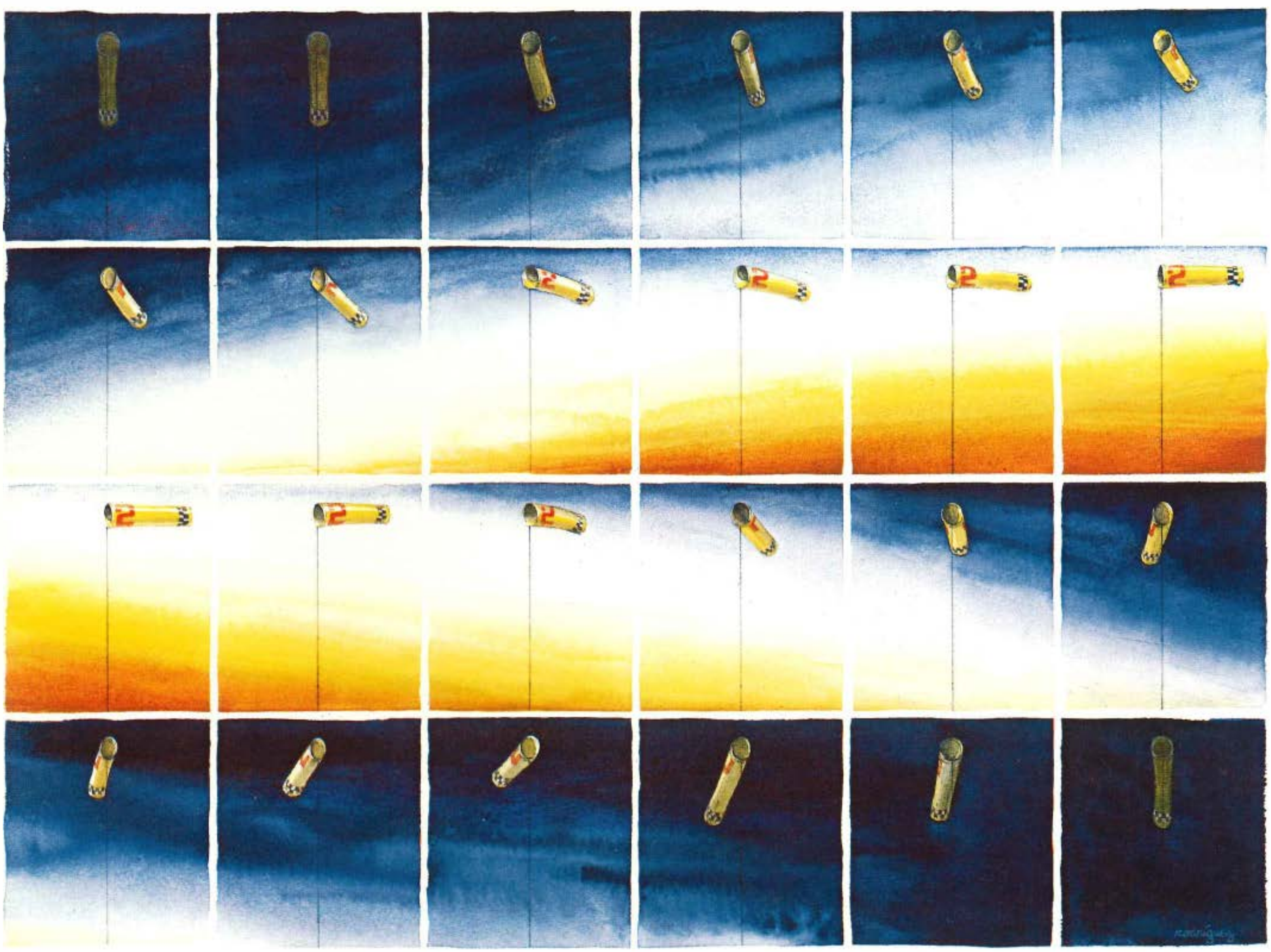
Going With the Wind

ELECTRIC POWER RESEARCH INSTITUTE

EPRI JOURNAL

MARCH
1980



EPRI JOURNAL is published by the
Electric Power Research Institute.

EPRI was founded in 1972 by the nation's electric utilities to develop and manage a technology program for improving electric power production, distribution, and utilization.

EPRI JOURNAL Staff and Contributors
Brent Barker, Editor
Ralph Whitaker, Feature Editor
Nadine Lihach, Feature Writer
Jenny Hopkinson, Feature Writer
David Dietrich, Technical Editor
Susan Yessne, Production Editor
Pauline Burnett, Copy Chief
Jim Norris, Illustrator
Marie Newman (Washington)
Barry Sulpor (Public Information)
Dan Van Atta (News Bureau)
John Kenton (Nuclear)

Graphics Consultant: Frank A. Rodriquez

Ray Schuster, Director
Communications Division

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

Cover: The movement of the wind sock indicates a representative daily variation in wind availability.

EPRI JOURNAL

Volume 5, Number 2 March 1980

Editorial

2 **Critical Juncture in Wind Energy Development**

Features

6 **Going With the Wind**
Great strides have been made in the development of large-scale wind turbine machinery, but more needs to be learned about wind patterns, site selection, and how utilities can incorporate an erratic energy source to best advantage.

18 **The Continuing Disposal of Coal Ash**
Disposal of power plant coal ash is a big job; an EPRI manual offers guidance.

20 **The Delicate Disposal of PCBs**
Careful disposal of PCBs will be a continuing utility industry responsibility. Three EPRI handbooks help utilities evaluate disposal alternatives.

22 **How Much Can We Rely on a Combined-Cycle Plant?**
A lot depends on the combustion turbine, but improved auxiliaries, controls, and operating practices are equally important.

Departments

4 **Authors and Articles**
28 **Washington Report: DOE Moves Ahead With Geothermal**
33 **At the Institute**

Technical Review

R&D STATUS REPORTS
37 **Advanced Power Systems Division**
39 **Coal Combustion Systems Division**
42 **Electrical Systems Division**
49 **Energy Analysis and Environment Division**
51 **Nuclear Power Division**

56 **New Contracts**

58 **New Technical Reports**

Critical Juncture in Wind Energy Development

From a research manager's viewpoint, wind energy development over the past several years represents one of the triumphs of the R&D process: fundamental research in place, conceptual designs produced, engineering development done, tests conducted, and even a few pilot installations completed. But, as always, the process must be protected from exploitation of its early success. This can easily generate too much enthusiasm, exaggerations of potential, and increased pressure to accelerate the R&D process, promising results that can't be attained. In such a boom/bust environment, program support could quickly be lost to the promise of some other rising star.

During the formative years, the U.S. wind program's security lay in its obscurity. For most of the 1970s, when other solar options held center stage, wind energy R&D was thoroughly defined and solid groundwork methodically carried out. The wind program was carefully managed and allowed to progress at a pace compatible with the attainment of its own logical and achievable milestones. As a result, wind energy conversion hardware today is in a maturing stage of engineering development.

The next five years are crucial in determining the role wind energy can play in utility plans for future generation expansion. Wind turbines are already operating on a few electric utility systems, and more units will soon be on-line. Their performance, reliability, and cost can now be carefully evaluated; and questions related to utility needs and impacts can be answered. Above all, during this period it is essential that efficient procedures for siting wind turbines be developed and that we greatly improve our understanding of wind as an energy resource—its distribution, magnitude, availability, and correlation with demand.

In an electric utility system, the value of wind power generation will be calculated essentially on two bases: the generating capacity it displaces and the fuel savings it represents. The capacity credit for a wind power plant is tied intimately to its reliability and to the correlation of the local wind resource with the local utility system's electricity demand. Most probably a wind turbine-generator will be primarily valued for the fuel it displaces.

We are now at that state of development where wind turbine-generators can be closely monitored in actual utility system operation. The job at hand is to evaluate pilot plant operations and put wind turbine-generator performance in perspective so a utility planner will know with confidence what wind energy truly means to a particular system.

To follow the R&D process through this critical phase of demonstration, evaluation, and education requires time and patience. The process of measurement, analysis, and communication must be conducted serially and carefully paced.

John E Cummings

John E. Cummings
Director
Renewable Resource Systems Department
Advanced Power Systems Division

Authors and Articles

Seafarers long ago mapped the prevailing winds over the world's oceans, establishing the reliable trade routes for commercial shipping. Now their art is being brought ashore and updated with modern meteorology, satellite data, and ground instruments to pinpoint reliable wind power sites for commercial electricity generation.

Going With the Wind (page 6) reviews encouraging recent developments in wind turbines scaled for utility applications. Writer William Nesbit also explains how the wind resource isn't amenable to conventional development. Inexhaustible, yes, but also infinitely variable. Mapping, measuring, siting, and eventually generating electricity are matters of adaptation.

Two EPRI professionals aided Nesbit in his assignment: Edgar DeMeo, who heads the Institute's Solar Power Systems Program, and Frank Goodman, Jr., project manager. DeMeo has been responsible for EPRI research in photovoltaic and wind energy conversion since August 1976. Earlier a research consultant in solid-state materials, DeMeo also taught for nine years at the U.S. Naval Academy and Brown University. He is an electrical engineering graduate of Rensselaer Polytechnic Institute, and he earned MS and PhD degrees at Brown.

Goodman joined the EPRI staff in August 1979 after six years with the Los Angeles Department of Water & Power, where he gained experience in system planning and then took responsibility for assessments of new energy technologies: wind, solar-thermal, and photovoltaic conversion; solar heating and cooling; and biomass utilization. For two years he taught a graduate-level course on solar energy theory and applications at the University of Southern California. Goodman holds BS, MS, and PhD degrees in electrical engineering from the University of California at Santa Barbara.

■

Just as air pollution is easily recognized, so are the steps taken by utilities to abate it. Less generally evident are the succeeding steps to dispose of the wastes thereby collected. Residues from other utility equipment and operations also require special attention, and the handling costs for all of them are far from insignificant.

The Continuing Disposal of Coal Ash (page 18) and **The Delicate Disposal of PCBs** (page 20) summarize the contents of two EPRI reports that have been published as guidebooks for utilities. Regulatory requirements are only the beginning of these texts. Their emphasis is on evaluating and designing disposal techniques and sites for compliance, reliability, and economy.

The author of both articles is Nadine Lihach, *Journal* feature writer. She drew on information from Dean Golden of EPRI's Coal Combustion Systems Division, who has managed research on the disposal of solid by-products from coal-fired plants since February 1978. His work now includes other wastes, such as PCBs (polychlorinated biphenyl compounds), used until recently for insulating electrical apparatus. Golden came to EPRI after six years with Southern California Edison Co., where he was responsible for water quality matters in waste discharge permit applications, environmental impact reports, and company policy statements to public bodies. Earlier he had been with the Los Angeles Department of Public Works in wastewater system design. Golden is a civil engineering graduate of the University of California at Berkeley; he also holds an MS in environmental engineering from Loyola University of Los Angeles and an MBA from the University of Southern California.

■

Using the exhaust heat from a combustion turbine as the input heat for a steam turbine gets more Btu out of the fuel. The combination is efficient and it looks like a good way to deal with the short supply and high cost of oil. But **How Much Can We Rely on a Combined-Cycle Plant?** (page 22).

Getting at objective answers to this question has involved a methodical sequence of data gathering, analyses, and trade-off studies that focus on combustion turbines and their auxiliaries. Feature editor Ralph Whitaker reviews the findings, aided by three of the EPRI staff members who are managing R&D to attain the higher reliability utilities need for widespread use of combined-cycle power plants.

Albert Dolbec is manager of the Power Generation Program in EPRI's Advanced Power Systems Division; Richard Duncan and Robert Schainker are project managers for combustion turbine reliability. Dolbec has been with EPRI since April 1977, following nearly 26 years with

General Electric Co., the last 10 in management of design engineering for combustion turbine and combined-cycle plant controls and equipment.

Richard Duncan came to EPRI in July 1976 after 15 years with United Technologies Corp., where he was manager of advanced planning and manager of advanced combustion turbine projects. A Purdue University graduate in electrical engineering, Duncan also earned a PhD in aeronautics there during a 24-year career as a Navy pilot and engineer.

Robert Schainker, who has been with EPRI since July 1978, was with Systems Control, Inc., for nine years as a research engineer and program manager in energy-environmental studies. A graduate of Washington University (St. Louis) in engineering science, he was a research assistant and lecturer there, while earning an MS in systems engineering and a PhD in applied mathematics.

■

Correction The November 1979 article "Synthetic Fuels Cheaper Than Oil?" contains a numerical error in the figure on page 20. All curves in that figure incorporate a general economic inflation rate of 6% annually. The two fuel oil curves further incorporate real-price escalations of 4% (not 6% as shown on the left) and 2% (not 4% as shown on the right).

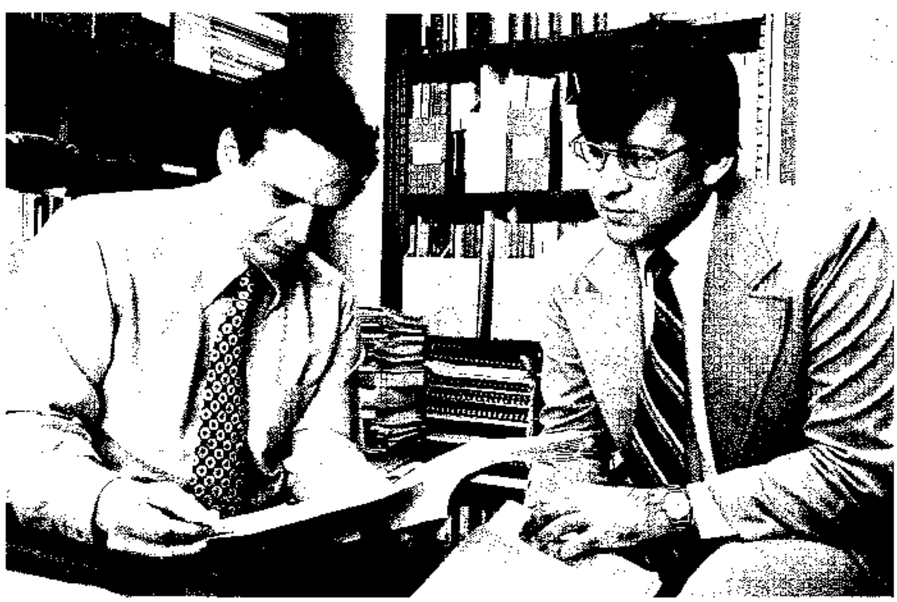
The 4% and 2% values were assumptions for the EPRI study reviewed, and the article text is numerically correct. The *Journal* editors regret any confusion that may have been caused by this inconsistency.

Duncan

Dolbec

Golden

Schainker



DeMeo

Goodman

Wind turbines of the future are symbolized by these federally sponsored prototypes. The DOE–NASA 200-kW MOD-0A machine was installed at Block Island, Rhode Island, in 1979. Similar machines had previously been installed at Culebra, Puerto Rico, and Clayton, New Mexico. Another will be going up soon in Hawaii.

(Insets, from top)

The first large horizontal-axis machine developed by NASA, a 100-kW MOD-0 machine, was installed at Sandusky, Ohio, in 1975 and its operation influenced the design of subsequent, larger machines. It continues to be used for supporting research and technical development.

The 2-MW MOD-1 machine was installed near Boone, North Carolina, in 1979. It will be used to obtain early operating experience with a megawatt-scale wind turbine but will not be put into mass production.

The 2.5-MW MOD-2 was developed for NASA by Boeing Engineering & Construction. A cluster of three machines will be installed near Goldendale, Washington, in 1980 and 1981. The MOD-2 incorporates substantial design improvements over earlier machines.

One of several vertical-axis Darrieus machines (axis of rotation perpendicular to the ground) is now under test at Sandia Laboratories in Albuquerque, New Mexico. Such machines may eventually be cost-competitive with horizontal-axis machines.

Going With the Wind

Extracting electric power from such an abundant but inconstant source as the wind requires the right site, a reliable machine, and the flexibility of the power system to adapt to a capricious air stream. Recent swift progress in these three areas has brought a surge of serious interest in wind-generated electricity. Large-scale wind turbine hardware is up and rapidly phasing into the demonstration stage, and information is being gathered on prospective sites and on machine performance in a utility environment. But the job is not yet done, and the development process cannot be rushed. We need to better understand the reliability of these new machines and the patterns of this ancient resource. Within five years the prospects for wind energy should be fully understood: whether it will become a major source of energy supply or one of limited value and limited use.

Early in the century, much of rural America used wind power to pump its water and generate its electricity. Then along came the Rural Electrification Administration in the 1930s, and wind machines for electricity generation went out of style.

Today, style and circumstances have changed, and in what might be described as a modern revival, wind—abundant, replenishable, and clean—is making a comeback.

As evidence of this, a recent EPRI survey identified 51 electric utilities in the United States that are conducting wind energy projects. These 83 projects, listed in EPRI's *1979 Survey of Electric Utility Solar Energy Activities,* reflect almost half again as many as were identified in a similar 1978 survey.

Why the interest? There are several reasons. Wind machines may provide a way to reduce oil and gas consumption through an approach that has a fairly low cost of entry for utilities.

The resource base is large. Created by nonuniform heating of the earth's surface, wind energy over the United States has been estimated at 30 times our current electric energy consumption. However, only a small fraction of this resource is likely to be accessible for economic power generation.

Perhaps most important, publicly and privately funded hardware development programs are beginning to bear fruit. Undertaken within the past five to eight years, these programs are quickly bringing to commercial readiness machines designed for mass production and compatibility with the nation's power systems.

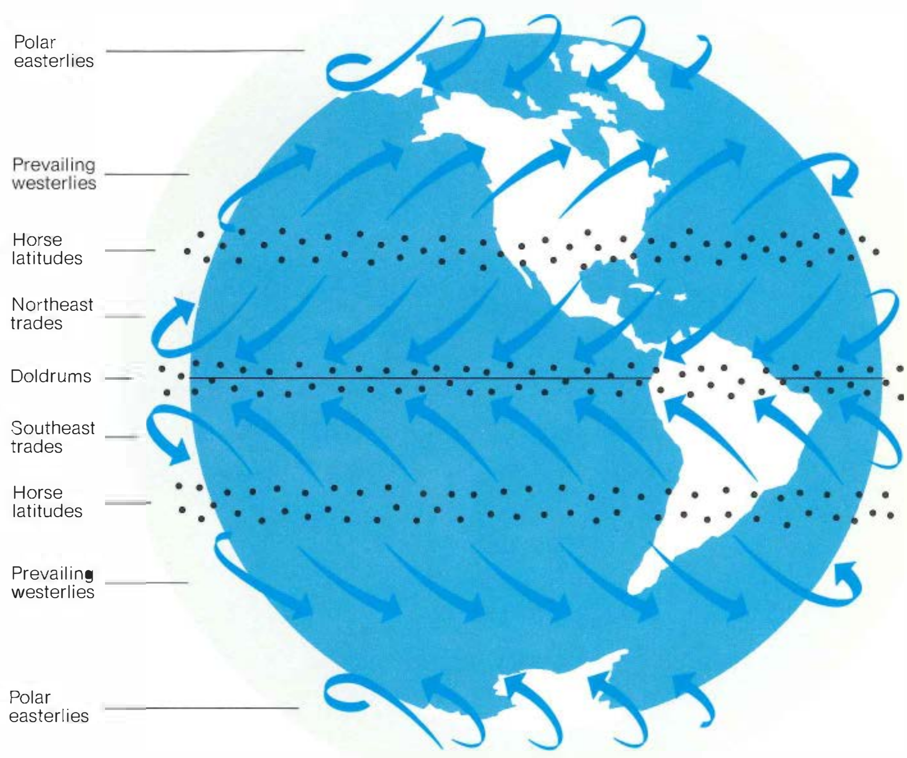
To date the development work has maintained a low profile, at least relative to other solar technologies. There has been a quiet accumulation of encouraging results based on a solid foundation of engineering activity. Barring any major unforeseen hardware catastrophe, it is becoming generally recognized that wind energy will be the first of the solar-electric technologies under development to emerge for serious consideration as a utility power generation source.

