These are associated with the three main contributors to IGSCC in welded type-304 stainless steel piping: weld sensitization, tensile stresses above the yield stresses of the material, and the reactor coolant environment. The relationship of these factors is illustrated in Figure 3.

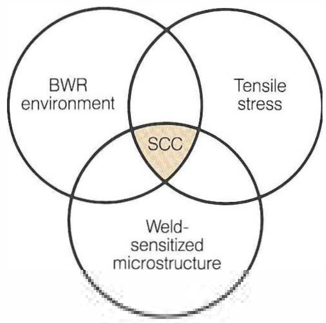


Figure 3 Three conditions must be present for stress corrosion cracking (SCC) to occur in welded type-304 stainless steel: a sensitized microstructure, tensile stress, and a facilitating environment. Thus three types of BWR pipe-cracking remedies are being explored, each aimed at reducing the severity of one of these conditions.

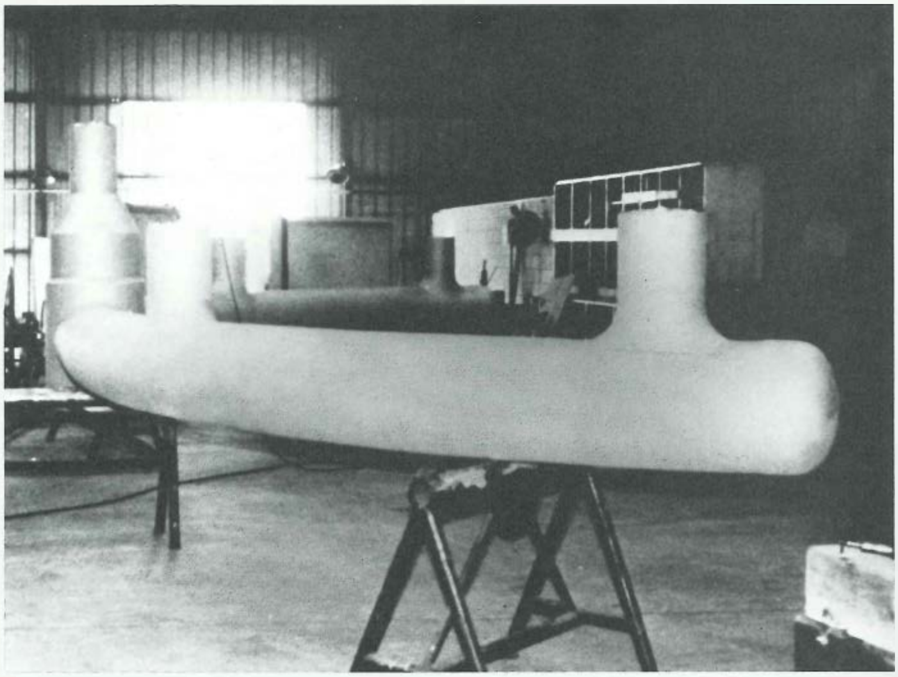


Figure 4 Shop-fabricated BWR recirculation pipe subassembly ready for shipping. Before welding, corrosion-resistant cladding was applied to the inside of the pipe at the weld joints, and the pipe was subjected to solution heat treatment to eliminate sensitization at the interface of the cladding and the base material.

Sensitization-related remedies

Three sensitization-related pipe-cracking remedies have been developed and qualified for field use: solution heat treatment, corrosion-resistant cladding, and alternative pipe materials.

A weld-sensitized microstructure is characterized by the precipitation of chromium carbide particles at the grain boundaries in the heat-affected zone of the 304 stainless steel. During solution heat treatment, which is performed at 1065°C (1950°F), these carbide particles are dissolved. In this metallurgical condition, the material is nonsensitized. To prevent reprecipitation of chromium carbide particles and resensitization of the stainless steel, the welded pipe section is immediately quenched in water.

This remedy provides another benefit—the elimination of weld residual stresses. Because the yield stress of 304 stainless steel at 1065°C (1950°F) is very low, the weld residual stresses are relieved through a process of creep. Thus this remedy eliminates two of the three contributors to IGSCC.

The second sensitization-related remedy, corrosion-resistant cladding, involves putting a lining of weld metal inside the pipe before the joint is welded. Weld metal with controlled levels of ferrite is extremely resistant to IGSCC in BWR environments. When type-308L weld metal with a minimum ferrite content of 8 vol% is applied inside a 304 stainless steel pipe weldment, it will protect the sensitized region from the environment.

Two versions of the corrosion-resistant cladding process have been developed—a shop method and a field method. In the shop method (Figure 4), the pipe with the cladding inside is solution-heat-treated and water-quenched. The purpose of the heat treatment is to eliminate sensitization at the interface of the cladding and the pipe base material. A variety of approaches have been used.

The field application technique is for use in the repair of piping in operating plants. In this case, a solution heat treatment is not practical. To minimize the level of sensitization at the cladding–base material interface, a low weld heat input is specified in this area. Beyond this area, normal welding practices may be used.

Manual welding or automatic machine

welding may be used in depositing the cladding. Machine welding is preferred, particularly in operating plants, because it reduces the exposure of skilled operators to radiation. Final machining of the clad pipe is performed to provide the necessary configuration for the closure weld.

The third sensitization-related technique is the use of alternative piping materials. One of the key factors in determining weld sensitization in 304 stainless steel is the carbon content. Reducing the carbon content of the steel to levels that will remain in solution in the austenite structure during pipe welding will avoid sensitization. Although levels are not precisely defined, carbon concentrations of less than 0.03 wt% appear to meet the requirements. In fact, commercial grades of 304L stainless steel (which have a maximum carbon content of 0.035 wt%) have performed extremely well in limited BWR piping applications.