ORIGIN OF THE WINDS

The winds are caused primarily by differential heating of the earth's surface by the sun. During the day the air above the earth's land masses heats more rapidly than the air above the surface waters because much of the incident solar energy is either absorbed by the water or consumed in evaporation processes. The heated air over the land expands and rises. The relatively cooler, heavier air over the water flows in to replace it, and local shoreline breezes are created. At night the breezes are reversed because the air cools more rapidly over the land than over the water.

Similarly, local breezes occur on mountainsides because the air above the slopes heats and cools more rapidly than the air above the lowlands. Heated air rises along the slopes during the day, and relatively cool, heavy air flows down at night.

Circulating planetary winds are caused by greater heating of the



It is at this point, however, that many individuals close to the programs draw the line of caution. Sudden exposure of partial success, they point out, with all the attendant fanfare of heightened expectation, could be wind's undoing. They stipulate that engineering development must continue in logical sequence, allowing adequate time and effort for the technology to mature. Also, they say, long-term operating experience must be gained through a variety of field experiments to answer critical questions, such as machine reliability and displacement of conventional generating capacity. The latter is highly variable, being a function of both site and utility system characteristics, and is distinct from energy displacement. In the worst case, no capacity displacement may be allowable, although fuel consumption is likely to be reduced (energy displacement).

Manufacturers and utilities alike have committed resources to the development of wind power generation. Pacific Gas and Electric Co., for example, has included 82.5 MW of wind power (in terms of machine ratings) in its generation expansion plans for 1990. Southern California Edison Co. has included 43 MW of capacity displacement by wind power in its plans for 1990. In terms of machine ratings, the corresponding number of megawatts would be larger. Hawaiian Electric Co., Inc., has recently signed an agreement to purchase up to 80 MW of wind-generated power (machine ratings) by 1985 from a private firm that will retain ownership of the wind machines.

Says EPRI's Edgar A. DeMeo, manager of the Solar Power Systems Program, "I think we'll know in 5 years if wind is going to play an important role in the electric utility supply picture. With any of the other solar-electric technologies, I don't think we'll know that for 10 or 15 years or more. The difference is that wind hardware is up and operating, we're getting a fix on the costs involved, and there is a near-term milestone."

The milestone is a test program that

earth's surface near the equator than near the poles. Air rises in the tropics and moves through the upper atmosphere toward the poles, while cold surface winds blow from the poles to the equator.

The rotation of the earth affects these planetary winds. The inertia of the cold air moving near the surface toward the equator tends to turn this air to the west, while the warm air moving in the upper atmosphere toward the poles tends to be turned east. The net result is a large counterclockwise circulation of the air around low-pressure areas in the northern hemisphere and clockwise circulation in the southern hemisphere.

Because the earth's axis of rotation is inclined relative to the plane of its orbit, seasonal variations in the heat received from the sun result in seasonal changes in the strength and direction of the winds.

FUNDAMENTALS OF WIND ENERGY

The characteristics of wind are such that for each doubling of the wind's speed the potential amount of power that can be extracted is increased eight times. As an example, if a wind turbine generates 100 kW of power in a 10-mph wind, theoretically it can generate 800 kW in a 20-mph wind.

The power in the wind stream is greater, however, than the power that can be extracted from it. This is a matter of fundamental physics: as a wind turbine takes energy from the wind, it returns part of that energy when the turbine's blades push the air along behind them. As a result of this give and take, the wind turbine's maximum efficiency is about 60%.

Further losses occur as the kinetic energy of the wind is converted into the mechanical energy of the rotating blades and drive train and then into the electric energy produced by the generator. These system losses amount to roughly one-third of the energy potentially available. In sum, about 40% of the total energy in the wind stream is converted into electric energy.

An important indicator of wind characteristics at specific sites is the wind duration curve. This curve is an empirically derived plot of the number of hours per year that the wind exceeds various speeds at the site under consideration. This curve, together with the operating characteristics of a specific wind machine, provides one measure of expected performance over a one-year period.

LOOKING AT THE MARKET

Gaining utility industry confidence in wind power is an essential part of the development process. This, in turn, means that the machinery has been developed with market requirements in mind and there is extensive testing of the hardware to develop experience, familiarity, and information. Utilities need conclusive demonstration of reliable service over extended periods of time; firm data on capital, operating, and maintenance costs over expected lifetimes; proven techniques for site selection; and assurance of operational compatability with conventional generating apparatus.

Recognizing that wind-generated electricity is subject to the vagaries of the wind, utilities need to learn through experience how to include such intermittent generation in their networks to greatest advantage. They also need techniques for determining the value and impacts of such generation, for wind does not behave in any of the conventional operating modes (i.e., baseload, intermediate, and peaking). These techniques must account for any allowable capacity displacement credits and identify any related limitations on penetration of wind power. Wind power's closest conventional counterpart is probably run-of-river hydroelectric generation.

In discussing the value of wind power generation, the meaning of two basic concepts, energy displacement and capacity displacement, must be understood. *Energy displacement* is the amount of electric energy that need not be generated by installed conventional generation because of the energy produced by installed wind machines. Energy displacement frequently implies the saving of a specific type of fuel (e.g., coal, nuclear, or oil), depending on which type of conventional generation is backed off during periods when the wind is blowing.

Capacity displacement is the amount of additional conventional generating capacity, if any, that might be omitted from a utility's planned future requirements because of the planned addition of wind machines. Capacity displacement is a function of effective capacity (also called effective capability). *Effective capacity* is normally defined as the allowable increase in utility system annual peak load that can be accommodated, while maintaining a fixed level of system reliability, by installing a new generating unit (wind machine, conventional, or otherwise). Effective capacity is calculated by established probabilistic techniques.

EPRI is developing methods that individual utilities can use in assessing value and prospective roles for wind in future generation expansion. It is also taking steps to enhance utility interaction with federal and other wind programs. These activities have been facilitated by early recognition within the federal program of the need to involve utilities in research, development, and implementation activities.

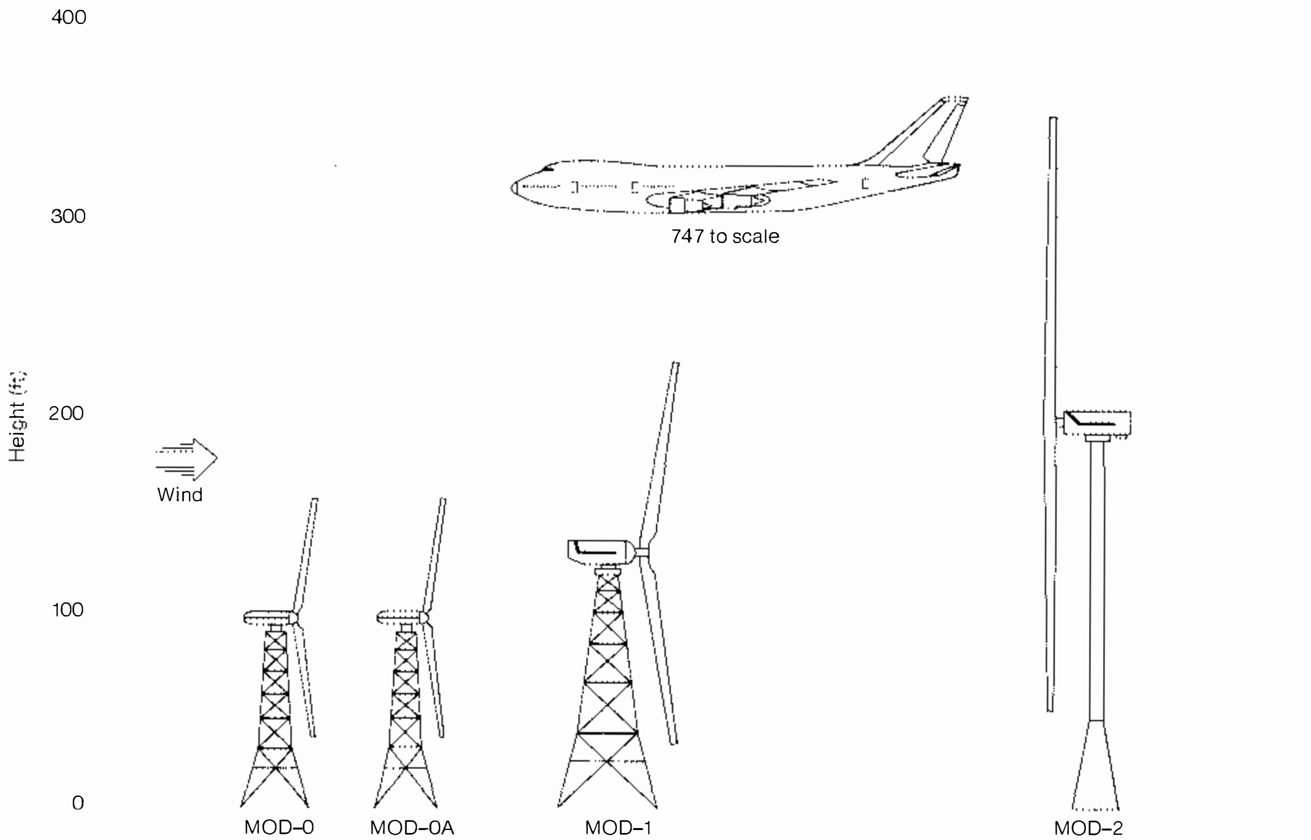
begins this October, when the biggest and most advanced wind turbine–generator ever built is scheduled to start operating at Goodnoe Hills, on the Columbia River near Goldendale, Washington. Eventually there will be three machines in a triangular cluster, each atop a 200-ft tower with a 300-ft rotor blade span. The turbines have been designed with a maximum rated output of 2.5 MW each. Tied into the Bonneville Power Administration's network, together they are expected to generate some 30 GWh of electricity a year.

These wind turbines are called MOD-2s, the fourth in a series of DOE and NASA models that so far have logged over 6700 hours of operational experience, supplying power to utilities in Ohio, New Mexico, Puerto Rico, Rhode Island, and North Carolina. This testing began with a MOD-0 machine in September 1975 at NASA's Plumbrook station near Sandusky, Ohio, and has progressed through three MOD-0A machines (with a fourth scheduled for 1980 installation in Hawaii) and one MOD-1 machine. Beyond MOD-2, DOE and NASA are looking toward mid-1983 for first rotation of the next generation of advanced multimegawatt systems, machines with outputs up to 4 MW.

Evolution in hardware design under the direction of NASA's Lewis Research Center in Cleveland has been marked by successively larger machines with greater output and progressive reductions in unit weight.

One major objective of the federal program is to drive wind generation costs down to competitive levels. Capital costs are to be reduced by focusing on less complex machines with improved performance, moving toward less expensive flexible towers and lower-cost rotor blades and, eventually, mass production. With the blades and hub accounting for half the cost of the early machines, the potential for savings is significant. The strategy for reducing energy costs includes clustering a number

FEDERAL LARGE WIND TURBINE PROGRAM: SCALING UP HORIZONTAL-AXIS MACHINES



	MOD-0	MOD-0A	MOD-1	MOD-2
Tower height	100 ft	100 ft	135 ft	200 ft
Rotor blade span	125 ft	125 ft	200 ft	300 ft
Rated power output for rated wind speed	100 kW	200 kW	2.0 MW	2.5 MW
Rated wind speed (at 30 ft)	14.5 mph	17.3 mph	25.7 mph	19.9 mph
Expected energy output per year*	700 MWh	820 MWh	3.7 GWh	9.3 GWh
Mean wind speed (at 30 ft)	14 mph	14 mph	14 mph	14 mph
Cut-in/Cut-out speed	10/35 mph	10/35 mph	11/35 mph	9/35 mph
Weight/kW	800 lb/kW	450 lb/kW	328 lb/kW	240 lb/kW
Location (first rotation)	Sandusky, Ohio (1975)	Clayton, New Mexico (1977) Culebra, Puerto Rico (1978) Block Island, Rhode Island (1979) Oahu, Hawaii (1980)	Boone, North Carolina (1979)	Goldendale, Washington (1980)
Prime Contractor	NASA	Westinghouse Electric Corp.	General Electric Co.	Boeing Engineering & Construction

*For the given mean wind speed and standard wind duration curve. The actual wind characteristics at any specific site may differ from those used in computing the expected energy values in this table.

of these mass-produced machines into energy parks at favorable locations.

Breadth of the federal program

Federal wind energy program activity under DOE direction is broadly based. The NASA effort, in fact, is but a portion of the overall program in that it concentrates on development of large horizontal-axis wind turbines (i.e., machines whose axis of rotation is parallel to the ground). DOE is also active in such areas as vertical-axis turbines; characterizing wind patterns and developing techniques for wind machine siting; studying innovative designs and small wind machines; and considering the legal, social, and environmental aspects of wind energy generation.

Work with vertical-axis machines is focused primarily on the Darrieus designs, vertical-axis turbines with curved blades—a characteristic that leads to the nickname egg beaters. This work shows great promise, according to DOE, with development to a point that indicates these machines may eventually be directly cost-competitive with horizontal-axis designs. Sandia Laboratories in Albuquerque is developing the Darrieus design for DOE.

There are two primary advantages of a vertical-axis machine over a horizontal-axis machine. The generator and gearbox are located closer to the ground, reducing the structural requirements of the tower and providing better access for maintenance. Inasmuch as vertical-axis machines need not turn to face the wind, yaw control is eliminated. Additionally, because vertical-axis turbines encounter a natural stalling in high winds, there may be a reduced need to protect the machines against gusting.

Disadvantages of the vertical-axis design include an aerodynamic efficiency about 10% less than horizontal-axis machines, limited ability of the rotor to self-start (thereby requiring an electric starter), and generally lower rotation speeds, which require a higher drive train torque capacity. Considering all these factors, a Darrieus machine will produce about 50% the annual energy of a propeller-type horizontal-axis machine of a comparable power rating. (Also, because of design considerations, maximum unit sizes are expected to be smaller for vertical-axis machines.)

DOE's primary attention and largest dollar outlay have gone to the horizontal-axis designs. This approach has historically appeared to be the most efficient way to generate electricity from wind, and until recently, virtually all effort in the United States and abroad was centered on horizontal-axis machines. In particular, these designs could build on the knowledge of aircraft propellers and helicopter rotors.

Ronald L. Thomas, deputy manager of NASA's Wind Energy Project Office in Cleveland, comments, "The vertical-axis people have had to go out and develop new analysis tools to understand the aerodynamics and structural dynamics of that design. It may turn out that the vertical-axis machine is competitive with the horizontal-axis machine. But it wouldn't have reached our time and cost goals in the time we were given."

Another area of federal attention is innovative design work. This activity, managed by DOE's Solar Energy Research Institute (SERI) in Golden, Colorado, primarily involves obtaining better performance from alternative wind systems at lower costs. Eleven systems have been under study. One concept involves work with a diffuser-augmented wind turbine, which entails building a shroud into a turbine to pull more air through and across the blades.

Characterizing this innovative design work, Dan Ancona, large-machine program manager in DOE's Wind Systems Branch, says, "These are long-range programs and probably will be paying off in 5 to 10 years rather than on the next generation of hardware. We're like the airplane industry in this work: we're developing propeller-type machines at this point, and we want to make sure we don't overlook a jet."

Small wind machines represent still another area of attention for the federal program. This work focuses on turbines with rated outputs of less than 100 kW and is centered at Rocky Flats, Colorado, where a number of towers have been erected for test purposes. The primary focus is to learn about the performance, efficiency, dynamics, and other technical issues associated with the numerous small commercial machines that have been developed without government funding. Many of the turbines tested here have been designed for home use, for farms, or for small industrial applications. The Rocky Flats program also includes management of contracted efforts to develop advanced machines under 100 kW.

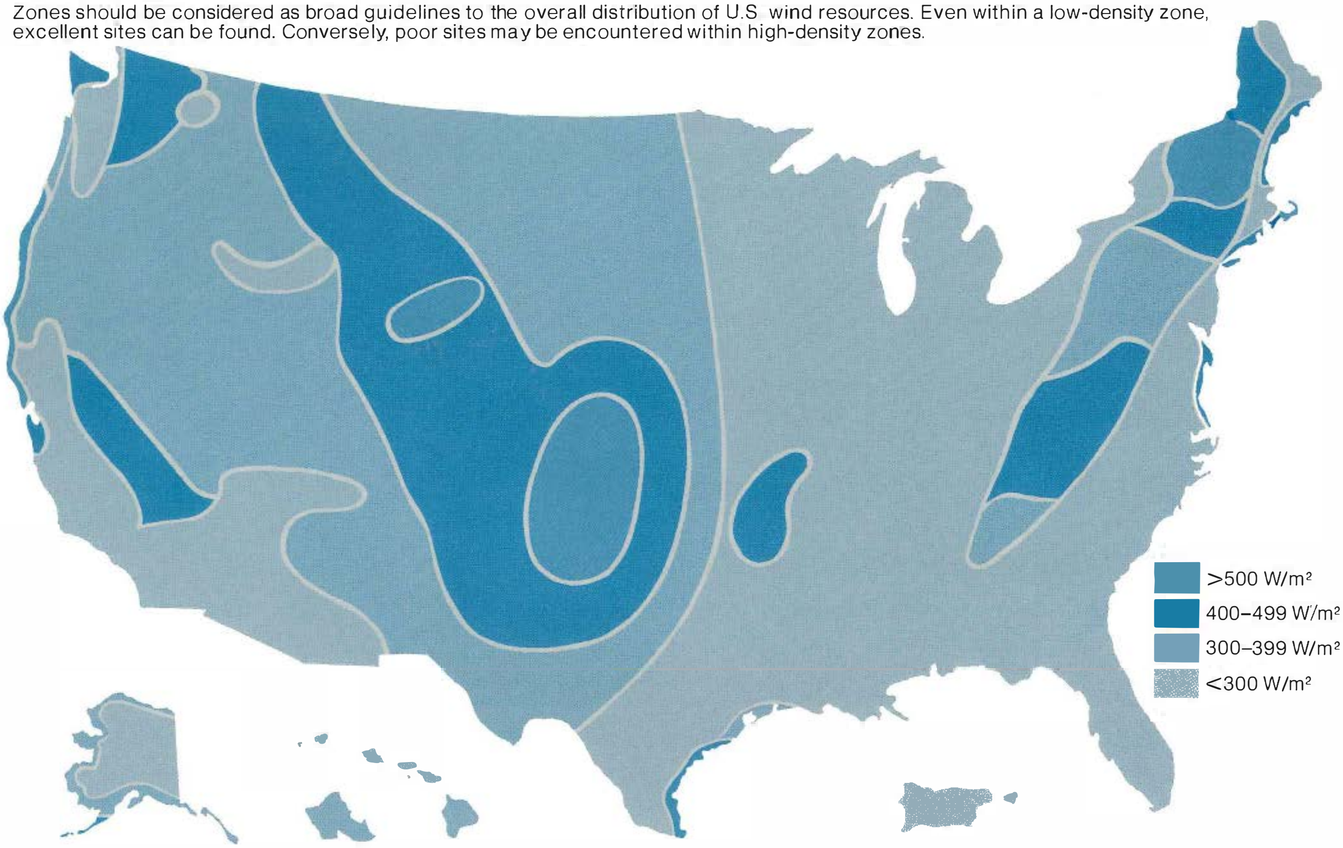
Siting considerations

DOE's work characterizing the wind, assessing it as a resource, and developing machine-siting techniques is understandably on a par in importance with hardware development. As EPRI's DeMeo points out, "Irrespective of success in hardware development, without a greatly improved understanding of the wind resource, wind generation cannot be responsibly integrated into electric utility systems."

Wind assessment and siting work is being managed for DOE by Battelle, Pacific Northwest Laboratory, Richland, Washington. The goal is to develop techniques to predict wind speed, direction, and profile that can be used to select the best sites for wind turbines. A five-state region in the Pacific Northwest was the first to be defined and surveyed. Investigators gathered information in various ways: from reporting weather stations, analyses of relief maps and surface pressure maps, and observation of wind-deformed vegetation and landforms. In this manner, average wind power density at various locations has been charted on a seasonal and annual basis, and graphs have been prepared showing annual, monthly, and diurnal variations of wind speed and power, as

Wind Power Density Across the United States

Zones should be considered as broad guidelines to the overall distribution of U.S wind resources. Even within a low-density zone, excellent sites can be found. Conversely, poor sites may be encountered within high-density zones.



well as curves of frequency and duration. DOE has contracts under way to conduct similar assessments for the other 11 regions of the country defined in the program, with a target goal for completion and publication of wind atlases by early 1981. These atlases are to be updated as new wind data become available.

In its work to develop site-screening techniques for wind turbine construction, DOE is using numerical and physical models and, again, visual surveys of vegetation deformed by the wind. In addition, the agency is preparing interim handbooks that are expected to be helpful in siting large and small wind machines and in planning for their use (large machines are generally considered to be those rated 100 kW or more). It is estimated that at least 20 utilities in the United States are now investigating wind machine sites in their areas, using these and other techniques.

An extremely important area of concern for future siting encompasses legal, social, and environmental issues raised by wind power generation. Questions of financing; zoning; wind rights; and state and local building, safety, and housing codes are now being explored by DOE. The social issue of greatest concern, according to many observers, is how the public will react to the hard reality—as opposed to the general concept—of wind power development. In one 1977 survey, 80% of those persons sampled were favorably disposed to the use of wind energy as a means of generating electricity. How these people will respond to the actual appearance of clusters of 25, 50, or more large machines the size of 20-story buildings remains to be seen.

Such large machines raise safety issues about potential tower collapse or rotor blade failure. Good design and proper maintenance are part of the answer, as is remote siting.

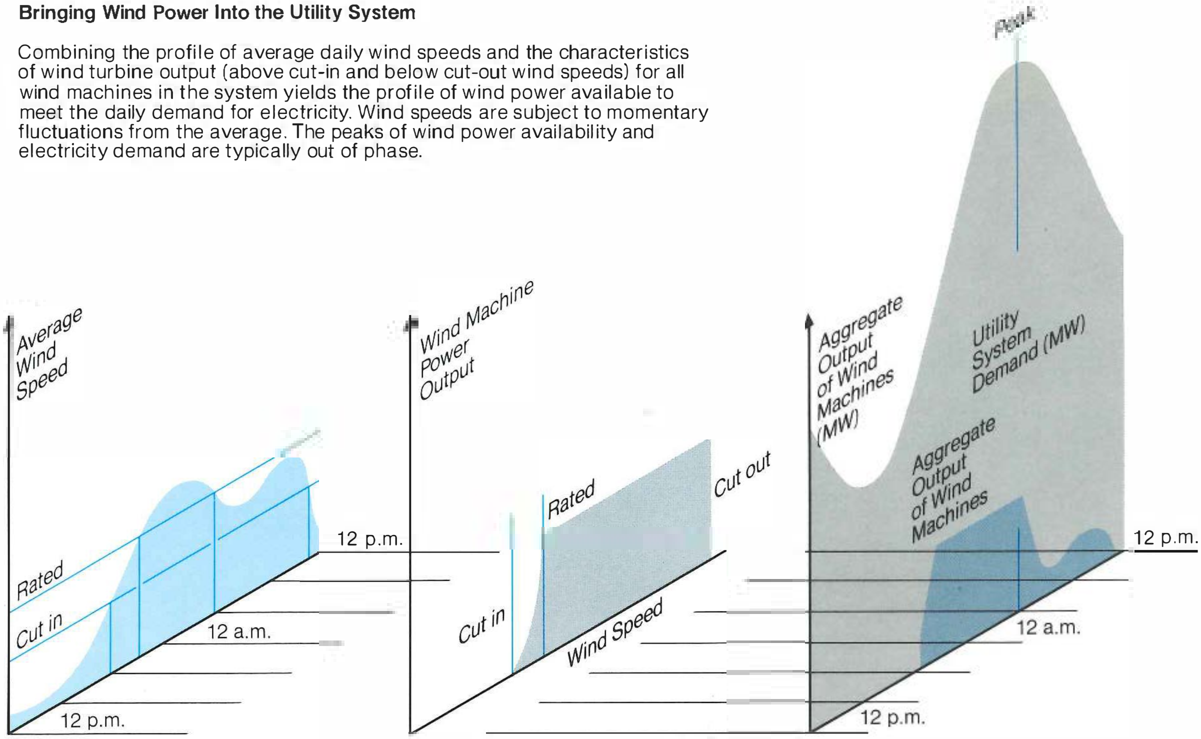
With regard to noise, tests conducted to date indicate that sound intensity levels will be tolerable even at distances relatively close to the turbine. However, some concern over very low frequency sound (infrasound) has arisen at the MOD-1 test in Boone, North Carolina.

Ecological concerns with wind turbines involve the potential impact on the microclimate near the turbine, on bird migrations, and on land-dwelling animals. Air navigation systems may be affected by interference with electromagnetic transmissions, as might communication and data links and television and radio broadcasts.

Overall, DOE believes there are no insurmountable institutional, legal, social, or environmental barriers to implementation of wind turbine systems. Of the potential problems, DOE believes electromagnetic interference with television signals and public acceptance are of greatest concern. Yet each of the potential impacts is extremely site-specific and could present significant problems in a given location under certain conditions.

Bringing Wind Power Into the Utility System

Combining the profile of average daily wind speeds and the characteristics of wind turbine output (above cut-in and below cut-out wind speeds) for all wind machines in the system yields the profile of wind power available to meet the daily demand for electricity. Wind speeds are subject to momentary fluctuations from the average. The peaks of wind power availability and electricity demand are typically out of phase.



The private effort

Apart from this federal effort, there is important and growing activity in large wind turbine development within the private sector. Several companies are now marketing large machines.

The first on the market with a utility-size machine is said to have been WTG Energy Systems, Inc., based in Angola, New York. This company has had a 200-kW unit operating on Cuttyhunk Island, Massachusetts, since June 1977 that has been providing power to the town of Gosnold since mid-1979. The machine achieves its rated output power at wind speeds of 28 mph at 80 ft above ground and is reported by WTG to produce about 500 MWh of electricity a year. WTG also recently sold a second 200-kW turbine of the same design to the Nova Scotia Power Corp. for $226,000. This turbine is expected to be up and operating in September of this year.

Aluminum Co. of America (Alcoa) is also active in wind turbine development, producing Darrieus machines with five different rated outputs between 8 and 500 kW. The company has sold about 20 machines. Southern California Edison bought one of the 500-kW machines, while another was purchased by the Eugene Water and Electric Board, representing municipally owned utilities in Oregon. Contract options for up to four 112-kW turbines have been arranged with Sandia Laboratories as part of the DOE program. Sandia has thus far exercised the option to purchase one of these machines.

Installed cost of the 500-kW Alcoa machines is estimated at $200,000. The company estimates the machine will produce approximately 1.1 GWh of electricity per year at a site with a mean annual wind speed of 17–21 mph at 30 ft. The machines are designed to achieve rated power output at wind speeds of 35 mph at 30 ft above ground.

Bendix Wind Power Products Co., with the Schachle turbine, is a third firm active in wind power generation. The first large Schachle machine, named after its designer, was recently sold to Southern California Edison and is scheduled to begin operation this year at a site near Palm Springs, California. The utility paid $1 million for the machine and anticipates spending another $1 million on site work, support equipment, design review, performance testing, and related expenses. The turbine is designed to achieve its rated 3-MW power output in a 40-mph wind at its hub height of 100 ft.

At the Palm Springs site it is expected that the Schachle turbine will generate 6 GWh of electricity per year (anticipated mean annual wind speed of 17 mph at 100 ft). Bendix says it will not be making any additional sales of the Schachle turbine until the Palm Springs installation is completed and performance is verified.

The Hamilton Standard Division of United Technologies Corp. has a megawatt-scale wind turbine development program that is being viewed with interest by many observers in the wind energy community. Earlier wind machine development at Hamilton Standard was funded by the federal program.

Another company active in wind turbine development is Merkham Energy Development Co. of Hamburg, Pennsylvania. This company has roughly 50 machines on order, delivered, or in service. The vast majority are rated at 45 kW. One, rated at 2 MW, was recently sold to a commercial customer in the area of Reading, Pennsylvania. Pennsylvania Power & Light Co. has purchased one 45-kW unit from Merkham, while some 10 other utilities around the country reportedly have Merkham machines tied into their systems at customer locations.

U.S. Windpower Inc., of Burlington, Massachusetts, is another company active in the field. It has recently announced plans to manufacture 2000 of its 50-kW turbines as part of a program to sell power to the California Department of Water Resources. The first increment of 20 (total, 1 MW) will be installed at Pacheco Pass to become operational in the spring of 1981. Additional machines will be installed over the following three years. The company says that at least initially, it intends to sell only power, retaining ownership of the machines.

U.S. Windpower has sized its machines on the basis of a minority view that the optimal output for a wind turbine is on the order of 50 kW, as opposed to multimegawatts. Part of the rationale is that smaller-size units give greater economies of scale in production. The company, which has had two test machines operational since the fall of 1979, projects that its 50-kW turbines will cost approximately $36,000 each when mass-produced. Rotor spans will vary from 40 to 80 ft as part of a program to tailor each machine to its site.

Depth of analysis

While the private effort is impressive, it nowhere approaches the federal wind energy program in terms of money, man-hours, or overall depth of analysis. It is, in fact, relatively easy to build a wind turbine, but extremely difficult to build one that can operate reliably over an extended period of time. Today, a 30-year life is generally thought to be required to generate cost-competitive electricity for economic utility application on a life-cycle cost basis.

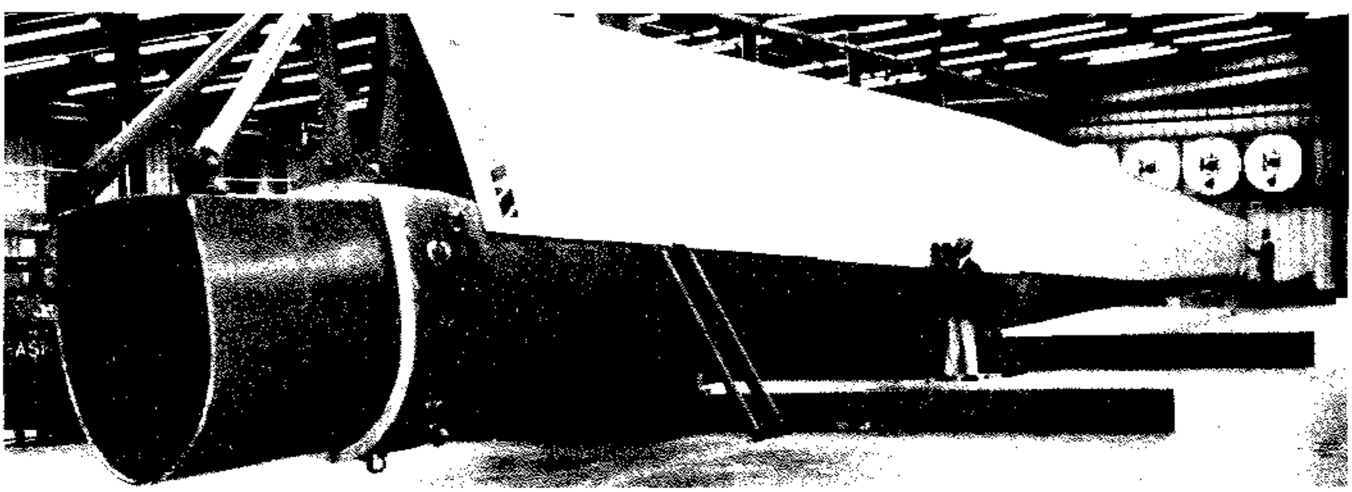
According to NASA officials, approximately twenty times more money, research, and engineering hours have gone into the federal program to date than into the private effort. While the federal government has been involved in wind energy since 1972, most private companies have only recently become active in the field.

"What is different about the MOD-2 project than the others?" asks John Lowe, director of wind energy programs for Boeing Engineering & Construction, which designed and will install these machines for NASA. "We've just done a whole lot more work more thoroughly."

The MOD-2 project incorporates over two years of design effort, using tools developed and refined since 1973. According to Lowe, Boeing alone has had 75 people working over 20 months looking at a wide variety of possible configurations for the MOD-2. It has completed over a dozen trade-off studies, including verification tests of the total system aeronautical and structural dynamics in a wind tunnel, something never before done.

In addition, the DOE—NASA program encompasses almost five years of actual operating experience, including production of over 700 MWh during more than 6700 hours of service connected to the local utilities where the machines have been sited. (Of this total, over 6000 hours apply to the MOD-0A at Clayton, New Mexico.) The MOD-2's coming synchronization with the Bonneville Power Administration system at Goodnoe Hills will go on top of this.

Summarizing the status of the federal effort, William H. Robbins, manager of



A 150-ft wind turbine rotor blade, assembled at Kaman Sciences Corp. in Colorado Springs, Colorado, was used in a series of structural tests.

SITE PROSPECTING: ONE UTILITY'S APPROACH

"There's a lot of wind data around. You just have to keep your eyes open for it," says Earl L. Davis, senior meteorologist for San Francisco–based Pacific Gas and Electric Co. Over two years ago PG&E began considering the feasibility of wind power generation in its service area. Today the company stands just short of purchasing a large wind turbine–generator for one of two promising northern California sites.

PG&E began its site-prospecting efforts with an extensive analysis of wind resource data in its own files: surveys of potential plant sites, studies of the effects of weather on transmission lines, and information gathered to plan gas dispatch strategies. With this information in hand, PG&E began to look elsewhere. That's when it really hit pay dirt. The State of California had data. So too did a local Exxon Corp. refinery, the University of California, and DOE's Lawrence Livermore Laboratory.

PG&E labels this assemblage of historical data as phase one of its work, a phase it capped by identifying eight sites that have substantial potential for wind energy generation.

Phase two of the effort involved analyzing each of the eight locations, using an in-house list of criteria. Wind characteristics and meteorological conditions were the key criteria. Beyond these, investigators looked at such factors as environmental and regulatory considerations, site geology and terrain, and land ownership and availability. Consideration was also given to the proximity of each site to existing PG&E facilities and to safety and public acceptance concerns. In all, the eight locations were evaluated by some 40 criteria.

On top of this, PG&E developed two computer programs to predict the performance of various turbine designs on an hour-by-hour basis at each of the candidate locations. Using historical wind information, these models simulated turbine operation and then predicted the number of hours at rated capacity, below cut-in and above cut-out speeds, as well as energy output and the turbine's on-peak and off-peak value to the utility.

According to James E. Schumann, supervising civil engineer in PG&E's siting department, his team is concentrating its attention on one site northeast of Vallejo in Solano County and another north of Livermore in Alameda County. In March 1979, he reports, they installed basic wind measurement equipment at those sites, including speed and direction sensors at 30-ft elevations. More sophisticated equipment will be erected on an incremental basis until the utility has the information it needs to site a machine.

One key aspect of the PG&E program, says Schumann, is that throughout the prospecting process he and his colleagues have been concentrating on identifying only wind turbine cluster sites, not single machine sites.

Schumann estimates that PG&E will spend about $1 million for this wind resource and location assessment work before the best site is determined. Once that is done, a megawatt-scale turbine already authorized for purchase by the company is to be installed. Target date for first rotation is January 1982. Assuming successful demonstration with this machine, an additional 80 MW of wind power is slated to go up on the site. This could conceivably be in place by 1990.

NASA's Wind Energy Project Office at its Lewis Research Center in Cleveland, says, "First, wind turbine system design is now understood. No major breakthroughs in technologies are necessary. Second, design tools are in an advanced state of development and are available to U.S. industry. Third, operational machines at utility sites have validated the basic system electrical, structural, and mechanical designs of the NASA machines. And fourth, the compatibility of single-unit NASA turbines with utility interfaces has been successfully demonstrated.

"We don't need any miracles in technology anymore," continues Robbins. "The barrier when we started was the technology barrier. That has changed. Now what we have to do is be sure the customer has the right information to accept the technology."

The customer in this reference is the nation's electric utility industry. In Robbins's view, in fact, the national challenge for wind energy today is to gain utility acceptance and then to create a competitive industry to produce reliable wind turbines. This transfer of federally developed technology to industry is already under way, he points out, with 85% of NASA's funding for the program going to private industry—to companies like Westinghouse Electric Corp., General Electric Co., Boeing, and Hamilton Standard.

Establishing utility requirements

Most informed observers agree that if wind is to play an important role in America's energy future, it must be embraced by the electric utilities. But utilities need conclusive demonstration of reliable service over an extended period of time. The allowable credits, if any, for displacement of conventional generating capacity must become predictable to allow accurate assessment of wind power's value to any specific utility.

Utilities also need firm information on capital costs, on operation and maintenance costs, and on the cost of energy produced. And they need proven techniques to inventory wind resources in their areas for siting purposes.

The DOE program is clearly keyed to address these concerns, and already some hard, encouraging information and experience have been acquired. EPRI, too, is active in helping to provide answers in these areas through a program of its own. This effort has two main objectives: to keep abreast of developments in wind power generation, improving and speeding two-way communication between development programs and the electric utility industry; to help utilities predict and evaluate the overall impact of integrating wind power generation into their systems.

In its liaison role, EPRI keeps utilities informed on what the federal effort (and as circumstances permit, private work) may mean to them. It also provides feedback to the federal program on the information utilities want and need. As part of this effort, EPRI has a project to gather, appraise, translate, and transfer raw data from wind turbine field tests to the utility industry on a regular basis. A technology status report will be available shortly.

EPRI is planning two new wind program activities during the current year. One is a project to document the entire experience associated with a wind turbine field test hosted by a utility and to report on this work to other interested utilities. The other is to augment federal activities in developing methods for assessing wind energy resources and siting wind turbines. The aim is to involve utilities directly in the development process.

Identification of sites for wind turbine clusters involves more than finding a location with a suitable wind resource. Criteria must be developed that include accessibility by roads, proximity of sites to existing transmission lines, influence of terrain features, environmental impact, meteorological hazards, compatibility with legal concerns, as well as availability of and alternative uses for the land. According to EPRI's project manager in the Solar Power Systems Program, Frank R. Goodman, "The development of siting procedures can be most effectively accomplished through utility industry, EPRI, and DOE cooperation. After reliable large wind turbines have become available at affordable cost, the tempo for penetration of wind power generation will depend on the rate at which acceptable sites can be identified and obtained."