In current steelmaking processes, carbon can be controlled to very low levels with only a modest increase in price. Given the commercial availability of low-carbon austenitic stainless steel, the research program focused on the evaluation of alternative materials. A major R&D effort culminated in the qualification of two materials: type-304 and type-316 nuclear-grade stainless steels. The important chemistry controls were the maximum limits on carbon and nitrogen—0.02 wt% and 0.10 wt%, respectively. With this chemical balance, the mechanical properties of the nuclear-grade materials—most important, the yield stress—are the same as those of 304 stainless steel. Thus the use of these materials does not require a redesign of the piping system or an increase in pipe wall thickness. In addition, the other metallurgical characteristics and the weldability of the nuclear-grade materials are identical to those of conventional 304 and 316 stainless steels.

Stress-related remedies

These remedies are used during or after the welding operation to change the residual stress distribution typical of conventionally welded pipe. Included in this category are heat-sink welding, last-pass heat-sink welding, and induction heating stress improvement.

As its name implies, heat-sink welding provides for a method of heat dissipation during welding. In this process flowing water, stagnant water, or sprayed water is applied after the root pass and several layers of weld metal are deposited. Initially, the process was designed to reduce the level of sensitization by lowering temperatures in the heat-affected zone. Although this was accomplished to a degree, the most significant effect was on the residual stress distribution. Heat-sink welding results in compressive residual stresses on the inside surface and partially through the wall of the heat-affected zone. The benefits of compressive residual stresses are that they prevent the initiation of stress corrosion cracking and retard its propagation. The primary application of heat-sink welding is in the repair of 304 stainless steel pipes in operating plants.

Last-pass heat-sink welding is a variation of heat-sink welding. Analytic studies involving the calculation of residual stresses resulting from heat-sink welding showed that the final state of residual stress in the weld was related to the conditions of the last weld deposit (the weld crown). Thus, in last-pass heat-sink welding, water cooling is used only during weld crown deposition to achieve compressive residual stresses on the inside surface and partially through the wall of the pipe weld. The level of sensitization, however, is expected to be greater than with heat-sink welding; it would be essentially the same as that produced in conventional welding.

Work on last-pass heat-sink welding is in progress to determine the best procedures and to quantify the benefits through pipe testing. When fully qualified, the process (like heat-sink welding) is primarily intended to be used in field applications without other pipe remedies.

The process of induction heating stress improvement was developed in Japan for use in operating plants and plants under construction that have 304 stainless steel piping. An induction heating coil located on the outside diameter of the pipe weld is used to bring the outside surface to a temperature of approximately 500°C (932°F); the inside temperature is maintained at 100°C (212°F) by flowing water. During the heat-up cycle, the outside surface is in compression and the inside surface is in tension. These stresses are reversed after the pipe weld cools down. This process can be performed in several minutes (the exact time depends on the pipe size and configuration), and the degree of sensitization in the weld does not change. Development work on this process has been completed, and assistance in technology transfer is being provided to the utility owners.

Environment-related remedies

These pipe-cracking remedies are based on the alteration of BWR water chemistry. Two concepts are presently under investigation. One involves startup deaeration; the other, hydrogen water chemistry.

At the startup of a BWR, the coolant water normally contains 8000 ppb of dissolved oxygen. This oxygen is released as the coolant heats up, and at approximately 200°C (392°F) a steady-state value of 200–300 ppb is reached. Because oxygen is known to enhance the susceptibility of 304 stainless steel to stress corrosion cracking, laboratory experiments were performed to determine if deaeration before startup would provide a solution to the problem.

The experimental results showed deaeration to have a beneficial effect; however, stress corrosion cracking continued to occur at the steady-state oxygen levels. On the basis of these experiments, startup deaeration is not considered to be a pipe-cracking remedy, although it may be beneficial in reducing the propensity for cracking.

The other environment-related remedy being explored entails the introduction of small quantities of hydrogen into the feedwater. The hydrogen combines with the radiolysis-produced oxygen in the reactor (200 ppb under steady-state conditions), thus reducing the dissolved-oxygen content of the primary coolant. By controlling the oxygen content at low levels (10 to 20 ppb), IGSCC of welded 304 stainless steel is prevented. When applied in operating plants, this remedy may well arrest existing cracks and permit IGSCC-free operation for the plant lifetime.

The first in-reactor experiments were performed in Sweden at the Oskarshamn-2 BWR, designed by ASEA-Atom. These short-term experiments demonstrated the feasibility of reducing the steady-state oxygen content by adding hydrogen. Later experiments of longer duration duplicated the earlier results; oxygen levels in the water coolant were controlled at levels that do not support stress corrosion cracking in welded or furnace-sensitized 304 stainless steel. Other in-reactor experiments, jointly sponsored by EPRI, DOE, and Commonwealth Edison Co., are in progress at Commonwealth Edison's Dresden-2, a BWR designed by General Electric Co.

On the basis of these experiments, the hydrogen water chemistry approach appears to be an attractive pipe-cracking remedy that could be applied in operating plants with very low installation and operating costs. Before this remedy is implemented, however, additional laboratory and long-term in-reactor experiments will be needed to determine possible system side effects. These include effects on various materials (fuel cladding, high-strength nickel-base alloys, pressure vessel materials, and tur-

Table 1
PIPE REMEDY DEVELOPMENT AND IMPLEMENTATION IN U.S. PLANTS

Remedy	Status
Sensitization-related	
Solution heat treatment	Development work completed; used in plants under construction that have type-304 stainless steel piping
Corrosion-resistant cladding	Development work completed; used in new plant construction and in repairs at operating plants
Alternative materials	Type-316 nuclear-grade stainless steel used in new plant construction and in repairs at operating plants
Stress-related	
Heat-sink welding	Development work completed; used in plant repairs
Last-pass heat-sink welding	Under development
Induction heating stress improvement	Development work completed; used in plants under construction
Environment-related	
Startup deaeration	Development work completed; used in a plant under construction
Hydrogen water chemistry	Under development

bine materials), crud release from the fuel, nitrogen-16 activity release, and hydrogen recombination.

Implementation

Since the start of the program a number of pipe-cracking remedies have been developed, qualified, and implemented in repairs at operating plants and in new plant construction. An important consideration in implementation is NRC acceptance according to the NUREG-0313 revision that provides relief from the augmented in-service inspection of welded 304 stainless steel piping. The accepted pipe remedies are solution heat treatment, corrosion-resistant cladding, and the use of nuclear-grade materials. Heat-sink welding and induction heating stress improvement will be considered on a case-by-case basis.

The status of each remedy is summarized in Table 1. With the exception of the hydrogen water chemistry technique, all the remedies will be developed and qualified for BWR implementation by the time the program is completed in 1983. *Program Manager: Joseph Danko*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP1348-14	Scoping Study: Molten Salt Solar Electric Experiment	3 months	74.7	Bechtel Group, Inc. *J. Bigger*
RP1604-4	Support Studies: Two-Stage Coal Liquefaction	1 year	49.3	University of Wyoming *N. Stewart*
RP1662-1	Alternative Technologic Pathways for Fusion	7 months	98.6	TRW, Inc. *N. Amherd*
RP2049-6	Emissions Sampling, Utility Diesel Synfuel Tests	4 months	59.4	Battelle, Columbus Laboratories *H. Schreiber*
RP2112-1	Evaluation of Coal-Derived Liquids as Utility Boiler Fuels; Western Test	4 months	229.0	Southern California Edison Co. *H. Schreiber*
RP2147-6	Reactive Solvent System for Coal Solubilization	1 year	56.3	University of Detroit *L. Atherton*
Coal Combustion Systems				
RP1030-22	CONAC Utility Applications	9 months	60.1	Bechtel Group, Inc. *O. Tassicker*
RP1179-15	Regenerable Cement Sorbent for SO_2 Control in FBC	5 months	58.2	Brookhaven National Laboratory *S. Ehrlich*
RP1871-5	Failure Mechanisms of Coatings Used in FGD Systems	2 years	207.1	Lehigh University *B. Syrett*
Electrical Systems				
RP996-2	Compact Capacitor/ Filter	8 months	311.6	Westinghouse Electric Corp. *S. Nilsson*
RP996-3	Compact Capacitor/ Filter	27 months	38.4	ASEA *S. Nilsson*
RP1468-2	Reliability Data Models for Transmission Outage Performance	17 months	135.3	Commonwealth Research Corp. *N. Balu*
RP2115-4	Critical Problems in Developing HVDC Converter Stations for Voltages Above 600 kV	1 year	50.0	Themag Engenharia *S. Nilsson*
Energy Analysis and Environment				
RP1104-6	Workshop: Value of Service Reliability to Consumers	9 months	125.0	Criterion Incorporated *A. Halter*
RP1614-1	Combining Supply and End-Use Alternatives	1 year	199.6	General Electric Co. *D. Geraghty*
RP2050-11	Assessment of Implementation Mechanisms, Electric Utility-Sponsored Conservation Programs	8 months	84.9	Synergic Resources Corp. *C. Gellings*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Energy Management and Utilization				
RP1090-3	Heat Storage Data Analysis and Reporting	5 months	46.3	Carrier Corp. *V. Rabl*
RP1136-17	Electric Vehicle Performance Testing	6 months	107.0	Tennessee Valley Authority *B. Askew*
RP1676-5	Performance of the Solid-Oxide Fuel Cell, Using Externally Reformed Natural Gas	6 months	47.5	Westinghouse Electric Corp. *J. Appleby*
RP1791-12	Underground Cavern Excavation and Lining Analysis	7 months	142.6	Cementation West Inc. *R. Schainker*
RP1940-3	Electric Utilities and Cogeneration: 1982 Survey	5 months	60.0	Synergic Resources Corp. *S. Hu*
RP2036-6	Survey of Alternative Materials for Off-Peak Electric Resistance Heat Storage	6 months	41.1	Dynatech R/D Co. *V. Rabl*
Nuclear Power				
RP1066-8	Applications of the Steam Generator Code ATHOS–TF, Phase 1	3 months	89.8	Jaycor, Inc. *G. Srikantiah*
RP1393-6	Workshop: Nuclear Power Plant Maintenance	6 months	81.9	Pickard, Lowe and Garrick, Inc. *T. Law*
RP1398-12	Microkinetics of Stress Corrosion Cracking in Steam Turbine Disk Alloys, Phase 3	8 months	171.9	SRI International *M. Kolar*
RP1447-3	Transformation of Iron Species During Sampling From PWRs	5 months	51.1	Science Applications, Inc. *T. Passell*
RP1560-2	Postaccident Kr 85 Effluent Control	7 months	42.7	Science Applications, Inc. *M. Naughton*
RP1561-6	PWR Transient Test Documentation, SONGS-2	15 months	123.5	Combustion Engineering, Inc. *P. Bailey*
RP1618-5	Stress Corrosion Crack Mitigation in Nickel Base Alloys	3 years	299.6	Rensselaer Polytechnic Institute *D. Cubicciotti*
RP1733-4	Analysis of Jet Expansion and Impingement Loads	10 months	128.8	S. Levy, Inc. *A. Singh*
RP1803-5	Design and Fabrication of Steam Turbine Disk NDE Test Bed Facilities	8 months	207.4	Southwest Research Institute *S. Liu*
RP2058-7	Literature Survey of Carbon and Alloy Steel Fastener Corrosion in PWR Plants	5 months	32.9	Combustion Engineering, Inc. *A. Giannuzzi*
RP2126-2	BWR Feedwater Digital Control and Analytic Level Measurement	2 months	54.7	Systems Control, Inc. *S. Divakaruni*

New Technical Reports

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

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

Requests for copies of specific reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081. There is no charge for reports requested by EPRI member utilities, government agencies (federal, state, local), or foreign organizations with which EPRI has an agreement for exchange of information. Others in the United States, Mexico, and Canada pay the listed price. Research Reports Center will send a catalog and complete price list (including foreign prices) on request.