In assessing utility wind turbine integration, EPRI is helping to establish economic and performance goals for utility hardware and is developing methods for utilities to use in determining the prospective roles and potential for wind power generation in their service areas.

These issues are discussed in a study of central wind power stations sponsored by EPRI and performed by General Electric (EPRI ER-978). Among other aspects, the report describes procedures for estimating the value of wind generation in utility networks, using planning tools available to the industry. A second study is now under way to examine the economic and technical impacts of wind power generation on transmission and distribution systems. In both studies, illustrative results are developed for several utility systems. For example, the variation in predicted energy and capacity credits with wind power penetration is shown for several case studies.

Moreover, EPRI has begun a study to estimate the importance of stability and dynamic considerations as potential limits to wind power's penetration into utility systems. The initial work will be carried out with Hawaiian Electric's system as a case study.

Through studies such as these, EPRI and others are helping utilities gain more information on such key points as fuel credits (the value of fuels displaced by wind), capacity credits (the value of conventional generating equipment displaced by wind), and the roles for electric energy storage with wind power generation. At present, it is believed that the largest potential contribution to be made by wind machines will be in the form of fuel credits. While many feel that capacity credits will be small because of the fluctuating nature of the wind resource, it is thought that with growing operational experience, some fraction of statistically calculated capacity credits may eventually be ascribed to wind power.

As for the need for storage equipment, the 1979 report prepared for EPRI by General Electric concluded that dedicated energy storage offers little if any advantage. (Dedicated storage is operated in conjunction with one energy source rather than with an entire utility system.) What is preferable is that the utility system be able to accommodate the variable output of the wind machines with other generating apparatus.

While further information is needed in these areas, electric utilities appear to be growing more interested in wind power generation. This interest is reflected in heightened activity across the board, including field tests and demonstrations; wind resource and integration assessment work; and residential, commercial, and agricultural wind machine monitoring.

Whether today's optimism over wind generation will be justified by tomorrow's reality is still at issue, however. Indeed, there is strong feeling that wind technology must have the opportunity to mature at a sensible pace. Wind should not be rushed, experts say, or it may be pushed into an engineering disaster that could significantly—and perhaps permanently—retard its development.

Large-scale use of wind power may well happen. Within the next five years, in fact, its prospects should be well understood. But in the meantime, it is enough for many in the field that the public has begun to pay attention.

Says NASA's Robbins, "People used to laugh when I told them I worked on windmills. They don't laugh anymore." ■

Coal ash disposal is no small job. Some 70 million tons of fly ash, bottom ash, and boiler slag were produced by the nation's utilities in 1978. Only 24% of it was reclaimed; the remaining 76% was disposed of. Until recently, the task was relatively simple and inexpensive: ash was sluiced to a pond or trucked to a waste pile at a cost of $2 or $3 a ton. But new federal regulations designed to protect surface water and groundwater are calling for more careful—and consequently more costly—ash disposal. With possible disposal costs ranging $50–$100 per ton of ash, and with long delays in obtaining permits for disposal facilities, the ability to zero in on the most economical and environmentally acceptable disposal site and method early in the design process can result in substantial savings to the utility.

With that in mind, EPRI's solid-waste disposal group produced the *Coal Ash Disposal Manual* (FP-1257), which gives utility engineers a firm basis for the preliminary screening of ash disposal sites and methods. The manual includes data and procedures for developing cost estimates and a quantitative procedure for evaluating environmental effects.

New regulatory climate

Two federal laws likely to have significant impact on coal ash disposal practices are the Resource Conservation and Recovery Act of 1976 (RCRA) and the Federal Water Pollution Control Act as amended by the Clean Water Act of 1977 (CWA). These laws protect groundwater and surface water, respectively, explains Dean Golden, who manages EPRI's solid by-product disposal research.

RCRA was passed in response to concerns that leachate from solid-waste disposal sites might cause groundwater pollution. Regulations and guidelines for disposal of all solid wastes are now being promulgated under this act. While RCRA's exact impact on ash disposal practices is still unclear, it is certain that tougher environmental standards will have to be observed in the future.

CWA, through the National Pollution Discharge Elimination System (NPDES) permit program, sets stringent effluent limitations for point-source discharges to surface waters. These standards apply to discharges from ash ponds, as well as to runoff from ash landfills.

The *Coal Ash Disposal Manual* includes chapters on the chemical, physical, and engineering properties of ash, examples of disposal systems, cost-estimating methods for such systems, site selection methods, environmental monitoring, site reclamation, and federal regulations. A looseleaf format will permit the manual to be updated as both regulations and technology evolve; an enclosed questionnaire will poll users for feedback on the manual's usefulness.

Ash chemistry

The chapter on ash properties is particularly timely. In the past most ash was sluiced to ponds with little or no subsequent handling. Little characterization of the ash's chemical or physical properties was necessary. Now, however, those properties are important to utilities. If an ash's chemistry includes certain levels of heavy metal trace elements, for example, the ash could be judged hazardous and therefore subject to special regulation. Similarly, an ash's engineering characteristics—its quality as a structural fill—are becoming increasingly important as more and more utilities switch from wet to dry disposal systems. (Dry ash has greater marketability and less volume.) The effects that coal origin and methods of combustion, ash collection, and handling can have on the chemical and physical characteristics of ash are also discussed.

Site selection receives due coverage in the manual, with a discussion of disposal system types and the physical, engineering, regulatory, environmental, and economic factors that influence siting decisions. A matrix that planners can use to rank sites according to environmental considerations is included; cost estimates for disposal systems, as well as methods for preparing more detailed cost estimates, are also presented.

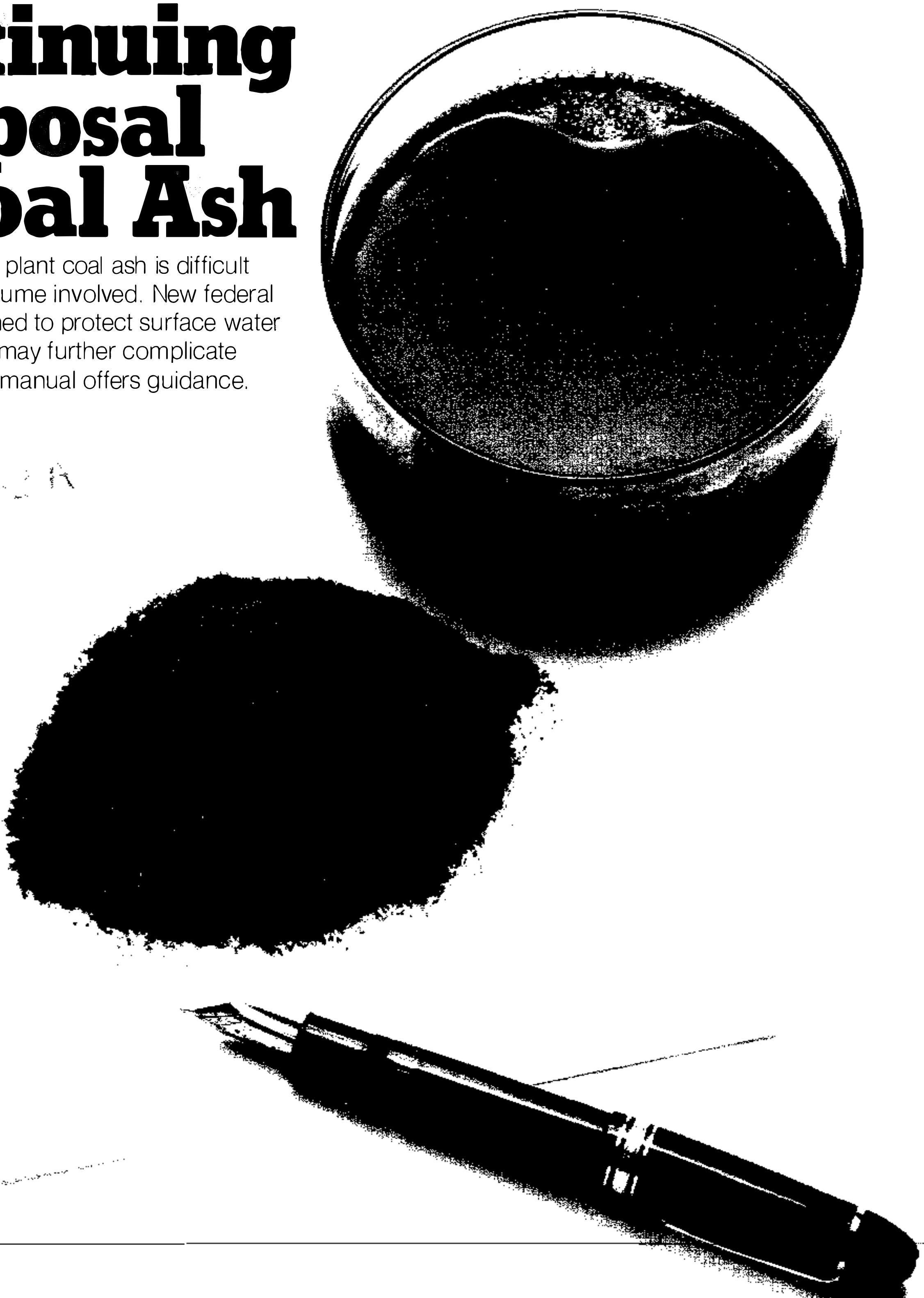
The chapter on environmental monitoring addresses another growing concern. Monitoring of ash disposal areas is increasingly being required by federal, state, and even local regulations because of the potential these areas have for adversely affecting local water quality. The manual explains monitoring-well systems and costs. Also covered are design and operation of these systems, monitoring schedules, recommended locations for monitoring points, and selection of a collection method to ensure representative samples.

Site reclamation merits yet another chapter. Not only is site reclamation desirable from an environmental standpoint, but the utility that practices it also benefits from reduced postclosure maintenance and increased future land-use options. There is considerable confusion today about which reclamation methods are most appropriate. Because of differences in soil and climate, what works at one site may fail at another; because of differences in ash properties, one investigator may report on the toxicity of ash to vegetation, while another notes its benefits as a soil supplement. The manual offers specific guidance to effective and economical site retirement and revegetation procedures, as well as sources of additional information and assistance.

The *Coal Ash Disposal Manual,* FP-1257, prepared by GAI Consultants, Inc., Monroeville, Pennsylvania, can be ordered from Research Reports Center.

The Continuing Disposal of Coal Ash

Disposal of power plant coal ash is difficult because of the volume involved. New federal regulations designed to protect surface water and groundwater may further complicate the task. An EPRI manual offers guidance.



Special PCB disposal will be a continuing utility industry responsibility for years to come. A series of EPRI handbooks helps utilities evaluate disposal alternatives.

The Delicate Disposal of PCBs

Polychlorinated biphenyls—PCBs—boast attractive dielectric properties, fire resistance, and chemical stability. Until 1976 they were a logical choice for insulating utility capacitors and transformers. But that year the Toxic Substances Control Act identified the all-too-sturdy PCBs as environmental contaminants. The utility industry, with some 375 million pounds of PCBs in distribution equipment, must now comply with stringent disposal regulations as this equipment is routinely taken out of service. Three newly published EPRI handbooks will help utilities evaluate their disposal alternatives.

The first handbook, *Disposal of Polychlorinated Biphenyls (PCBs) and PCB-Contaminated Materials* (FP-1207, Vol. 1), provides utility engineers with general information on PCB production and use, details on present and proposed disposal regulations, the projected requirements for disposal capacity, and an overview of available disposal technology (both incineration and landfill). The second and third handbooks provide guidelines on the development of spill prevention techniques and countermeasure control plans to ensure that risks associated with PCB activities are minimal. Included are model operation plans that address assembly and servicing of PCB-filled components, spill-free use of equipment, and containment procedures for preventing accidental releases. All three handbooks were developed through EPRI's solid-waste disposal subprogram.

EPA stipulations

The reason for the concern is that PCBs are highly toxic. They tend to accumulate in animal tissue and to persist in the environment. The Toxic Substances Control Act of 1976 authorized federal regulation of PCB manufacture, processing, distribution, use, and disposal. Resultant EPA regulations originally stipulated that beginning January 1, 1980, all waste PCB liquids with PCB concentrations greater than 500 ppm must be incinerated. PCB destruction requires incineration at high temperatures for specific residence times. Appropriate facilities were not certified by that date, however, so EPA proposed an amendment to require incineration 30 days after the first incinerator is certified. Other EPA regulations require that all PCB-contaminated solids be deposited into landfills and stipulate special decontamination provisions for PCB transformers and capacitors. The EPA also specified stringent design criteria for both incineration facilities and landfills.

To satisfy these requirements, significant PCB disposal capacity will be needed nationwide as the transformers and capacitors now in service are gradually retired, according to Dean Golden, who manages EPRI's solids by-product disposal research. Average transformer life is 40 years; average capacitor life is 20 years. Disposal of PCBs and PCB-contaminated materials will therefore be a continuing industry responsibility through the year 2018.

Unfortunately, EPRI research indicates that disposal capacity will be less than adequate as EPA regulations go into effect. Only seven landfills in the country presently measure up to EPA standards for PCB disposal; eight more await EPA approval. These landfills, however, are not ideally distributed throughout the United States. With the cost of PCB transport at about 15¢ per ton per mile, long-distance hauls to far-flung disposal sites will be costly. The PCB disposal handbook advises the establishment of local utility-owned landfills to keep costs down and offers a conceptual design for a PCB landfill.

Incineration capacity is an even bigger problem for utilities. There are no approved PCB incineration facilities anywhere in the United States that will accept utility PCB waste at this time. Two existing commercial hazardous waste disposal facilities have applied for approval; neither has been certified to date.

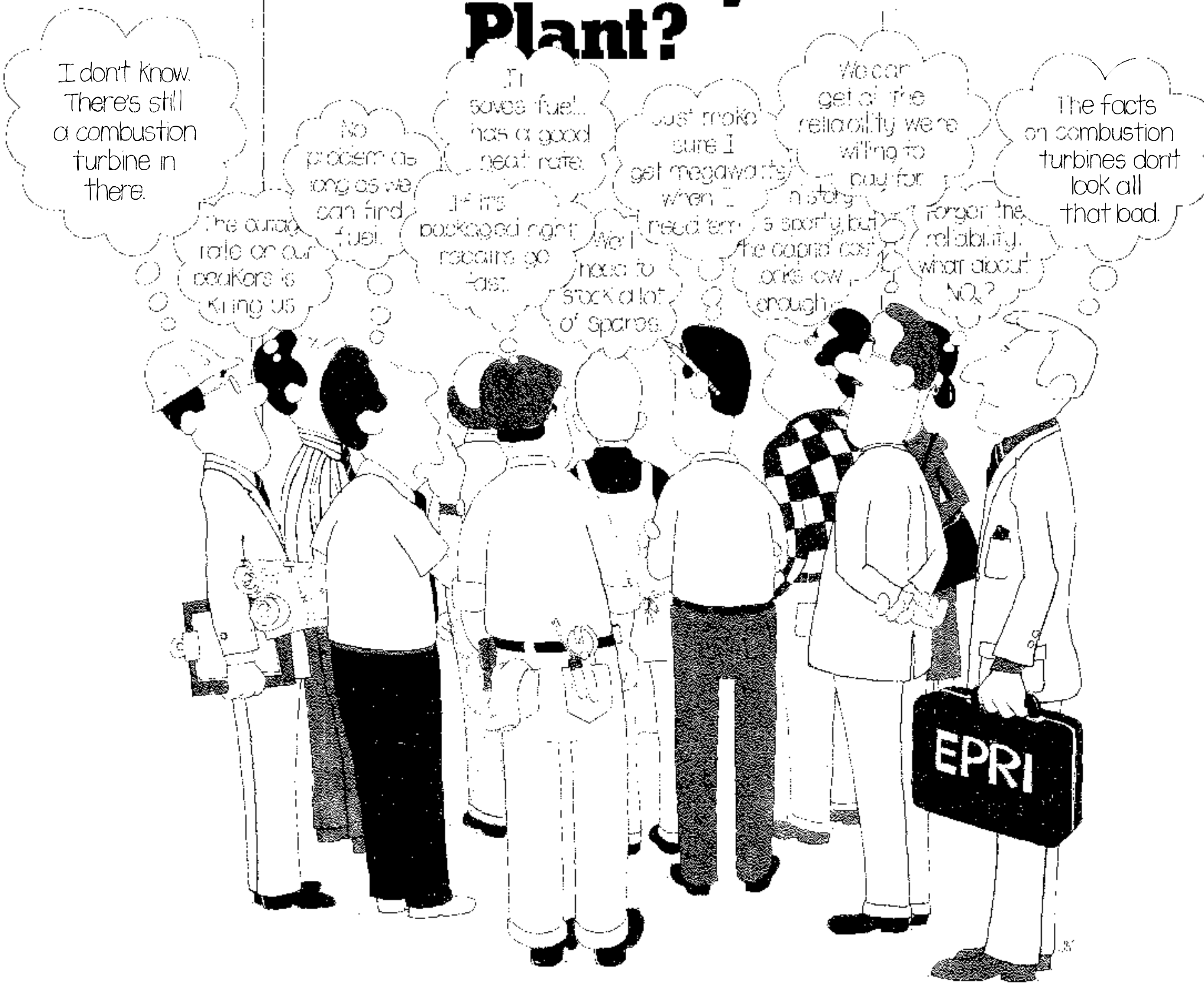
There are numerous reasons for the shortage of commercial incineration capacity. Many existing disposal facilities cannot meet tough EPA design criteria. PCB destruction requires higher temperatures and longer residence times than are needed for most chemical-waste incineration. Furthermore, the chlorine present in PCBs can form extremely corrosive substances in incinerator exhaust gases, so special materials must be used to construct PCB incinerators and their air-pollution control devices. New facilities tailored to PCB incineration could certainly be built, but a demand for such facilities must first be demonstrated before new construction can be financed. Even if a significant demand develops after the effective date of certification, there is much public opposition to the siting of new facilities.

Utility alternatives

Despite these odds, PCB incineration technology is available, according to the disposal handbook. Utilities might develop new incineration systems specifically for PCB combustion. Existing utility boilers might also be adapted to incinerate PCB liquids. Besides establishing their own PCB disposal capacity, utilities are advised to make long-term commitments to the waste disposal industry to ensure commercial facility construction and operation. Conceptual systems for PCB incineration are included in the handbook, along with cost estimates.

The PCB handbooks, prepared by SCS Engineers, Long Beach, California, can be ordered from Research Reports Center. The first handbook's looseleaf format will permit updating as the state of the art of PCB disposal develops. The second and third handbooks, *Suggested Procedures for Development of PCB Spill Prevention Control and Countermeasure Plans* (FP-1207, Vol. 2) and *Example Preparation of a Utility PCB Spill Prevention Control and Countermeasure Plan* (FP-1207, Vol. 3), are in standard report form. ■

How Much Can We Rely on a Combined-Cycle Plant?



Experience with combustion turbines in peaking units has raised doubts about combined-cycle reliability. But new analyses have more precisely defined the inherent reliability characteristics of combustion turbines, their auxiliaries, and their controls. The implications of these findings are important—high reliability is a practical goal for combustion turbines in combined cycles, and design improvements can make them adaptable to coal-derived fuels. Success in these efforts will enable utilities to make wider use of the intriguingly high thermal efficiency of combined-cycle plants.

Shortly after noon on a hot August day, air conditioners begin to hum in a big city on the eastern seaboard. It could be Philadelphia, or Baltimore, or Washington. The utility's power dispatcher sees a sharp demand peak taking shape, and he reaches for the phone.

Responding to his call, the power plant operator pushes a single button. An electric cranking motor whirs, the first step in a totally automated 30-minute sequence for starting up a 90-MW standby generator. Once its shaft is turning at perhaps 20% of full speed, jets of expensive distillate fuel are ignited and a combustion turbine begins to wind up to the roar of full power. Spinning at 3600 rpm, inflamed by the 1060°C (1950°F) gases from burning oil and air, the turbine blades expand into dimensional clearances that have been designed to accommodate the stresses and strains of this rapid thermal cycling. The generator spins at the other end of the shaft, voltage and frequency are automatically synchronized, and the utility's newest peaker—only 22 months old—is on-line.

The problem

But there's more. Less than an hour later, diagnostic instruments signal that a hydraulic servo valve is sticking. Moments later a protective relay trips, fuel pumps are cut out automatically, and the turbine begins to wind down.

Forced outage! By now all the other available peakers are fully loaded, or perhaps a little overloaded; so the dispatcher calls for purchased power over the intertie from a neighboring utility. The system remains intact and no one loses electricity service. But the plant maintenance crews now have some work to do, and the station log shows that it has been only 210 operating hours since this unit went down the last time. What's more, it will take at least 12 days to get delivery on a new servo valve.

What kind of reliability is this?

The fact is, nobody knows. Or, more precisely, nobody did until a lot of records from a lot of utility combustion turbine (CT) units and combustion turbine combined-cycle (CTCC) plants were compiled and analyzed during the last two years. Much of the work was done under three research contracts awarded by EPRI to General Electric Co., Westinghouse Electric Corp., and United Technologies Corp.

In light of these analyses, the characterization of a 22-month-old CT peaker's being forced out of service for nearly a month, only 210 hours after a previous failure, carries several lessons between the lines.

□ Duty cycle. Employed as a peaker, a CT experiences thermal cycling stresses that reduce component life (especially in the hot section) well below what would be expected under the more familiar steady-state conditions of baseload service.

□ Automated operation. It's undeniably contemporary, and it's economical in concept, but it can lead to neglect of small units in a station where shift maintenance crews are preoccupied with the apparently more imminent needs of big baseload generators that are not as fully automated as the CT peaker.

□ Immaturity. There's a learning period of 1–3 years during which reliability is poor, especially evident in frequent forced outages. The equipment itself, as well as O&M crews and their procedures, undergoes a shakedown. Reliability thereafter improves—availability by some 20–25% and mean time between failures by as much as 700%.

□ Dependency. A utility frequently owns and operates several CT peakers but doesn't need to depend on any single one of them because the others can be "squeezed" to generate the last 90 MW or because purchased power can so easily be delivered over system interties. The utility protects the peaker from major damage by automatic trip-out relays rather than preserving its functional availability by rigorous on-line maintenance.

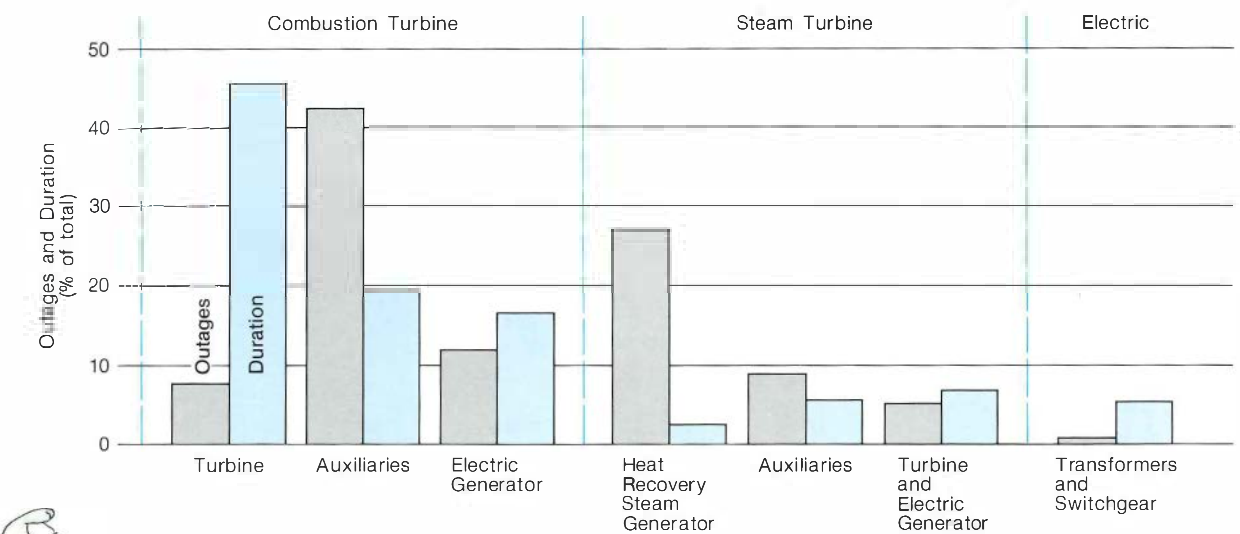
□ Repair urgency. Despite the reason a CT peaker is forced out of service, its availability record is further affected by the duration of downtime. Again, the availability of other peakers and the accessibility of purchased power, when reasonably priced, takes precedence over fast repair.

□ Spare parts. The lead time for obtaining spare parts can reduce availability (hence, perceived reliability) drastically. Analyses for EPRI on just this one point revealed a difference between about 87% availability (all parts in utility stock) and 75% availability (2-month supplier lead time). The same analyses showed a typical lead time of 1–2 months.

COMBINED-CYCLE PLANT RELIABILITY

	Utility Experience	EPRI Analysis		EPRI Goal	
	MTBF[1] (h)	MTBF[2] (h)	Availability (%)	MTBF[2] (h)	Availability (%)
Combustion turbine only	2690	5560	94.7	9000	System-dependent
Combustion turbine system	593	980	92.2	6000	95.0
Steam turbine system and balance of plant	545	663	91.1	System-dependent	System-dependent
Total plant	184	281	77.5	3000	90.0

Note: Data are average figures from EPRI-sponsored analyses of mature plants with two combustion turbines and one steam turbine.
[1]Inherent and noninherent mean time between failures.
[2]Inherent mean time between failures.



Inherent data from representative mature combined-cycle plants show the percentage of forced outages and the percentage of total downtime (forced and scheduled) attributed to a given subsystem. Combustion turbines in themselves are not the most frequent cause of outage, but their outage durations are long. This is because of problem complexity, inaccessibility for repair, repair scheduling, and unavailability of parts. Combustion turbine auxiliaries (e.g., fuel pumps and hydraulics) cause a much higher percentage of outages but are easier and faster to repair. Redesign of some components, redundancy of others, and reevaluation of spare parts inventories and maintenance practices will make combined-cycle plants more reliable.

The questions

The six factors described above show that CT availability—the benchmark of reliability—is strongly influenced by operating context. The example is a peaker, running fewer than 1000 hours annually. The described practices may make economic sense in that application, but they all penalize CT availability, and they distort the utility's picture of the reliability that could be attained under intermediate (1000–4000 hours) or baseload (more than 4000 hours) service conditions.

But is CT reliability as bad as it looks? If so, how can CTs possibly be considered for routine application in combined-cycle baseload plants? On the surface, CT units in utility peaking service have an unenviable record of short mean time between failures—200–500 hours. And regardless of the duration of outages, their frequency leaves a bad taste. In contrast, similar machines, from some of the same manufacturers, power most U.S. commercial passenger aircraft with satisfactory reliability. More directly relevant, they are steadily and economically run for baseload power production by several companies in the chemical process and pipeline industries and even by several electric utilities.

In the utility applications CTs are combined with steam turbine generators for greater overall thermal efficiency and fuel economy and correspondingly lower operating cost. The combined-cycle requirement is for at least 1300–1700 hours mean time between failures if reliability is to be comparable to that of conventional fossil and nuclear plants.

What is being done to make up this gap—approaching a factor of 10—between CT peaker reliability today and the reliability needed in a CTCC baseload plant? What are the major problems? Can a reliable CTCC plant be developed? What R&D will it take? How would the reliability in baseload service compare with that in the peaking service that dominates the record today?

WHY CONSIDER COMBINED CYCLES FOR BASELOAD?

EPRI's special focus on CTCC plant reliability stems from its studies of future fossil fuels (and the environmental requirements likely to govern their use), the power technologies that can burn those fuels (and meet those requirements), and the busbar costs that call for various combinations of fuels and thermal cycles to make up a generation mix of baseload, intermediate, and peaking.

Future fuels

Coal is the dominant fossil fuel, but it is a solid, and the power technologies most adaptable to cycling operate better on liquid or gaseous fuels. Growing restrictions on petroleum and natural gas supplies suggest the use of synthetic, coal-derived liquids and gases, the technologies for which are under urgent development and expected to be commercially productive in the 1990s.

Power technologies

Synthetic fuels will be expensive, either in their own right or as determined by the market for petroleum, which will likely still be the bellwether. Generation process efficiency and fuel economy can offset this problem, and here is where the CTCC plant comes in, using exhaust heat from one or more CT units to raise steam in a heat-recovery steam generator and drive a steam turbine. The overall thermal efficiency, fuel to busbar, increases from about 30% to about 40%.

However, although the CT unit is characteristically a standard, factory-packaged generator with relatively low capital cost (prime attributes for its use as a peaker), the CTCC plant is another matter. Its steam bottoming cycle may cost twice as much as the combustion topping cycle, and a CTCC plant may cost three times as much as a simple CT unit alone. The O&M cost (mills/kWh) is attractive, but the capital cost is not, unless the CTCC plant is dispatched (used to generate electricity and revenue) more often than during peak periods alone. This means intermediate or baseload duty, more annual hours of steady operation, and a need for dollar-and-cents reliability as well as performance. Fuel production considerations also drive this rationale.

Busbar cost

Coal liquefaction processes can stand alone and run steadily because their output is easily stored and transported. The coal liquid and its use as a generation fuel can thus be decoupled from the liquefaction process. Coal gasification processes also run best on a steady-state basis, but economy dictates that they be functionally integrated with electric power production; for example, interchange of steam and boiler feedwater between the gasifier and the steam cycle, and shared operation of auxiliary systems. Also, because the unit heat content of the gas product is 300 Btu/ft^3 or less (compared with natural gas at 1000), storage and transport of the coal-derived gas is more limited than for liquid fuels. In short, economy demands that the gasifier and the CTCC plant be sited and operated together.

The bottom line, of course, is busbar electricity cost. This means baseload operation, yielding low figures for both the fixed and O&M costs and also—through thermal efficiency—for fuel costs. The CTCC plant can produce this result, if it is reliable.

The contradiction

EPRI's approach has involved two different assessments of market potential, a survey of utility perceptions and practices in CT and CTCC operation, and the three objective analyses by equipment manufacturers—all leading to criteria for a highly reliable CTCC and identification of the R&D needed to make it possible.

Generation expansion analyses, using computer models of six hypothetical U.S. utilities with a range of sizes and service area conditions, show that plants using CTs will be able to compete with all other baseload, intermediate, and peak generation technologies in the 1990s and beyond, assuming that certain main requirements are met.

- Reliability adequate for thousands of annual operating hours, including hot-section component life of more than 50,000 hours, with a maintenance cost of 2 mills/kWh or less
- System flexibility, permitting use of a range of petroleum fuels and coal-derived liquids and gases
- Design that ensures adequate limits on emissions, particularly of oxides of nitrogen (NO_x)

In contradiction to this market projection are both the recent market history of CTs and the outlook expressed by a significant number of utilities. By recent count there were about 2100 CT units in U.S. utility service, totaling more than 58,000 MW. Some 6000 MW of this capacity is in CTCC plants, the rest in simple-cycle CT units. However, the market slipped during much of the 1970s. Between 1970 and 1974, annual shipments ranged widely, between 5500 and 9000 MW. But for 1975 through 1977, the annual figure was only 1400–1800 MW. At least two reasons account for this pattern: uncertainty about oil and natural gas fuel supplies (and their cost) and reduced load growth in most utility service areas.

Surveying the 38 utilities that operate some 60% of today's CT and CTCC generating capacity (34,000 MW), EPRI found fewer than a third of them planning new CT capacity (about 11,000 MW). Those utilities, mostly in south Atlantic and western states, are driven by (1) slippage of other baseload capacity, leaving gaps that only short-lead-time CT units can fill; (2) continued need for new peakers; and (3) extraordinary emissions restrictions that preclude other kinds of plants.

The preponderant showing by the entire group was decreasing use of CTs in the future. The main reason, again, was fuel supply uncertainty. But the secondary reason, given by about half the respondents, was dissatisfaction with perceived CT reliability.

The findings

EPRI's research toward a highly reliable CT appraised the record of aircraft jet engines. Three factors immediately distinguish their service conditions from all others. Planes breathe clean air most of the time; they fly at high altitude, well above the atmospheric contamination of urban industrial plants. Planes run on clean, highly refined (and expensive) jet fuel so they are not subject to fouling from ash-forming fuel constituents. Once a plane reaches cruising altitude, its turbines are throttled back to as little as 30% of full power; most of the utility turbines run as peakers, operating at or above nameplate rating.

The research by General Electric, Westinghouse, and United Technologies addressed the records of their own market offerings, focusing on CTCC units but also including the larger number of CT peakers. The work was undertaken to expand an essentially scanty, inconsistently documented history, get at the objective detail it might contain, and analyze it to comb out the failures not applicable to CTCC baseload service. As written, that history failed to account for many circumstances, and it failed to discriminate among many outage causes. Even among and within the units and plants surveyed in new detail, the raw data alone were not revealing.

Forced and planned outages had to be separately tallied in number, frequency, and duration. It took extensive analysis to define failures consistently and to correlate the significance and interactions of failures in the turbine itself, the generator, the auxiliary fuel pumps, the system controls, and (for a CTCC plant) the heat-recovery steam generator and entire steam turbine. Within the CT alone there was separate scrutiny of the compressor stages, the combustor section, and the turbine stages.

Beyond these subsystems other factors were found that introduced marked differences in the evolving tabulations of data on failure rate: fuel used, duty cycle, number of starts, manned or automated operation, maintenance practices, and (startling in its effect) spare-parts inventory.

The R&D needs

Taken together, these data and their analyses yielded average values of inherent reliability, that is, the reliability of one component based on its design only. In effect, this separated reliability from operating context or, in a more practical sense, defined reliability in terms of a stated context. The cost-benefit relationship could thereby more easily be established for any given design improvement.

Similarly, the findings revealed markedly different failure rates for components (hence for units and plants) as a function of their maturity. Reliability thus involves a learning curve for a utility and its personnel as operating and service procedures are established and only gradually become a familiar routine.

As CTCC plants are envisioned for widespread baseload service, these findings permit two conclusions. One is the strong influence of utility operating practices on availability. Learning periods can be shortened (hastening plant maturity), two-shift maintenance is desirable, and spare-parts inventories can be more ex-

RELIABILITY—WE MEASURE IT SEVERAL WAYS

What we mean by reliability isn't always clear. The problem is to agree on what must be measured, and why. Here are definitions of four reliability measures that are important in utility practice.

- Availability: The percentage of a year that a unit was or could have been generating electricity. This percentage is based on experience records.

- Operating reliability: The percentage of a year that a unit was or could have been generating electricity or was undergoing scheduled maintenance. This figure is used for advance planning because it accounts for anticipated repair intervals.

- Starting reliability: The annual ratio of successful startups to attempted startups of a unit. This measure is especially important to a dispatcher or operator.

- Mean time between failures (MTBF): The average number of operating hours between forced outages. MTBF is used to make consistent reliability comparisons between components, subsystems, generating units, and entire plants.

The first three definitions are most valuable in utility operations; the fourth, in R&D analyses, where inherent durability is a major concern. MTBF does not correlate with availability percentage. By measuring the frequency of malfunction, however, it correlates directly with our emotional perceptions of unreliability. It thus directs attention to those root causes that are most frustrating because of their frequency alone.

tensive (reducing outage durations). For such actions, the methods of assigning economic costs and benefits have been demonstrated by the research assessment. If they are thoroughly applied by utilities, today's CTCC plants can attain better reliability and produce electricity at lower busbar cost, suiting them to more effective intermediate and baseload service.

The other conclusion is that R&D is needed to permit the critical design changes needed for better inherent reliability. Examples are most evident in the CT itself: cooling and corrosion resistance. EPRI-sponsored research is already well under way toward new turbine blade and vane cooling schemes (both wet and dry) that will reduce hot-path metal temperatures to 790°C (1450°F), or even below 540°C (1000°F), while turbine inlet gas temperatures remain at 1180°C (2150°F) or higher. Below a metal temperature of 790°C, it is possible to use a wider range of metals and alloys that are stronger, more corrosion-resistant, less expensive, and more available. Below 540°C, the choice is even greater because hot corrosion ceases to be a significant problem.

This R&D is motivated in part by the foreseen advent of coal-derived fuels and their characteristics that differ from petroleum fuels or natural gas. But even broader fuel flexibility is needed in the short term because the short supply and high price of distillate fuel are already driving some utilities to blended and residual grades for CTCC operation. These fuels contain corrosive vanadium, aluminum, iron, and silica that can shorten parts life.

But perhaps more important are requirements in the balance of plant. This conclusion is based on a comparison of availability data for mature CTCC plants and for mature steam plants in the 100–200-MW capacity range. In the former, the combustion turbines alone are more reliable than their controls and auxiliaries. In the latter, the reverse is true. Accordingly, continuing EPRI research toward a more reliable CTCC plant involves two avenues, especially for components and subsystems that are outside the turbine itself. One is redundancy; for example, install two fuel pumps to heighten starting reliability. Experience suggests that fuel pump problems may be the root cause of many failed starts and consequent outages.

The other avenue is straightforward redesign of mechanical auxiliaries for better inherent reliability. Switches, thermocouples, and hydraulic control valves are examples under study. Operating context is highly relevant here, as current components were designed for machines that would be competitive only in peaking service, whereas the reliability requirement (component life) is greater in baseload service.

The future

Research requirements are thus becoming more focused. Two of the three contractors who conducted the reliability and requirements assessments, Westinghouse and United Technologies, are now developing preliminary designs for a more reliable combustion turbine. As examples, a three-stage (rather than a four-stage) turbine has been conceived and a two-bearing (rather than a three-bearing) design. These rely on reductions of mechanical complexity to boost reliability by perhaps one-third. The overall cost of a combined-cycle plant may be reduced in even greater proportion by such new developments, thereby yielding lower capital and operating expense per unit of capacity or output.

Critical R&D tasks will flow from these design concepts, and their results will converge in a single reference design, tentatively scheduled for about 1985. Expected to use conventional fuels when first produced, it will specifically be adaptable (e.g., by combustor modifications, fuel pump change, and the addition of fuel-line heaters) to the use of coal-derived fuels—and thus to the widespread use of CTCC plants as a reliable baseload generating option. ■

DOE Moves Ahead With Geothermal

During the 1980s the Department of Energy is striving to commercialize underground hot water for electricity production and direct heat. Cooperation with industry is an integral aspect.

While many energy specialists are looking up to the sun as a future source of abundant heat and electric power, others are looking down to the natural energy that exists within the earth's interior. DOE, through its Division of Geothermal Energy, is supporting an annual $150 million effort to develop geothermal resources as one alternative for helping to reduce U.S. reliance on costly imported oil.