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ADVANCED POWER SYSTEMS

Centaur Gas Turbine Modification and Development for Solar-Fossil Hybrid Operation

AP-2550 Final Report (RP1270-1); $10.50

This report documents a project to design the modifications necessary to adapt a commercial gas turbine to solar-fossil hybrid operation. The design, performance, and operating requirements for commercial Brayton-cycle solar-thermal power plants are described, and their impacts on plant turbogenerators are outlined. Bench-scale test results indicate that a modified Centaur unit would perform in a normal manner during startup, steady-state, and transient operations. The contractor is Solar Turbines, Inc. *EPRI Project Manager: J. E. Bigger*

Detailed Simulation of a Moving-Bed Gasifier

AP-2576 Final Report (RP1268-1); $16.50

This report reviews the development of a computer simulation code for modeling the design and operation of commercial-size dry-ash and slagging moving-bed coal gasification reactors. The capabilities of the model, a two-dimensional transient version of a previous model, are described; the results of limited model tests are presented; and a preliminary comparison of these results with published data is made. The contractors are the University of Delaware and the Massachusetts Institute of Technology. *EPRI Project Manager: G. H. Quentin*

Combustion Test of SRC-Oil Mixture: Technical Study on SOM Fuel for Oil-Fired Power Plants

AP-2580 Final Report (RP1412-7); $13.50

This report summarizes the results of an investigation of solvent-refined coal–oil mixtures (SOMs) as a fuel for oil-fired utility boilers. It discusses the conversion of heavy fuel oil to SOM fuel at existing oil-fired power plants; the necessity of reinforcing pollution control facilities to conform to emission standards; and the need to develop facilities for storing and transporting high-concentration SOM slurries. The contractor is the Central Research Institute of the Electric Power Industry (Japan). *EPRI Project Manager: H. H. Gilman*

Benefits to Utility Systems of Coproduction of Methanol and Electricity

AP-2587 Final Report (TPS81-781); $9.00

This report discusses the potential economic benefits to electric utility systems of coproducing methanol and electricity in baseload coal gasification–combined-cycle power plants. (The methanol would be produced by a once-through synthesis process.) The evaluation considered two utility systems, one predominantly oil-fired and the other predominantly coal-fired. The contractor is Zaininger Engineering Co. *EPRI Project Manager: B. M. Louks*

Advanced Cooling Full-Scale Engine Demonstration Program

AP-2605 Final Report (RP1319-1); $28.50

This report evaluates the practicality and economic desirability of applying water cooling to the first-stage turbine nozzles (stators) of a near-term utility gas turbine power plant. Water-cooled nozzles were fabricated and tested. The required engine design modifications were planned, and engine cost, heat rate, and cleaning cycles were evaluated. The deposition characteristics of ash-containing fuel were measured over a range of metal temperatures. The contractor is General Electric Co. *EPRI Project Manager: Arthur Cohn*

Illinois No. 6 Coal Tests on Ruhrkohle-Ruhrchemie's 165-t/d Texaco Gasifier

AP-2607 Final Report (RP1799-1); $7.50

Results are presented from tests conducted in 1980 on Ruhrkohle and Ruhrchemie's 165-t/d Texaco gasifier at Oberhausen, West Germany. The test coal was Illinois No. 6. The report discusses single-pass carbon conversion, postrun measurements, cold-gas and overall efficiency percentages, and dynamic performance. The contractors are Ruhrkohle and Ruhrchemie. *EPRI Project Manager: John McDaniel*

Thermal Barrier Coatings for Gas Turbines

AP-2618 Final Report (RP1039); $10.50

Laboratory combustion tests were conducted to help determine the potential of thermal barrier coatings for use in utility gas turbines. The premature failure of coatings in combustion gases containing alkali and vanadium is discussed, as are the coatings found to be acceptably durable when used with clean fuels. The effects of gas and metal temperatures, fuel impurities, water washing, cycling, and pressure on coating durability are documented. The contractor is the National Aeronautics and Space Administration. *EPRI Project Manager: Arthur Cohn*

Assessment of Distributed Photovoltaic Electric Power Systems

AP-2687 Final Report (RP1192-1); $28.50

This report documents a study to develop a methodology for assessing the potential impact of distributed photovoltaic systems on electric utility systems, including subtransmission and distribution networks, and to apply that methodology to several examples. The methods developed are described, the quantitative results of the utility case studies are reported, and conclusions based on these results are presented. The contractor is JBF Scientific Corp. *EPRI Project Managers: F. R. Goodman, Jr., and E. A. DeMeo*

COAL COMBUSTION SYSTEMS

Cofiring of RDF and Coal at Oak Creek: Boiler Slagging and Fouling Evaluation

CS-1983 Final Report, Vol. 2 (RP898-1); $9.00

An evaluation of the potential for slagging and fouling in a coal-fired boiler cofiring a mixture of coal and refuse-derived fuel (RDF) was conducted at Wisconsin Electric Power Co.'s Oak Creek Units 7 and 8. This effort included short-term furnace optimization studies for coal and coal plus RDF; laboratory studies on ash fusion for various mixtures of coal, RDF, glass, and aluminum; and analyses of deposits taken from various boiler locations after coal-RDF cofiring. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: C. R. McGowin*

Engineering Assessment of an Advanced Pulverized-Coal Power Plant

CS-2555 Final Report (RP1403-2); $27.00

This report describes a study of the potential for improving the thermal performance of conventional pulverized-coal power plants. By comparing the performance of the base plant (725 MW, 3500 psig, 1000/1025/1050°F) with the advanced plant (725 MW, 4500 psig, 1050/1075/1100°F), the study showed that an improvement of about 10% in heat rate can be achieved with advanced steam conditions, improved component efficiencies, and novel waste heat recovery devices. The contractors are General Electric Co., Stone & Webster Engineering Corp., and Babcock & Wilcox Co. *EPRI Project Managers: A. F. Armor and D. V. Giovanni*

Landfill Disposal of Limestone Dual-Alkali FGD Waste

CS-2559 Final Report (RP1405-1); $22.50

This report documents an industrial-scale landfill disposal program to demonstrate the feasibility of fly ash–lime stabilization of flue gas desulfurization (FGD) sludge from a limestone dual-alkali scrubber. It describes the installation of a waste-handling and -blending system and the construction of a lined, diked landfill disposal site, which was filled with a waste mixture of FGD filter cake, fly ash, and lime. The comparison of field samples with laboratory mixtures is discussed, and the results of laboratory revegetation studies are detailed. The contractor is Thyssen Environmental Systems, Inc. *EPRI Project Manager: D. M. Golden*

Coal Waste Artificial Reef Program, Phase 4A

CS-2574 Interim Report (RP1341-1); $27.00

This report discusses the environmental acceptability of coal waste blocks used to form an artificial reef in the Atlantic Ocean off Long Island, New York. Results are presented from several biological studies conducted to determine the success of the coal waste blocks as a substrate for colonizing organisms. The structural integrity of the blocks is also addressed. The contractor is Marine Sciences Research Center. *EPRI Project Manager: D. M. Golden*

Observation and Analysis Work Associated With a 1000-Hour Test Program in a PFBC Facility

CS-2582 Topical Report (RP979-3); $15.00

This report presents an analysis of the results from a 1000-hour test program in a pressurized fluidized-bed combustion (PFBC) facility. The test facility is described, and test observations and nominal operating conditions are summarized. A survey of models available for investigating fluidized-bed combustion mechanisms is discussed, and the test data are compared with predictions from two models, one that addresses elutriation in fluidized-bed systems and one that addresses cyclone performance. The contractor is Fluidised Combustion Contractors Limited. *EPRI Project Manager: John Stringer*

Workshop Proceedings: R&D Needs for Use of Fly Ash in Cement and Concrete

CS-2616-SR Special Report; $24.00

This report details an EPRI workshop held in Palo Alto, California, in March 1981 to determine if R&D on fly ash and on cement and concrete products containing fly ash could help stimulate fly ash usage and identify profitable research areas. Panel topics included fly ash production, fly ash utilization, and long- and short-term R&D needs. Fly ash use in various countries was reviewed. *EPRI Project Manager: W. T. Bakker*

Engineering Evaluation of Projected Solid-Waste Disposal Practices

CS-2627 Final Report (RP1728-1); Vol. 1, $18.00; Vol. 2, $25.50

This report documents the results of an engineering cost assessment of various control technologies that may be required by the evolving regulations under the Resource Conservation and Recovery Act. Volume 1 summarizes the national cost impacts of different levels of environmental control. Volume 2 contains the eight case studies that served as the basis for estimating these cost impacts. The contractor is Michael Baker, Jr., Inc. *EPRI Project Manager: D. M. Golden*

ELECTRICAL SYSTEMS

Transmission System Reliability Methods

EL-2526 Final Report (RP1530-1); Vol. 1, $28.50; Vol. 2, $13.50

This report summarizes a project to develop probability methods for the steady-state reliability evaluation of combined generation and transmission systems of an electric utility. Volume 1 summarizes the mathematical models, computing methods, and results; Volume 2 contains the computer program documentation. The contractor is Power Technologies, Inc. *EPRI Project Manager: N. J. Balu*

New Methods and Chemicals to Control Regrowth in Trees

EL-2569 Final Report (RP214-2); $12.00

This report presents a study of new methods and chemicals for controlling growth in trees that interfere with overhead electrical distribution lines. A portable, air-powered injection system was developed, and numerous growth retardants were tested in both the greenhouse and the field. The transport and metabolic fate of injected chemicals were also addressed. The contractor is the U.S. Department of Agriculture. *EPRI Project Manager: R. S. Tackaberry*

Development of Improved Tree-Trimming Equipment and Techniques: Phase 1

EL-2599 Final Report (RP1780-1); $27.00

This report evaluates present tree-trimming techniques and tools, identifies possible improvements, and develops new concepts for cutting tools and positioning equipment. Data collected by a computer-based literature search, a patent search, and surveys are discussed. The decision analysis methodology used to evaluate new concepts is presented. Economic considerations—development costs, benefit-cost ratios, and savings to average-size utilities—are summarized for the most promising concepts. The contractor is Asplundh Environmental Services. *EPRI Project Manager: R. S. Tackaberry*

Analysis Techniques for Power Substation Grounding Systems: Design Methodology and Tests

EL-2682 Final Report, Vol. 1 (RP1494-2); $16.50

This volume discusses procedures for analyzing the performance of complex grounding grids. Complex computerized analysis procedures applicable to general grounding systems are presented, as well as simplified graphic procedures that produce accurate results for simple grid structures and that can be used in the preliminary analysis of more complex systems. The limitations and accuracy of the simplified procedures are defined. The contractor is the Georgia Institute of Technology. *EPRI Project Manager: J. H. Dunlap*

ENERGY ANALYSIS AND ENVIRONMENT

Eastern Regional Air Quality Measurements

EA-1914 Final Report, Vol. 1 (RP1630-1); $16.50

This report documents the eastern regional air quality measurement project, which extended for 14 months the comprehensive aeromatic measurement initiated under the Sulfate Regional Experiment (SURE). Volume 1 describes the measurement methods and protocols, the data capture, and the process of data access for research and analysis purposes. The contractor is Environmental Research & Technology, Inc. *EPRI Project Manager: G. R. Hilst*