Geothermal energy is the natural heat of the earth that is close enough to the surface to be tapped for generating electricity or heating buildings. It exists in several forms: dry steam and hot water (hydrothermal resources), geopressured water with dissolved methane gas, and dry, hot rock.

Dry steam is the most convenient form of geothermal energy for electric power production. It has been used to generate electricity since 1904 at Larderello, Italy. Dry steam sites are limited, however. The only site within the United States that has been identified thus far is The Geysers in northern California, where Pacific Gas and Electric Co. (PG&E) produces nearly 700 MW of electricity from dry steam.

A more prevalent form of geothermal energy is hot water, which was used as far back as Roman times for bathing and therapeutic purposes. Underground hot water can be used to generate electricity, to heat buildings directly, or for industrial and agricultural processes. Hot water has been used for many years to heat homes in New Zealand; Iceland; Boise, Idaho; and Klamath Falls, Oregon. Electric power has been produced from liquid-dominated resources in Mexico, the Philippines, New Zealand, and Japan, and power plants using this type of resource are under construction in California, Idaho, and New Mexico. DOE and several private companies are supporting development of these facilities in the United States to demonstrate the production of electricity from underground hot water. Although hot water can be expensive to recover for power production, and there are problems with impurities that corrode and scale generating equipment, this form of energy is expected to be competitive with other energy sources.

Even more abundant in supply than dry steam and hot water are geopressured water and dry, hot rock. Along the Gulf Coast of Texas and Louisiana, highly pressured salt waters containing dissolved methane gas are widely dispersed in sedimentary deposits. Both the gas and the heat can be recovered, but the process is expensive. It is estimated that dry, hot rock resources represent over half the U.S. geothermal potential, but no satisfactory technologies have yet been developed for extracting the heat.

Federal Program

DOE, other federal agencies, and private industry are cooperating in a national effort to develop technologies that will expand commercial use of geothermal energy. Private industry has long been in the forefront of geothermal development. Magma Power Co., Thermal Power Co., and Union Oil Co. of California have all been active in development of The Geysers. Magma Power is also operating an 11-MW hot water electric power plant at East Mesa in California's Imperial Valley. Several individual electric utilities have been actively involved, and EPRI supports utility efforts with a centralized R&D program.

The federal agencies involved in geothermal are coordinated by the Interagency Geothermal Coordinating Council (IGCC), which was mandated by the Geothermal Steam Act of 1974 and chartered in 1977. DOE is the lead agency on the council, which is chaired by DOE's assistant secretary for Resource Applications, Dr. Ruth Davis. More than 20 federal agencies are members, including the Treasury, Interior, and Agriculture departments, the National Science Foundation, and the Environmental Protection Agency. A staff committee, chaired by members of DOE's Division of Geothermal Energy, formulates the overall federal geothermal program plans.

The Division of Geothermal Energy is responsible for the R&D activities in geothermal technologies. Until last summer that division was part of the Office of the Assistant Secretary for Energy Technology. When ET was split according to specific energy types (fossil, nuclear, and so on) following the DOE reorganization, geothermal R&D moved to the Office of the Assistant Secretary for Resource Applications, which is responsible for taking technologies from the development stage through commercialization.

DiBona

Bennie DiBona, division director, explains why the resource was placed in the commercialization unit and why the decision represents somewhat of an inconsistency.

"There are a large number of people in DOE and private industry that believe geothermal is ready for commercialization—that it is ahead of other new technologies," he says. "But they are primarily referring to liquid-dominated geothermal resources, the so-called hydrothermal resources. We do have two other technologies that are much more in the R&D stages: geopressured and dry, hot rock. But rather than break up the division, they decided to bring the whole package over to Resource Applications at one time—which I prefer."

When DiBona's division was transferred to Resource Applications, it joined a geothermal group located in that office that was responsible for commercialization activities, legislative affairs, the loan guaranty program, and other nontechnology activities. All geothermal work in DOE is now centralized in Resource Applications.

DOE has set definite commercialization goals for the various forms of geothermal energy. DiBona explains that the agency hopes to stimulate private development of hydrothermal resources in the near term (around 1985), geopressured resources in the midterm (1990–1995), and dry, hot rock in the long term (2000). He stresses the integral role of private industry in this effort. In fact, as he explains it, the intent is to stimulate private industry to develop the resource.

"We feel it is extremely important for us in our division to work closely with private industry," he remarks, explaining that private industry includes the utilities, the resource developers, and other organizations interested in nonelectric applications. "We do that in several ways. For one, we contract primarily with private companies to do our work for us."

DiBona explains that some 75% of DOE's geothermal funding goes to private companies (approximately 60% directly to private companies and 15% to subcontractors of the national laboratories). Representatives from the private sector contribute to DOE's program through participation on special advisory boards and review panels. Vasel Roberts, manager of EPRI's Geothermal Power Systems Program, for example, sits on the geothermal panel of DOE's Energy Research Advisory Board. Also, for most R&D components of the DOE program (drilling, logging instrumentation, reservoir engineering), there are separate steering committees that include industry representation. "We generally follow what [the advisory panels] recommend," says DiBona. "There is very close interaction."

DOE's Objectives

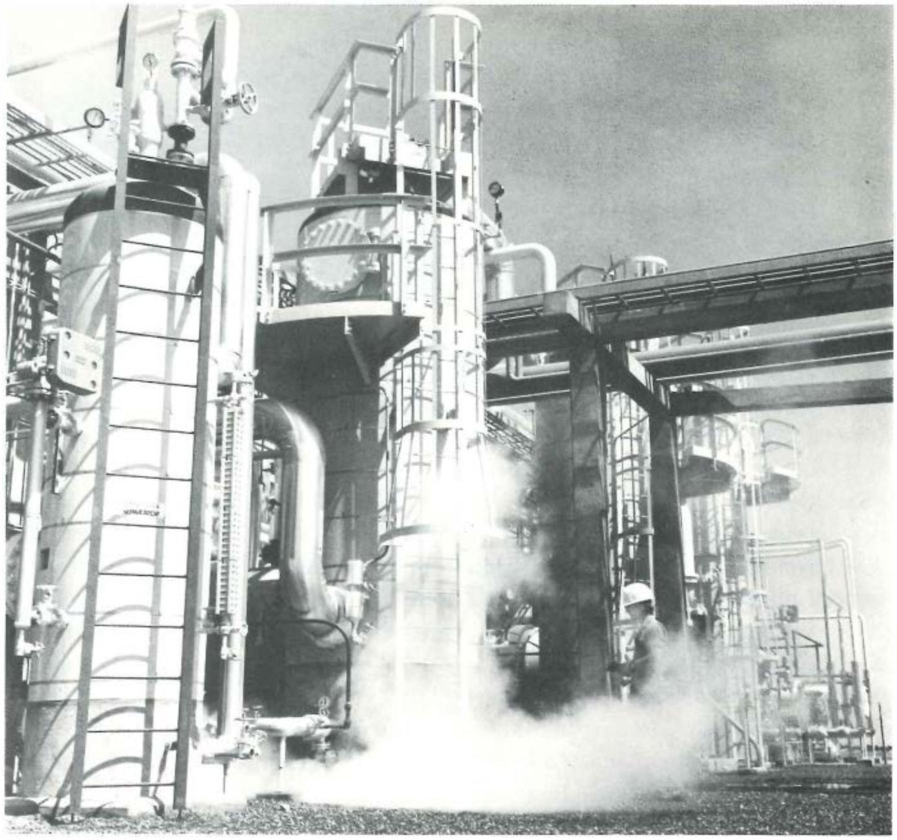
Overall objectives for DOE's geothermal program, according to DiBona, are to define the resource (identify its location and the extent of supply); to confirm its existence through drilling and production testing; to develop the technology that will reduce the cost of generating power and using heat directly from geothermal energy; to evaluate the environmental impact and develop control technology; and to demonstrate geothermal use in pilot- and commercial-scale facilities.

DOE works closely with the U.S. Geological Survey, Department of the Interior, in its resource assessment activities. Typically, after prospective geothermal resources are identified at a particular location, exploration and drilling follow to confirm the resource.

DiBona explains that for hydrothermal resources, DOE is now targeting its research and resource assessment activities at sources of moderate and low temperatures—those below about 400°F (200°C). "Industry is already moving in the higher temperature areas," he explains. "Power plants that use the higher temperature range are on-line today in other parts of the world. However, if you look at the distribution of temperatures for hydrothermal resources, you'll see that 80% of them fall below 400°F."

Specifically, DiBona explains, DOE, as well as private industry, is now working in temperature ranges between 300° and 400°F (150–200°C) for electric power production. This range is what he calls "the next group of geothermal resources to come on-line." Plants planned or already operating that use this temperature range include the 11-MW system built by Magma Power in East Mesa, the 50-MW plant proposed by Southern California Edison Co. at Niland, California, and the 50-MW plant being built by Republic Geothermal, Inc., at East Mesa.

Temperatures below 300°F are too low to be used for electricity production, DiBona explains, but they offer great potential for direct heat applications. He says that there are large areas of the country that have lower-temperature hot water underground that could be tapped for directly heating homes and buildings and for agricultural and industrial process heat. Therefore, DOE is directing its resource definition activities beyond the western states that have traditionally been the site of geothermal efforts and toward other parts of the country, including the Atlantic coastal plain. The agency has conducted a major drilling program to locate geothermal energy resources on the East Coast. Last July an exploratory well drilled at Crisfield, Maryland, confirmed the presence of geothermal hot water of about 133°F (56°C) under the Atlantic coastal plain.



Niland geothermal loop experimental facility in the Imperial Valley of California. The 10-MW facility is jointly funded by San Diego Gas & Electric Co. and DOE.

In addition to its drilling and exploratory activities to discover these lower-temperature resources, DOE is also sponsoring some 22 demonstration projects that use underground hot water for direct heat applications, such as industrial processing, district heating, and space conditioning.

The largest such demonstration project is in Boise, Idaho, where underground hot water has been used for decades to heat some homes and buildings. With a $4.9 million DOE grant awarded to Boise this fall, city officials are expanding Boise's system to supply heat to buildings in the downtown business district.

Technology Development

The broad objective of DOE's technology development program for geothermal energy is to reduce the high cost associated with recovering and using geothermal energy for electric power or for direct heat. One key element in the electric power part of the program is development of advanced conversion systems, particularly one that applies binary-cycle technology to extract heat from underground water and uses the heat to spin a turbine-generator to produce electricity. Binary-cycle systems are of particular interest to DOE because of their potential for use with the lower-to-moderate temperature resources that are now being targeted as prime areas of geothermal development.

"There is a belief both within DOE and the industry that to really make a significant contribution from resources in this temperature range, binary systems are the answer," says DiBona. "That is why we are heavily involved in binary systems in an R&D way."

Conventional flash technology for extracting geothermal heat brings the hot water out of the ground and part of it spontaneously "flashes" to steam. In the binary cycle, hot water from the ground heats a secondary working fluid with a lower boiling point and this, in turn, expands to a gas to spin a turbine-generator. The cooled water is then deposited in wells near the reservoir. For moderate-temperature resources, binary cycles are expected to produce power at lower costs and more efficiently than flash systems.

DOE is also working on an advanced binary system called the direct contact heat exchanger. DOE expects that this technology will lower the cost even further.

In addition to technology development of the binary cycle and more advanced forms of conversion equipment, the Division of Geothermal Energy is supporting other work to help reduce the cost of geothermal energy use. DiBona notes that private industry has identified some of the key efforts needed.

"Industry has told us that the three main areas of R&D needed to bring geothermal on-line in a significant way are drilling and well-completion technology, exploration technology, and well stimulation," says DiBona.

DOE estimates that improvements in drilling and well-completion technology could reduce the cost of developing geothermal wells 25% by 1983 and 50% by 1986. Drilling is a high-cost item and the agency is therefore supporting work on improved drill bits and downhole drill motors, as well as on drilling fluids. To improve well-completion techniques and associated equipment, materials research focuses on cementing compounds and elastomers (synthetic polymers) for seals, packers, logging cables, and blowout preventers.

DOE is also working on better exploration techniques for helping to identify and assess the extent of geothermal resources. "Most of the resources that we find today are because of surface evidence, such as a hot spring or mud bubbling on the ground," says DiBona. "But there are many resources that don't have surface manifestations and these exploration techniques will help to identify them." Such technologies would reduce the cost and substantially increase the amount of geothermal energy that could be identified and developed, he contends.

DOE has also inaugurated a program to develop stimulation technologies, such as hydraulic fracturing or explosives, to increase the production from an individual well, thereby reducing the number of wells required to exploit a reservoir. Since wells account for up to 50% of geothermal power costs, such stimulation techniques could go a long way toward helping to make geothermal cost-competitive with other resources.

Environmental Impact

Evaluating the environmental impact of geothermal energy is also a key element in the DOE program. In 1978 DOE issued *Environmental Development Plan for Geothermal Systems,* which identified hydrogen sulfide (H_2S) emissions as a major air quality problem that causes corrosion and odors at geothermal plant sites. The report also cited land subsidence as a possible problem because of the large quantities of water removed from the land to extract the energy. It also noted that disposal of both hydrothermal and geopressured fluids, which may contain certain toxic substances and large quantities of dissolved solids, is a major waste management problem.

DOE's research program for developing environmental control technology focuses primarily on the reduction of H_2S emissions. At The Geysers, in cooperation with PG&E and Union Oil, the agency has sponsored pilot-scale tests of a type of scrubber system that uses copper sulfate ($CuSO_4$) to remove the H_2S from the steam before it goes to the turbine-generator. The tests were successful in removing some 99% of the H_2S, according to DiBona. Because of these results, PG&E is considering building a full-scale commercial scrubber that uses this process at The Geysers. "This is one major contribution that the federal dollar has made to the geothermal program," remarks DiBona.

Demonstration Projects

Several of DOE's projects to demonstrate geothermal use for electric power production will reach major milestones during 1980.

Construction will begin in May of the nation's first commercial-scale plant (50 MW) using hot water to produce electricity. The plant will be located in the Valles Caldera in New Mexico and will use the flash steam method to produce 50 MW of power that will be fed into the grid of Public Service Co. of New Mexico. Most of that power will go to the

Los Alamos Scientific Laboratory, notes DiBona. The plant will begin operation in 1983. Public Service and Union Oil are cofunders.

DOE is now considering an amendment to the FY81 budget for the design and construction of a second 50-MW plant that will use the more advanced binary-cycle technology to generate electricity from underground hot water. The agency has selected the Heber, California, reservoir as the site that has the best potential to meet all the objectives of such a demonstration. This determination is consistent with the results of site selection studies conducted by EPRI.

Operation should begin in late summer of the Raft River plant, a 5-MW facility in Malta, Idaho. The Raft River plant will also use the binary-cycle technology to convert moderate-temperature (300°F) hot water to electricity.

"Raft River, together with a 50-MW binary plant and the 11-MW binary system that Magma Power is operating at East Mesa, should give us enough information to estimate the cost and examine the reliability of binary cycles," says DiBona.

Later in 1980, the geothermal wellhead generator at Puna on the island of Hawaii should begin operating. This is a 3-MW flash steam system that is called a wellhead generator unit because it is portable. The project will help to determine the feasibility of using wellhead generators to produce baseload electric power in small amounts, particularly in remote regions.

Other DOE experimental facilities include the Geothermal Loop Experimental Facility (GLEF) and the Geothermal Component Test Facility (GCTF).

The GLEF in Niland, California, is designed to demonstrate the feasibility of using both flash and binary systems to produce electric power from high-salinity, high-temperature brine. Salinity at the GLEF site is about 180,000 parts per million, notes DiBona. (Seawater is 30,000 parts per million.) The project is cost-shared on an equal basis with SDG&E. The project is now coming to a close, and the site is being decommissioned.

"It's been a big success," says DiBona. "They've solved most of the brine handling and disposal problems." He notes that Magma Power is now proposing to build a power plant at Niland and use some of the GLEF facilities.

The GCTF at East Mesa is available to manufacturers for testing geothermal components. DOE provides the wells, manifolds, and test equipment. The facility has been operating for several years and will continue to do so, according to DiBona, as long as there is a need for it.

Geopressure and Hot Rock

DOE's $36 million geopressured geothermal program is evaluating the feasibility of obtaining commercial quantities of hot water and natural gas from the sedimentary deposits located along the U.S. Gulf Coast. The saltwater is trapped at higher-than-normal temperatures and pressures and is mixed with methane gas. "There is a large volume of the resource in place," says DiBona, "but whether it is economically recoverable is the question."

Cost is a major problem, as well as such environmental concerns as subsidence and disposal of the large volumes of water. There is also a concern that as the water is moved out, sand may be produced that will erode the casing and wellhead equipment of the well.

To address these concerns, DOE is drilling at least three new wells each year into selected reservoirs and is testing three or four existing wells that were drilled in an unsuccessful search for gas.

DiBona adds that in the geopressured program, the primary goal is to recover the gas and the secondary one is to determine whether the hot water that comes with it can be used for electric power or direct heat.

DOE's dry, hot rock program is aimed at assessing the potential of the resource and developing new techniques for extracting the heat. Thermal loops have been tested by the Los Alamos Scientific Laboratory at Fenton Hill, New Mexico.

Commercial use of either geopressured resources or hot rock is many years down the road, however. For now, DOE is concentrating on development of hydrothermal resources to help diversify the U.S. energy supply and ease its reliance on imported oil. With advances in technologies to help reduce the high cost, geothermal hot water resources may well move toward commercialization in the decade ahead. ■

Harsh Energy Future Foreseen

The 1980s will mark the first decade of the transition to future energy technologies. The dangers of foreign oil dependency will be the driving force.

The energy situation in the 1980s can only be considered dismal, with the United States teetering on the brink of catastrophe, warned EPRI Vice Chairman Chauncey Starr recently.

Addressing the annual meeting of the American Association for the Advancement of Science, Starr said that this situation will be a result of the country's continued dependence on foreign oil. "The nation's objectives for the 1980s must be to reduce oil imports and lessen the untrammeled ability of OPEC to impose its economic will on the rest of the world."

Starr, the founding president of EPRI, stated that conservation is the quickest way to reduce oil consumption. But despite conservation, oil consumption will increase by the end of the decade. However, this increase will be at a rate about 25% lower than if no conservation effort is made.

The United States might be able to conserve about 10–15% of its oil consumption during the 1980s by improved equipment, such as gas-efficient automobiles. Higher energy costs may reduce consumption by another 10%. This means that the nation may be able to hold oil imports to current levels of roughly 50%.

Starr said he agreed with most analysts that the nation will have to continue to depend on oil, expanded coal use, and increases in nuclear power and natural gas, even though consumption will probably not rise as rapidly as in the past. There are several reasons why so little can be done during the next 10 years to reduce foreign oil imports.

- Because of the high initial capital costs of new and emerging energy sources, only very modest contributions can be made by the end of the 1980s.
- Indigenous oil and natural gas resources will barely be able to maintain present production levels, and new major oil fields are unlikely to be developed in the 1980s.
- Coal mining production will probably not double during the next decade (as some energy experts have predicted) because of environmental and other constraints.
- Shale oil will only be able to make a small contribution to the energy picture and synthetic fuels from coal conversion will just be reaching the demonstration stage by the late 1980s.

The consequences of this energy scenario, he predicted, may well be a "downtrend in the U.S. economy, increased social stress between economic levels of the population, a reduction in our scale of living, and short of war, a major reduction in the influence of the United States in foreign affairs."