Energy Supply Restrictions: Energy System and Economic Effects

EA-2553 Final Report (RP1152); $13.50

This report examines the effects of changes in energy supply conditions on the electric power industry, the energy system, and the U.S. economy to the year 2000. Various combinations of supply restrictions are defined, and their quantitative effects are assessed by using a simulation model. The contractor is Dale W. Jorgenson Associates. *EPRI Project Manager: E. V. Niemeyer*

Electric Appliance Energy Consumption Survey: Analysis and Revision of MRI Data

EA-2565 Final Report (RP576-2); $12.00

This report summarizes work to improve and analyze the residential energy use data base originally prepared as part of RP576-1. This data base contains electricity and gas billing information, itemized appliance stock data, appliance energy use data, and information on socioeconomic characteristics collected from almost 2000 households. The process of detecting and correcting errors in the data is described, as is the construction of data on a number of related variables. Analyses of the electricity billing data and the energy consumption data from individually metered electrical appliances are included. The contractor is Cambridge Systematics, Inc. *EPRI Project Manager: S. D. Braithwait*

TELPLAN Electric Utility Corporate Planning Model: User's Guide

EA-2581 Final Report (RP1318); Vol. 1, $22.50; Vol. 2, $18.00

This report is a user's guide for TELPLAN, a corporate planning model designed to simulate electric utility capacity expansion and unit-specific capital, fuel, operating, and pollution control costs in response to load growth, environmental regulations, and alternative fuel choices. Volume 1 documents model input, output, and methodologies. Volume 2 presents more-complete sample input and output for three representative utilities. The contractor is Tera Advanced Services Corp. *EPRI Project Managers: D. M. Geraghty and P. F. Ricci*

Leachability and Aqueous Speciation of Selected Trace Constituents of Coal Fly Ash

EA-2588 Final Report (RP1061-1); $10.50

Feed coal, fly ash, and ash pond effluents from 11 large power plants in the southeastern United States are characterized. The bulk content of several inorganic elements in 22 fly ash samples collected from cyclones and electrostatic precipitators is correlated with the feed coal content. The aqueous chemistry of arsenic in ash ponds is examined in detail, and the results of laboratory leaching studies investigating the release of arsenic from the solid phase are presented. The contractor is Oak Ridge National Laboratory. *EPRI Project Managers: R. M. Perhac and I. P. Murarka*

Price Elasticities of Demand for Energy: Evaluating the Estimates

EA-2612 Final Report (RP1220-1); $30.00

This report evaluates available econometric research on the demand for energy products. It addresses studies that focus on the sensitivity of fuel consumption to changing economic incentives and that analyze the final demand for specific fuels by separate consuming sectors. Five categories of estimation issues involved in analyzing demand behavior are identified, and individual models are discussed with respect to these issues. A critique of available literature and recommendations for future research directions are included. The contractor is Resources for the Future, Inc. *EPRI Project Manager: A. N. Halter*

ENERGY MANAGEMENT AND UTILIZATION

Aquifer-Based CAES: Preliminary Design and Site Development

EM-2351 Final Report, Vol. 3 (RP1081-3); Part 1, $13.50; Part 2, $27.00

This two-part volume covers the site selection activities of a study that assessed the viability of an aquifer-based compressed-air energy storage (CAES) facility. Potential sites were identified and ranked, and one was selected to serve as the host site in a preliminary design of a CAES facility. The contractors are Sargent & Lundy Engineers and Public Service Co. of Indiana, Inc. *EPRI Project Manager: R. B. Schainker*

Modeling of Long-Term Decay in the Molten Carbonate Fuel Cell

EM-2596 Final Report (RP1085-5); $9.00

This report documents a study to construct a mathematical model of the mechanisms of electrolyte loss from a molten carbonate fuel cell and to identify operating parameters that might have a significant effect on this loss. The contractor is Physical Sciences, Inc. *EPRI Project Manager: A. J. Appleby*

EPRI–TVA Pilot Electric Vehicle Demonstration Project: Phase 1

EM-2600 Final Report (RP1136-5); $13.50

The electric vehicle (EV) operating experience gained during Phase 1 (March 1978–June 1981) of this joint EPRI–TVA demonstration project is summarized. The report focuses on the testing and evaluation of 10 Volkswagen EVs (5 buses and 5 vans) operating in a real-world environment. Vehicle maintenance, service facilities, data acquisition systems, and system energy efficiency are described. The contractor is the Tennessee Valley Authority. *EPRI Project Managers: G. H. Mader and F. H. Klein*

NUCLEAR POWER

BWR Large-Break Simulation Tests

NP-1783 Interim Report, Vol. 2 (RP495-1); $39.00

This volume presents appendixes that contain (1) the results of a scoping-test series and (2) data reports on the large-break simulation tests. The contractor is General Electric Co. *EPRI Project Manager: S. P. Kalra*

Homogeneous Nonequilibrium Critical Flow Model

NP-2503 Final Report (RP1754-4); $9.00

The development of a simplified nonequilibrium flashing model is reported. The isentropic process used to calculate the nonequilibrium stream quality and the critical flow rate is discussed, as is the liquid decompression pressure drop (or superheat) feature of the model. The contractor is S. Levy, Inc. *EPRI Project Manager: L. J. Agee*

Value Assessment Aid to Complex Decision Making

NP-2507 Final Report (RP1391-4); $13.50

This report presents a value assessment methodology for multiple-criteria decision problems. The four major stages of the methodology are discussed: the evaluative process, multiple-criteria decision analysis, cost-benefit or cost utility analysis, and standardization and quantitative comparison. The generic character of the methodology allows for broad application to any problem characterized by multiple criteria and conflicting objectives. The contractor is Southwest Research Institute. *EPRI Project Manager: J. M. Huzdovich*

Portable Monitor for the Determination of Reactor Coolant Surface Radionuclide Activities

NP-2523 Interim Report (RP825-2); $9.00

This report describes the design and construction of a lightweight gamma-ray spectrometer that can tolerate conditions around reactor coolant circuit components and thus can be used to monitor radioisotopes on surfaces in LWR power plants. The testing of the equipment at a PWR is also discussed. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. A. Shaw*

Value-Impact Methodology for Decision Makers

NP-2529 Final Report (RP1810-3); $13.50

This report presents a case study illustrating the use of a value-impact methodology in nuclear safety system design analysis. Multiattribute decision theory is combined with reliability, availability, and probabilistic risk assessment techniques to analyze design alternatives for the auxiliary feedwater system of a specific nuclear plant. Decision attributes in the areas of financial impact, investment risk, health risk, and licensability are used to rank the alternatives. The contractor is General Atomic Co. *EPRI Project Manager: A. G. Adamantiades*

Proceedings: Technology Transfer Workshop

NP-2562 Proceedings (WS81-234); $22.50

A workshop was hosted by EPRI and Battelle Memorial Institute in September 1981 in Seattle to generate a better understanding of technology transfer, which was defined as the process and resources needed to move from problem definition to general acceptance of a technology. Presentations and discussions addressed relevant theories, the importance of early planning, possible organizational structures to help promote the process, identifying incentives, and personalizing the process. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: G. J. Dau*

Electric Generator Monitoring and Diagnostics

NP-2564 Final Report (RP970-2); $15.00

This report presents test results on radio-frequency monitoring to detect internal generator arcing and to alert the operator if the arcing level becomes destructively high. It also presents test results on fiber optic temperature sensors used to detect hot spots in generator stator windings—a high-voltage and high-electromagnetic-flux environment. Suggestions for further research are made. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: H. G. Shugars*

Improving Ultrasonic Inspection Reliability

NP-2568 Final Report (RP1448-1); $13.50

This report documents three studies into ultrasonic signal analysis. The first study addressed signal fidelity as a function of couplant thickness and defined a method for continuously verifying couplant adequacy for manual inspections. The second study developed a procedure for the digital recording of ultrasonic signals. The third study addressed the characterization of ultrasonic pulser-receiver transducer systems and identified system parameters that can be measured to characterize system performance. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: G. J. Dau*

Passive Neutron Dosimetry for Measurements at the McGuire Reactor

NP-2570 Final Report (RP772); $9.00

Passive metal foils and powdered oxides were installed in the cavity outside the McGuire station reactor pressure vessel to monitor the fast neutron levels to which the vessel wall is exposed. This report presents a detailed description of the foils and their installation. The contractor is IRT Corporation. *EPRI Project Managers: H. A. Till and T. O. Passell*

Information System for Generation Availability: System Specification

NP-2571 Final Report (RP1391-6); $19.50

This report, a general system specification, presents the results of a study into the functional software and hardware requirements for a proposed national data system (Information System for Generation Availability). Typical implementation costs, a pilot program startup cost estimate, and two levels of service possible with the information system are identified. The contractor is TRW Energy Development Group. *EPRI Project Manager: J. M. Huzdovich*

Development of Reload Safety Analysis Methodology and Code Package: Uncertainty Analysis

NP-2577 Final Report (RP1761-4); $10.50

The development of a statistical methodology proposed for use with the EPRI reactor analysis support package is described. The uncertainties in the basic PWR code package are examined as a whole and on a code-by-code basis. Advanced statistical techniques, such as stochastic simulation, are discussed and suggested for application where appropriate. The uncertainties are combined into a revised specified acceptable fuel design limit. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: G. S. Lellouche*

Mechanisms of Environmental Cracking in Systems Peculiar to the Power Generation Industry

NP-2589 Final Report (RP1332-1); $18.00

This report concerns the stress corrosion cracking (SCC) of materials used in the electric utility industry, with special emphasis on type-304 stainless steel and 3Cr-Mo low-alloy steel. A slip-dissolution model is used to describe SCC. In this model SCC is controlled by the rupture rate of the protective oxide film at the crack tip, the speed of film repair, and the rate at which the metal dissolves before the film is repaired. The report relates these rate-controlling processes to variables of engineering significance, such as stress, vibration, dissolved oxygen, and metallurgical conditions. The contractor is General Electric Co. *EPRI Project Managers: M. J. Fox, A. J. Giannuzzi, J. C. Danko, and R. Smith*

PWR Power Plant Pump Reliability Data

NP-2592 Interim Report (RP1233-1); $9.00

This report describes the collection and analysis of failure and repair data for pumps in PWR plant operating and safety systems. Failures are classified by failure mode, cause, and part. Different approaches to aggregating the data are presented, and failure parameters are estimated under each approach. Common-cause failures are identified, a repair time distribution is estimated, and the unavailability of pumps in different systems due to repair is calculated. The contractor is Science Applications, Inc. *EPRI Project Manager: D. H. Worledge*

Condenser Inleakage Monitoring System Development

NP-2597 Final Report (RPS182-1); $13.50

This report describes the design and fabrication of an instrument-hardware package for locating air and condenser cooling-water inleakage by means of helium and Freon techniques. The package consists of design details for tracer gas distribution hardware, injection plenums, and a sample preconditioner and instrument module. Results from in-house detector testing and a field demonstration show the helium technique to be preferable. The contractor is NWT Corp. *EPRI Project Manager: R. L. Coit*

Effect of Momentary Loss of Primary Coolant on a Developing Natural Circulation

NP-2598 Interim Report (RP1731); $10.50

As a partial simulation of the Ginna transient, a series of thermal-hydraulic experiments were performed in a 1/30-scale PWR-like test facility to assess the effect of momentary loss of primary coolant on a developing natural circulation. The test matrix and the data obtained are discussed. The contractor is SRI International. *EPRI Project Manager: J. P. Sursock*