The former dean of the UCLA School of Engineering also said that the 1980s will mark the first decade of the transition period, laying the foundation for future energy technologies, such as solar. "It is therefore important that research, development, demonstration, and large-scale testing of alternative energy technologies be a major national endeavor," he concluded. ■

Wilkinson to Head INPO

The new Institute for Nuclear Power Operations (INPO) recently began functioning on its own. A chief executive was named, temporary office quarters were opened in Atlanta, and a start was made on recruiting the staff.

The president of INPO is Eugene P. (Dennis) Wilkinson, a pioneer of the nuclear Navy and first captain of the first nuclear-propelled submarine, *Nautilus*. A chemical engineer, Wilkinson was assigned in 1948 to Argonne National Laboratory, where studies on a nuclear-propelled submarine began. He participated in the design and construction of the world's first PWR, the *Nautilus*'s land-based prototype reactor in Idaho, and made important contributions to the design of its core. As the prospective commanding officer of *Nautilus*, he supervised the work of bringing the prototype's seagoing counterpart into operation. Three and a half years later he carried out the same functions as the first captain of the world's first nuclear surface ship, the cruiser *Long Beach*.

Only four years later he was appointed commander of the submarine force, Atlantic, where he was responsible for more than 100 ships manned by 25,000. His last naval assignment was as deputy CNO for submarine warfare. He retired from the Navy in 1974 with the rank of vice admiral.

Since June 1977 Wilkinson has been executive vice president, products and systems, for Data Design Laboratories of Cucamonga, California, a diversified technology company.

"We are delighted to have the dynamic leadership of this distinguished American," said INPO Board Chairman William S. Lee (president of Duke Power Co.). "He is an expert in nuclear safety, operations, and training. He has impeccable integrity, inspires total confidence, and his expertise is extraordinary."

Wilkinson assumed his newest command, INPO, on February 1. Awaiting his arrival, the acting director, Randall Pack of EPRI, opened temporary offices at 1770 The Exchange, Suite 280, Atlanta, Georgia 30339. April is the target date for occupancy of INPO's permanent quarters at 1820 Water Place, Atlanta, which will include administrative offices, classrooms, and expansion space to permit the possible addition of human-engineering laboratories and simulators.

As of the last week of January, the personnel numbered 25, including professional staff on loan from utilities. The INPO Advisory Council held its first meeting in Atlanta on February 12, and the Board of Directors its third meeting the following day. (For the names of board members, see *EPRI Journal*, December 1979, p. 35.) ■

NSAC Workplan Unveiled

The Nuclear Safety Analysis Center (NSAC) entered its first full calendar year with a full load of work. NSAC's 1980 program falls into eight categories.

- Evaluation of significant events—causes of outage and off-normal occurrences—in nuclear plants.
- What-if studies, which will examine what would have happened at TMI-2 if the operators had followed different courses of action or if different conditions had existed. Work to date shows that even if circumstances had been worse, the defense-in-depth philosophy of plant design would have been sufficient to prevent any significantly greater releases of radiation.
- Identification and study of generic safety issues and the development of appropriate recommendations.
- TMI-2 cleanup and recovery support studies. Their implementation will be by EPRI's Nuclear Power Division.
- Qualification testing, functional testing, and reliability testing of reactor components, such as pumps and valves. NSAC's role will be to outline the technical requirements and the practical means of implementing new NRC requirements in this area.
- Support to the newly established Institute for Nuclear Power Operations.
- Expansion of NSAC's function as a clearinghouse for exchange of technical information on reactor safety.
- Continued participation in the health effects surveys in the area around TMI that are being conducted by the State of Pennsylvania Department of Health.

NSAC has already embarked on an expansion of its computerized microfilm indexing system to support two major efforts. These are the significant event evaluation program and the TMI-2 recovery effort. All licensee event reports, which NRC requires reactor-operating utilities to file on every off-normal event, are being indexed, abstracted, and stored in NSAC's computer. ■

Reactor Building Withstands Test

A recent test sponsored by EPRI demonstrated that the reinforced-concrete outer wall of a nuclear reactor containment building can safely withstand being struck by a 1.5-t piece of steel traveling 195 mph. Performed at the rocket sled facility of DOE's Sandia Laboratories in Albuquerque, New Mexico, the test simulated the highly improbable failure of one of the large steel rotors in a nuclear plant's steam turbine.

Previous testing showed that although a fragment from a rotor failure is slowed substantially during its passage through the steel housing surrounding the turbine, it could leave the turbine building at a speed of 195 mph. It is possible that such a missile would strike other plant structures, including the nuclear reactor containment building.

The target in the recent test was a full-scale, 20 × 20-ft, 4.5-ft-thick wall of heavily reinforced concrete, similar to the wall of a containment building in some operating nuclear power plants. Rockets accelerated the 1.5-t turbine fragment to a speed of 195 mph along a sled track and hurled it squarely at the center of the concrete wall. A sharp corner of the projectile penetrated 1.5 ft. Slight cracks in the back of the wall were the only other evidence of the impact. This test points out that if such an extremely unlikely event occurred, the reactor and other safety-related equipment inside the building would be protected.

In earlier rocket sled tests the reinforced-concrete walls protecting plant buildings gave adequate protection against potential tornado-driven missiles, such as steel pipes and wooden telephone poles. This new test proved that design calculations for turbine fragments striking reinforced-concrete buildings are quite conservative.

Testing will continue as other potential impact situations are studied. ■

Heat Pump Conference in West Germany

An international conference to exchange information on the status and different applications of electric heat pump technology is planned for June 18–20, 1980, in Düsseldorf, West Germany, at the Exhibition Congress Center.

EPRI and the Rheinisch-Westfälisches Elektrizitätswerk (RWE) are sponsoring the conference, which is expected to attract over 1000 participants. RWE, the largest privately owned electric utility in West Germany, is actively involved in technology research and development.

Electric heat pumps are devices used to increase the efficiency of the heating process by making maximum use of the heat present in a source such as ambient air. They extract heat at a low temperature and convert it to heat at a higher and more usable temperature. Heat pumps can be used for space conditioning and water heating, as well as for industrial and commercial heating and cooling applications.

"The need for energy conservation has spurred the development of heat pumps in the United States, Germany, and other countries," states Quentin Looney, EPRI project manager for industrial energy conservation and an organizer of the conference. "However, because of different requirements among countries for air conditioning and heating systems, heat pump technology in Europe has evolved along somewhat different lines than in the United States. To avoid unnecessary duplication and to further advance the development of the technology, an exchange of information at this time is highly appropriate."

Official conference languages will be English and German, with simultaneous translation provided. Topical areas to be discussed include space conditioning, commercial and industrial process applications, and advanced technology. Twenty-one papers will be presented, followed by discussion among the participants. Floyd Culler, EPRI president, and Günther Klätte, member of the RWE Board of Directors, will welcome the group.

In addition to the formal presentations, participants will be able to present papers in poster format. The conference organizers welcome such contributions.

Anyone interested in receiving the program and registration form should contact either Quentin Looney, EPRI, 1800 Massachusetts Avenue, Suite 700, Washington, D.C. 20036, (202) 872-9222 or Arvo Lannus, Gordian Associates, Inc., 711 Third Avenue, New York, New York 10017, (212) 697-9023. ■

Openings for Loaned Employees

From its beginning, EPRI has used the reservoir of talent within its utility membership to help keep its R&D programs on target. This has been accomplished primarily through the utility advisory committees and through a continuing program of loaned employees.

Shortly after EPRI opened its doors, Chauncey Starr (then president) sent a memorandum to member chief executive officers, suggesting they designate qualified technical personnel as candidates to work at EPRI for a year or more. Since that time 46 utility experts have served EPRI as loaned employees, injecting practical utility viewpoints into R&D program areas. Another 23 loaned employees from suppliers have worked with EPRI over the past seven years. Twenty-one loaned employees from utilities and suppliers are currently on the EPRI technical staff.

There are current openings for three loaned employees, all in the Engineering and Operations Department of the Nuclear Power Division. They would be called upon to assist program managers in preparation of program plans, as well as to conceive, develop, and manage research projects.

One opening is for a project manager, plant systems performance. Key requirements include experience in national data systems, human factors, and utility operations. The candidate should be software oriented.

EPRI also needs a loaned project manager, plant operations support. Qualifications include a chemical background and a minimum of 10 years' system-oriented experience, with emphasis on laboratory work and design.

The third opening is for a project manager, plant component performance. This is primarily a mechanical engineering position, calling for a minimum of 10 years' experience, heavy in component design.

The EPRI contact is Melba Cross, (415) 855-2368. ■

CALENDAR

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

MAY

1–15
Electric Utility Rate Design Study, Regional Conference
San Francisco, California (1–2)
Kansas City, Missouri (8–9)
Washington, D.C. (14–15)
Contact: Gene Oatman (415) 855-2629

OCTOBER

6–7
Third NO_x Control Technology Seminar
Denver, Colorado
Contact: Edward Cichanowicz
(415) 855-2374

20–23
Coal Conversion Technology Conference
San Francisco, California
Contact: Seymour Alpert (415) 855-2512

27–29
Coal and Ash Handling Systems Reliability Workshop
St. Louis, Missouri
Contact: I. Diaz-Tous (415) 855-2826

R & D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

COAL LIQUEFACTION PILOT PLANTS

The construction phase of the H-Coal pilot plant has recently been completed. The second important milestone in EPRI's coal liquefaction program will also soon be passed: The Exxon Donor Solvent (EDS) pilot plant will be mechanically complete by April. The H-Coal pilot plant, a 250–600-t/d facility, represents the final development stage of a process developed by Hydrocarbon Research, Inc., with the help of DOE, the State of Kentucky, EPRI, and private industry (RP238). The EDS pilot plant, a 250-t/d facility, plays a similar role for a process developed by Exxon Research and Engineering Co. with DOE, EPRI, and industry support (RP778). Each of these projects will have cost approximately $275 million, including pilot plant engineering and construction and two years of plant operation.

H-Coal process

The H-Coal process, a direct catalytic hydrogenation process for liquefying coal, can be modified to produce a variety of liquid fuels, ranging from an all-distillate synfuel to a heavy fuel oil. Following early small-scale development sponsored by the petroleum industry, the current project has brought the technology through the 3-t/d process-development-unit stage. An extensive R&D program at this level has determined the proper operating conditions for the large pilot plant and identified preferred catalysts.

The pilot plant was designed by Hydrocarbon Research, with the exception of the solvent de-ashing unit required for operation in the heavy fuel oil mode, which was designed by C–E Lummus. The $155 million plant, located in Catlettsburg, Kentucky, was constructed by Badger Plants, Inc. Figure 1 shows the plant as it nears mechanical completion.

The H-Coal pilot plant will be operated by Ashland Synthetic Fuels, Inc., a wholly owned subsidiary of Ashland Oil, Inc. The plant was completed in sections, with the first sections being commissioned for test operations in December 1979. Startup of the major process sections is presently under way, and oil circulation has begun in preparation for the introduction of coal. Tests will be run on three fuel production operations. Following a break-in period on Kentucky coal, the plant will operate in the syncrude mode, processing 250 t/d of Illinois No. 6 bituminous coal to produce an all-distillate fuel. In addition to generating experimental data at larger scale, which is required for commercialization of the process, this period will provide an opportunity for plant debugging and operator familiarization. In the second mode, plant throughput will be increased to 500 t/d to demonstrate the production of heavy fuel oil. Finally, the plant will again be put into the syncrude mode, this time to demonstrate the production of liquids from Wyoming subbituminous coal.

EDS process

The EDS process, based on indirect catalytic hydrogenation, yields various all-distillate products; it can produce either transportation fuels or distillate fuel oil, depending on

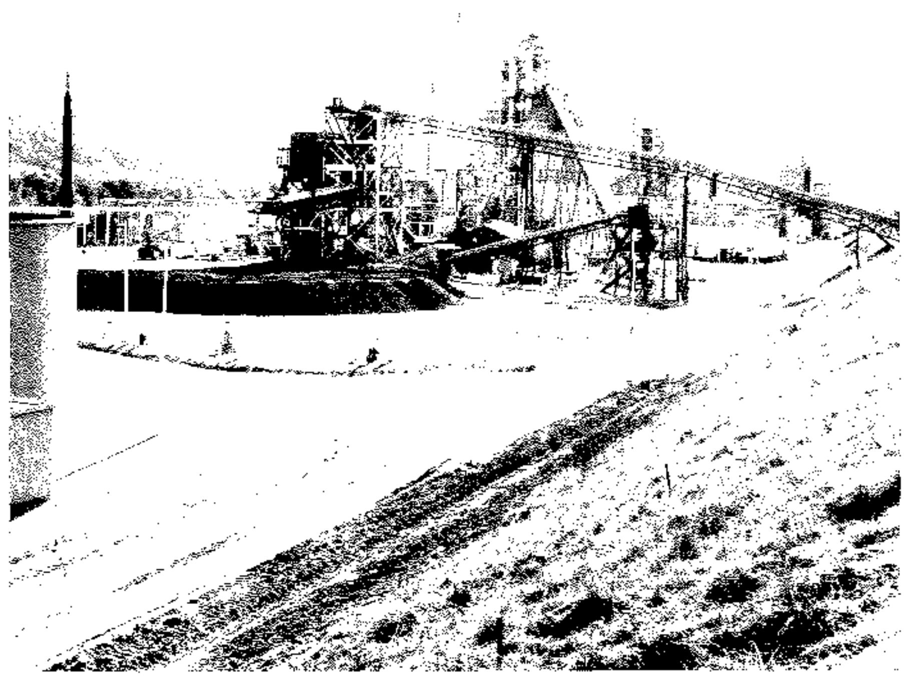


Figure 1 The 250–600-t/d H-Coal pilot plant at Catlettsburg, Kentucky, is undergoing startup operations in preparation for the initial coal-processing runs.

the mode of operation. An important part of the EDS project has been the support R&D function, which not only has guided the development of operating plans for the large pilot plant but also has led to basic process improvements. Extensive engineering studies by Exxon Research and Engineering have defined basic flow sheets for several commercial plant variations.

The EDS pilot plant was designed by Arthur G. McKee & Co. and constructed by Daniel International Corp. The facility, to be operated by Exxon Coal USA, Inc., an Exxon subsidiary, will process 250 t/d of coal under a variety of test conditions. Plans call for operating the plant on Illinois No. 6 bituminous coal, Wyodak subbituminous coal, and a third coal yet to be named. An extensive test plan to define operational limits has been developed. Oil circulation is scheduled to begin in early May in preparation for the introduction of the coal slurry.

Testing for commercial application

An important aspect of coal liquefaction commercialization is the development and demonstration of equipment that can handle coal slurries in extreme operating environments. Both the H-Coal and EDS projects have extensive equipment test programs. Every significant piece of equipment in the pilot plants, ranging from coal slurry pumps to heat transfer equipment to high-pressure slurry letdown valves, will be tested. Data on erosion rates, coking tendencies, and metallurgical requirements for proper commercial plant design will be gathered.

An important reason for EPRI's participation in these projects is the testing of product samples in boilers and combustors. When operating, these plants will produce from 600 to 1500 barrels a day of coal liquids. Roughly one-half of this output will be potential utility fuel. EPRI has arranged to obtain substantial quantities of this utility-grade fuel to be stored for further testing by the utility industry. Products from each of the operating modes will be collected, totaling about 30,000 barrels from each plant.

The use of products from coal liquefaction plants is being developed in EPRI projects on combustion and emissions characterization (RP1412-5 and RP1412-6). Small-scale combustion tests at KVB, Inc., and the Massachusetts Institute of Technology are exploring the differences in composition and emissions that are characteristic of liquids produced by the various processes. On the basis of this small-scale project, a large-scale combustion test will evaluate the liquids produced by the H-Coal and EDS pilot plant facilities. This program will include on-site utility boiler combustion tests and large-scale development programs in combustion turbines. It is expected that higher-quality coal liquids will be used to best advantage in combustion turbine combined-cycle electricity generation systems.

The two coal liquefaction processes discussed here each produce an ash-concentrated residual stream, which must be processed further to provide process fuels and hydrogen. EPRI is developing a project to store this residual product from the two processes and to demonstrate how it can be gasified to produce hydrogen. Partial oxidation of residual material has been shown to be the preferred means of producing hydrogen for direct coal hydrogenation processes.

The H-Coal and EDS projects will entail two to three years of plant operation. The results, coupled with results from the residuum gasification program, will mark the completion of the development of technologies required for commercial production of liquid utility fuels from coal. *Project Manager: J. V. Fox*

R & D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

WET SCRUBBING SYSTEMS

The utility industry's near-term commitment to wet scrubbing for SO_2 emission control is established. However, comprehensive information on full-scale systems is still not available. To further complicate the issue, SO_2 emission limitations have already been promulgated that are stricter than most existing plants must presently meet. Government attention is also being given to expected future emission regulations in such areas as fine (<2 μm) and inhalable (<15 μm) particulates, trace elements, and organics. EPRI is conducting a major research effort to collect information on wet scrubbing systems to improve the existing technology and to understand the capabilities of this technology for dealing with emissions that are not currently regulated. The project involves comprehensive field testing and data collection to characterize selected full-scale sites.

One important question for which no satisfactory answer has yet been developed concerns the relationship between the emission control capabilities, cost, and operation of flue gas desulfurization systems. (This is especially important in light of the increasingly strict emission limits being placed on these systems.) The perfect scrubber would combine maximum emission control and reliability with ease of operation and minimal cost. In practice, these systems are designed for a specific coal and a specific level of SO_2 removal, usually at the lowest proposed cost. Emphasis on operability and reliability has been limited because it has tended to increase system costs, requiring more sophisticated controls, redundant equipment, and additional personnel. A better understanding of these systems should help reduce costs for both future and existing systems. In view of the utility industry's large investment in SO_2 scrubbing systems (expected to be as much as $30 billion by 1990), such information should be a significant source of cost savings.

Site studies

To learn from the present state of the art, EPRI initiated a two-year, $3 million project to collect and disseminate comprehensive information from representative full-scale sites (RP1410). In the past, such projects have been limited to a specific aspect of wet scrubbing—economics, control capabilities, or operation. This is the first project to integrate all three. Black & Veatch Consulting Engineers is the prime contractor.

The project is designed to collect data from sites representative of current technology. Site selection was narrowed to plants of more than 100-MW capacity that have been in operation less than two years, have high SO_2 removal (>80%), use lime or limestone, and include current equipment designs. The first two sites selected were Columbus and Southern Ohio Electric Co.'s Conesville Unit 5 and The Montana Power Co.'s Colstrip Unit 2.

The Conesville system was chosen as representative of high-sulfur eastern coal operations. It consists of two parallel UOP, Inc., turbulent contact absorbers that use a magnesium-containing lime as the alkali absorbent. The unit, which began operation in 1977, has shown high SO_2 removal (>90%) but low availability. The Colstrip system was chosen to represent low-sulfur western coal operations. The system consists of three parallel trains of venturi–spray tower combinations (Combustion Equipment Associates, Inc.). Fly ash, inherently alkaline, is used for absorption, aided by lime. The unit began operation in 1975, achieves SO_2 removals in the 80% range, and has shown good availability. The Conesville system has a flue gas bypass; the Colstrip system does not.

Data collection

Field testing entails two site visits, with sufficient time between the testing periods for evaluation of the initial data and any necessary adjustment of the sampling and analysis techniques. Data are being collected under as many as eight test conditions (i.e., combinations of boiler and SO_2 system operating conditions).