Parametric Study of CHF Data

NP-2609 Final Report (RP813); Vol. 1, $15.00; Vol. 3, Part 1, $55.50; Vol. 3, Part 2, $28.50

This report details the compilation of critical heat flux (CHF) data from tests conducted over a 20-year period. Volume 1 describes the experimental facilities used to obtain the data, including the test loops and sections and the instrumentation, and describes the range of test conditions. An error analysis of the results is also given. Volume 3 (in two parts) presents the actual data. Volume 2 (forthcoming) will address the development of a general CHF correlation. The contractor is Columbia University. *EPRI Project Manager: Mati Merilo*

Boiling Heat Transfer in a Narrow Eccentric Annulus

NP-2610 Final Report (RPS133-1); $19.50

This report describes the fundamental boiling processes that occur in the crevice between a tube and a tube support plate in a PWR steam generator for the geometry of a circular tube hole with adjacent flow holes. Visual observations and tube wall temperature measurements are compared and used to develop a description of the crevice boiling processes. An approximate semitheoretical model is proposed to describe the extent of an existing dry patch and the resulting steady tube wall temperature profile. The contractor is Northwestern University. *EPRI Project Manager: C. L. Williams*

Main Coolant Pump Shaft Seal Reliability Investigation

NP-2611 Interim Report, Vol. 1 (RP1556-1); $9.00

A survey of reactor coolant pump shaft seal reliability was conducted. This volume identifies operationally incurred or induced problems and seal redesign parameters. Failure hypotheses in the form of fault trees are presented, as well as recommendations for seal reliability improvement. The contractor is Borg-Warner Corp. *EPRI Project Manager: M. J. Kolar*

Natural Circulation Experiments in a UTSG Four-Loop Test Facility

NP-2615 Interim Report (RP1731-1); $9.00

This report describes the final series of single- and two-phase natural circulation tests performed in a four-loop U-tube steam generator (UTSG) facility. Results are presented for over 20 experimental conditions, including asymmetric cooling, hot leg and cold leg cold-water injection, noncondensable gas injection in the upper head, occasional two-phase natural circulation, continuous two-phase natural circulation, and reflux condensation. The contractor is SRI International. *EPRI Project Manager: J. P. Sursock*

Stress Corrosion Cracking of Alloys 600 and 690 and Weld Metals No. 82 and No. 182 in High-Temperature Water

NP-2617 Interim Report (RP1566-1); $9.00

This report presents the results of laboratory tests on the intergranular stress corrosion cracking (IGSCC) of Alloys 600 and 690 and weld metals No. 82 and No. 182 in a simulated BWR environment. The test explored the interaction of stress, environment, and metallurgical conditions. Results indicate that when creviced, Alloy 600 and the two weld metals are susceptible to various degrees of IGSCC in oxygen-containing pure water; they are immune when uncreviced. Alloy 690 is immune under all conditions. The contractor is Southwest Research Institute. *EPRI Project Manager: A. R. McIlree*

Decay Heat Removal Experiments in a UTSG Two-Loop Test Facility

NP-2621 Interim Report (RP1731-1); $16.50

This report documents a year-long experimental project in a two-loop U-tube steam generator (UTSG) test facility; the project is part of a continuing research program aimed at developing a data base for future code verification. Steady-state single- and two-phase tests involving natural circulation, reflux boiling, phase and loop transition, transition between forced and natural circulation, small-break loss-of-coolant accident simulation, and noncondensable gas injection are described. The contractor is SRI International. *EPRI Project Manager: J. P. Sursock*

TMI-2 Mechanical Component Information and Examination Program Plan and Progress Report

NP-2625 Interim Report (RP1544-2); $16.50

This report details a five-year program plan for collecting, recording, and interpreting information from in situ and laboratory examinations of mechanical components exposed to accident and postaccident conditions at TMI-2. Candidate components for the examination program are listed in terms of value to the industry, and rough cost estimates for implementation are made. The status of the recovery and examination of two components selected to serve in prototype demonstrations, mechanical snubbers and reflective insulation, is presented. The contractor is International Energy Associates, Ltd. *EPRI Project Manager: R. K. Winkleblack*

Safeguards for Spent-Fuel Storage With Fuel Rod Consolidation

NP-2626 Final Report (RP2062-2); $10.50

This report assesses the safeguard requirements associated with storing spent nuclear fuel and evaluates the impact these requirements have on advanced storage concepts. Rod consolidation in spent-fuel storage pools is studied as the selected advanced storage technology. A review of existing NRC regulations is included, as well as comments from representatives of organizations involved with spent-fuel programs. The contractor is INET Corp. *EPRI Project Manager: R. W. Lambert*

LMFBR Thermal-Striping Evaluation

NP-2672 Interim Report (RP1704-11); $12.00

This report details a study of damage in LMFBRs caused by thermal striping, a fluctuating temperature field that is imposed on a structure when fluid streams at different temperatures mix near the structure surface. Included are (1) a program plan that identifies needs and presents specific tasks to define damage experienced by ordinary construction materials, (2) a description of the thermal-striping test facility and its operation, and (3) results from the preliminary test phase. The contractor is Rockwell International Corp. *EPRI Project Manager: Joseph Matte III*

Nuclear Component Wear Measurements

NP-2684 Final Report (RP1567); $7.50

This report describes the development and demonstration of techniques for measuring the quantities of cobalt released to the primary coolant by wear of high-cobalt alloys. Field measurements were performed on several cobalt-containing components, including various BWR valves and the journal portion of a PWR main coolant pump shaft. The project demonstrated that obtaining field wear measurements of in situ nuclear components is practical. The contractor is Battelle, Columbus Laboratories. *EPRI Project Manager: M. D. Naughton*

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