The data being collected at the scrubber inlet and outlet include data on SO_2, NO_x, and total particulates for the regulated emissions and data on particulate size distribution, trace elements, organics, sulfates, and vapor-phase metals for unregulated emissions. Special tests are being performed to study mist eliminator efficiency and scrubber chemistry and to estimate emissions associated with SO_2 system operation.

All the gas-phase tests are being performed simultaneously at the inlet and outlet of one scrubber module, and material balances around the SO_2 system are being performed to assess the quality of the data. The historical data being collected and evaluated include capital and operating costs as well as operating and maintenance performance. The evaluation should result in a better understanding of how the full-scale systems are operating and what can be done to improve their design, operation, and maintenance. The information gained will be used to improve scrubber specifications and define R&D requirements.

Both series of field tests have been completed at the Conesville site, and one has been completed at the Colstrip site. The data from the Conesville tests are being analyzed and the results should be available by mid-1980.

Preliminary findings

An example of the type of useful data being produced is illustrated in the preliminary data analysis for the Conesville tests. This system is demonstrating a capability for very high (>90%) SO_2 removals over a wide variety of operating conditions because of the magnesium-containing lime being used. Normally, some dissolution of alkali is necessary in the scrubber to obtain good SO_2 absorption. Dissolution is slow, and high liquid rates are necessary to make enough dissolved alkalinity available for SO_2 absorption in the short time the liquid is in the scrubber. With magnesium-containing lime, the dissolved alkalinity is already high at the entrance to the scrubber because of alkalinity solubility enhancement in the presence of magnesium. Accordingly, low liquid-to-gas (L/G) ratios can be used to obtain the same results as lime that does not contain magnesium. Calculations indicated, and further tests confirmed, that the L/G ratio could be reduced at Conesville by one-third to one-half without significantly affecting the SO_2 removal. This indicates a potential for a significant savings in pumping costs. *Project Manager: Richard Rhudy*

MUNICIPAL SOLID WASTE AS A UTILITY FUEL

In recent years escalating landfill disposal and fuel costs have increased the incentive for municipalities to recover energy and raw materials from municipal solid waste (MSW). Electric utilities are being encouraged to become customers for the recovered fuel or energy. Initial experience with supplemental firing of processed refuse in utility boilers at Ames (Iowa), St. Louis, and Milwaukee has demonstrated the difficulty of forecasting its effect on power plant performance and reliability. EPRI's research on unconventional fuels is addressing these technical uncertainties. The two key objectives of this program are to maintain an up-to-date technical and economic assessment of refuse-to-energy technologies and to assess the impact of supplemental firing of refuse-derived fuel (RDF) on utility boilers. Nontechnical and institutional issues involved in using RDF are being addressed by EPRI's Energy Analysis and Environment Division.

Refuse-to-energy technologies

Numerous technologies in various stages of development are being promoted for recovering energy and raw materials from MSW. Fuel preparation technologies include shredded RDF, dry-powder RDF, pyrolysis to low-Btu gas or to liquid fuel, anaerobic digestion to gas, recovery of low-purity methane gas from sanitary landfill, and composting. Steam and electricity production technologies include supplemental firing of gas, liquid, and solid refuse fuels in a utility boiler, retrofit of a utility boiler with an external combustor, water-wall incineration of 100% RDF or MSW, fluidized-bed combustion, multiple-hearth incineration, and integration of steam into the power plant steam cycle. With the exception of European water-wall incineration, these technologies are not sufficiently developed to accurately forecast process operability and economics. This is particularly true in the case of the advanced technologies—pyrolysis and anaerobic digestion.

Economic assessments

In 1975 EPRI published a technical and economic assessment of refuse-to-energy technologies (EPRI 261-1). Because this report has been outdated by rapid cost escalation and technological developments, EPRI and the New York State Energy Research & Development Authority (NYSERDA) are cosponsoring a new assessment (RP1255). Preliminary results indicate that supplemental firing of processed RDF with coal or oil in existing boilers, water-wall incineration, and landfill recovery of gas are the best defined and most economical technologies. Fluidized-bed combustion has particular potential merit but is in an intermediate stage of development and is being applied on a limited scale. The economic potential and technological development of pyrolysis and anaerobic digestion processes are not sufficient for wide-scale application at the present time. The updated technology assessment is expected to be completed in mid-1980.

In a second project cosponsored by EPRI and NYSERDA under RP1255, Stone & Webster Management Consultants, Inc., evaluated the economics of energy recovery from MSW in an oil-fired power plant. The Arthur Kill station of Consolidated Edison Co. of New York, Inc., located on Staten Island, was used for the evaluation. This station has two oil-fired units, one 350 MW and one 500 MW, both originally designed for coal. (Consolidated Edison recently announced plans to convert these units back to coal.) Three cases are evaluated:

- Supplemental firing of a specially prepared low-ash RDF with oil in the boilers
- Incineration of prepared RDF in separate municipally owned boilers and integration of the steam into the power plant steam cycle
- Incineration of unprepared MSW in municipally owned water-wall incinerators and integration of the steam into the power plant steam cycle

The economics were evaluated for the utility power plant–municipal resource and energy recovery system. The price paid by the utility for recovered fuel or steam was set to keep the cost of generating power constant. The price was then determined by the price of the replaced fuel oil less incremental capital, operating, and maintenance expenses and economic dispatch penalties resulting from refuse firing. The RDF price paid by the utility was factored into the economics of the municipally owned resource and energy recovery facility. A tipping fee was calculated to make up the difference between the capital, operating, and maintenance expenses of the resource recovery plant and the revenues received for steam, RDF, and recovered raw materials.

The analysis indicated that MSW incineration yields the lowest tipping fee, followed by the RDF supplemental firing option. It is anticipated that the final report will be published in the spring of 1980.

Improving RDF quality

Most resource recovery plants in the United States produce a shredded RDF and use magnetic separation and air classification to recover metal and reduce the ash content. The glass and metal are pulverized before separation; however, much of the glass is forced into the paper or is carried overhead in the air classifier and ends up in the RDF product. A large-mesh screening device called a trommel screen has been added to many second-generation plant designs to remove glass bottles and metal cans before the shredding operation. This is expected to reduce the ash, glass, and metal content of the RDF, thus reducing the potential for boiler fouling and slagging but at the cost of reducing the plant's Btu yield.

The potential trade-offs of trommel screening was demonstrated in a brief study for EPRI by Cal Recovery Systems, Inc. (RP1180-6). Simplified unit process models for screening, shredding, air classifying, and magnetic separation were used to represent four resource recovery plant flow sheets. These included the flow sheet used at Ames and a hypothetical Ames system with a preshredder trommel screen. The addition of the trommel screen was predicted to reduce the RDF's ash content from 18.8% to 6% and the glass content from 5% to 0.6%, while reducing Btu yield from 88% to 50%. It should be noted that existing systems with trommel screens are designed for lower ash removal, producing RDF with a 10–15% ash content and a 70–80% Btu yield.

Supplemental firing of RDF in utility boilers

In 1977 Wisconsin Electric Power Co. (WEP) began cofiring shredded RDF with coal at Units 7 and 8 of its Oak Creek station near Milwaukee. These units have identical 310-MW tangentially fired boilers.

RDF is injected into the furnace through nozzles at each corner located above the top coal nozzles. Severe boiler slagging, bottom ash handling, and induced-draft fan limitation problems were encountered, and RDF firing is now limited to 10–15% of heat input and 12–14 hours a day to allow time for boiler deslagging. The boiler slagging problem was initially attributed to glass and metal in the RDF, and subsequent changes in the resource recovery plant (operated by the Americology Div. of the American Can Co.) reduced the glass and ash content. The operating problems now appear more closely related to the fact that the boilers, built in the 1960s, were designed for eastern coal but now burn Wyoming subbituminous as well. Supplemental RDF firing appears to contribute to but is not the primary cause of boiler slagging and other problems.

Under joint EPRI and WEP sponsorship, Combustion Engineering, Inc., (C–E) is evaluating the long-term impact of RDF cofiring on boiler tube corrosion at Oak Creek (RP898-1). Previous corrosion studies have emphasized short-term exposure of corrosion coupons and samples. In this project a combination of air- and water-cooled corrosion probes and integral tube sections are used to assess the corrosion rate over long exposure periods (two 4000-hour periods).

After some delay caused by the operating problems described above, five corrosion probes were installed in Unit 7 during October 1978: two water-wall probes, two superheater probes, and one back-pass probe (Figure 1). These are composed of rings of the tube materials used in the boiler, welded and threaded together. Thermocouples inserted in the tube walls are connected to temperature control and automatic data-logging systems.

An explosion at the Americology resource recovery plant in December 1978 suspended RDF production and firing for several months. The corrosion probes were removed from the boiler during this period and reinstalled in May 1979. On completion of the first 4000-hour exposure period in October 1979, the probes were removed for inspection and laboratory evaluation. As of November 1979, visual examination of the probes showed no evidence of increased corrosion. It is anticipated that one of the water-wall and one of the superheater probes will be reinserted in the boiler for a second 4000-hour exposure period in 1980.

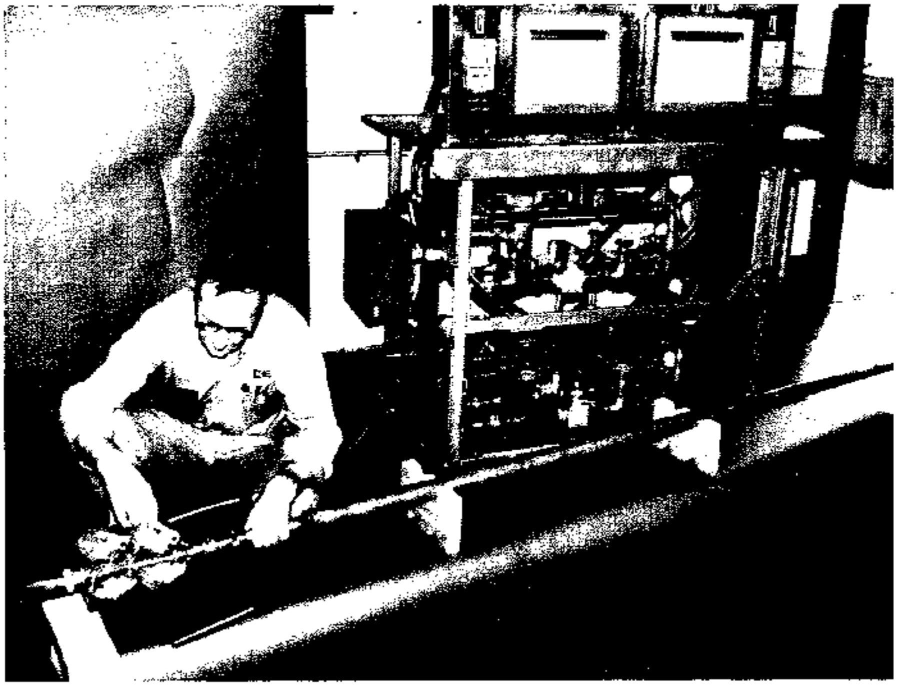


Figure 1 Combustion Engineering, Inc., superheater corrosion probe and probe temperature control and recording system, shown before exposure to coal-refuse cofiring. This and four similar probes were located in the water-wall, superheater, and back-pass sections of the boiler during coal-refuse cofiring.

During 1980 EPRI will also sponsor an evaluation of the fouling and slagging potential of the RDF and coals burned at Oak Creek. This study will supplement a field evaluation conducted by C–E for WEP and Americology during 1979.

Additional projects are being considered to evaluate the incremental impact of supplemental refuse firing on power plant performance and reliability. Because most utility experience has involved cofiring coal and shredded RDF in stoker and tangentially fired boilers, future projects are expected to emphasize other primary fuel, RDF, and boiler types (e.g., oil, powdered RDF, and wall- and cyclone-fired boilers). The overall objective of these evaluations will be to add to the data base of refuse firing experience and to develop the technical basis for energy recovery from refuse fuel in utility boilers. *Project Manager: Charles McGowin*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

DISTRIBUTION

Controlling decay in southern pine poles

Today there are over a hundred million wood poles in service, approximately 80% of which are southern yellow pine, with an average service life of 15–25 years. If the useful life of these poles could be extended to 35 or 40 years, utilities could effect substantial cost savings. These savings could be further increased by instituting a plant management program of in-service inspection, decay detection, and effective pole retreatment. Effective retreating methods that use Vapam, Vorlex, or chloropicrin for Douglas fir and western red cedar were recently developed under RP212. Results indicate that these volatile chemicals arrest fungal decay and prevent reinfestation for 10 years.

Closed-tube bioassay tests have been effectively used to determine the need for supplemental treatment of poles in service. A variety of pole inspection methods and devices were also evaluated. An early interim report (EL-366) is available that presents the results of the first three years of investigation; a final report covering the last three years is expected to be published by June 1980. (Also currently available through Research Reports Center is *Wood Pole Maintenance Manual,* dated February 1979.)

Similar work is under way with southern yellow pine poles in a three-year project at the State University of New York at Buffalo (RP1471). Through this work researchers should be able to identify the principal decay microorganisms, analyze all time-related decay mechanisms, and determine the chemical and physical changes in wood as it decays. An investigation of how effectively volatile preservatives control pole decay and a search for useful decay indicators will also be conducted.

The approach will be to conduct an intensive study of treated poles (both new and aged) that have been treated with two preservative types, with varying exposure times of up to 48 years of service. Decay organisms will be isolated and identified, and fumigant sensitivity tests will be conducted. The most promising fumigants will be selected for field tests and their overall effectiveness determined through a long-term regional pole-sampling and treatment program. Extensive use will be made of the Western Electric Co.'s pole farm in Chester, New Jersey. A second farm will be established near Syracuse, New York, and numerous pole core samples will be obtained from utilities representing the mid-Atlantic, southern, and midwestern states, which will broaden the overall data base of the project. *Project Manager: Robert J. Stanger*

OVERHEAD TRANSMISSION

Dc line insulators

EPRI is sponsoring the development of new dc insulators to improve the operating performance and reduce the construction cost of overhead HVDC lines. By using new insulating materials and new insulator configurations especially suited to dc voltage stress, more compact line designs can be produced, thus saving money on towers and rights-of-way. New insulators that are lighter and easier to handle should reduce line construction costs.

Although the mechanical considerations are similar for both ac and dc lines, electrical characteristics of insulators on dc lines are significantly different from those on ac lines. For example, when conventional ac insulators are used on dc lines, flashovers occur much more frequently than on an ac line of equivalent voltage. This is caused partly by the electrostatic forces of the steady dc field, which increases the deposit of pollution on the insulator surface. Also, arcs tend to develop into flashovers more readily in the absence of voltage zero.

Two contracts are under way to develop dc insulators. An earlier *EPRI Journal* report (October 1979, p. 54) described a new Polysil* insulator that will be similar in appearance to a conventional suspension disk insulator. The second, a project by Sediver, Inc., discussed below, will produce a composite (nonceramic) insulator designed for optimal HVDC operation (RP1206-1).

Composite insulators for ac applications have received much attention in recent years, particularly at voltages above 220 kV, because of their light weight, high strength, flexibility, slim profile, and resistance to vandalism. For HVDC, the use of organic materials offers several other possibilities for design improvement.

Because line construction cost can be reduced significantly by shortening the insulator string, one important goal will be to reduce the overall length of the insulator string to just above that needed to withstand switching surges. The accumulation of pollution deposits is much more severe for dc lines than for ac; therefore, the leakage distance must be greater for dc insulators. However, since the new composite insulator eliminates the metallic cap and pin, a significant improvement in leakage distance is possible. This can be further improved by optimizing shed geometry and by using antistatic additives, thus providing a more uniform distribution of the electric field.

The HVDC project was started in September 1978 and will continue through 1980. In the first part, behavior of the materials under HVDC conditions was investigated. The study of shed design modifications to reduce the detrimental effects of contamination is now under way. Prototype insulators will be fabricated and tested for mechanical strength, electrical performance, and effects of pollution. If possible, a number of prototype insulators will be installed on an operating HVDC line for field testing. *Project Manager: John Dunlap*

Laterally loaded drilled piers

GAI Consultants, Inc., is conducting research on laterally loaded drilled piers to

*Polysil is an EPRI trademark.

develop an improved analytic model for predicting the behavior of drilled piers subjected to high overturning moments (RP1280). The model is being verified by full-scale, destructive field tests on drilled piers that have been fully instrumented and installed in a wide variety of subsurface soil conditions. The field testing is scheduled to be completed by the summer of 1980; nine tests were completed in 1979 and four are scheduled for 1980.

An initial shakedown test for this program was held on April 25 and 26, 1979, on a section of Duquesne Light Co. right-of-way in Pittsburgh, Pennsylvania (*EPRI Journal,* July-August 1979, p. 33). Engineers and designers, representing the participating utilities, took part in evaluating the test. Since then, eight utility-cosponsored tests have been conducted. In general, these tests have revealed that existing state-of-the-art techniques for predicting displacement tend to overstate measured displacements, and state-of-the-art methods for predicting ultimate capacity tend to understate the measured ultimate capacity.

A dramatic example of the difference between state-of-the-art theory and test results is shown in Figure 1 for a test cosponsored by EPRI and Jersey Central Power & Light Co. The figure shows a range of elastic displacement predictions and a predicted ultimate capacity for the pier. As can be seen, the current state-of-the-art predictions fell far short of the true displacement and ultimate capacity of the pier. It is the objective of RP1280 to develop more accurate models for predicting pier displacement and ultimate capacity.

Figure 1 shows that the response of laterally loaded drilled piers is highly nonlinear. A linear elastic model can only intersect the true moment-displacement curve at a single point. Therefore the research objective is to develop a nonlinear model that accurately predicts the displacement of laterally loaded drilled piers at all load levels.

A theoretical linear model has been developed, and this model will be used to form the basis of a nonlinear model to be developed this year. Predictions based on this nonlinear model will be compared with test data and modified, if necessary, to give a best fit to the data. A design/analysis computer program based on this model will also be developed as a part of this project and will be made available to the utility industry later in the year. *Project Manager: Phillip Landers*

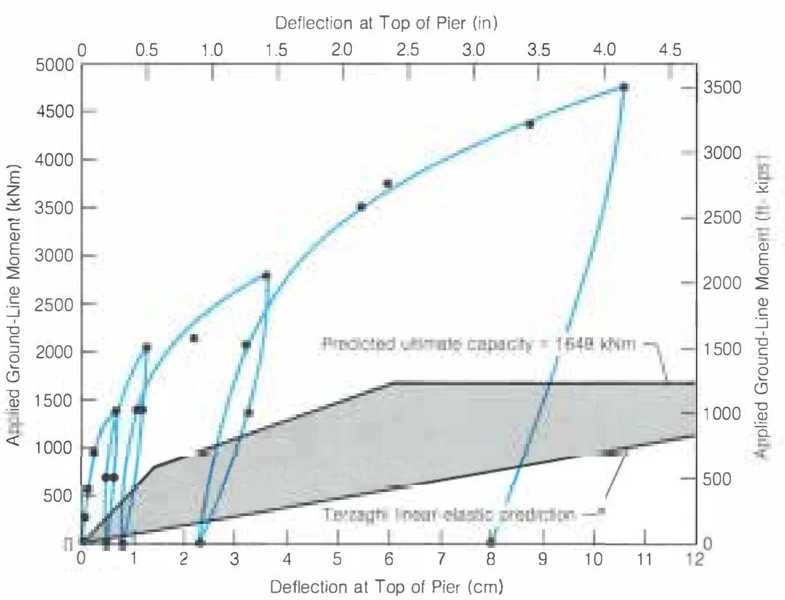


Figure 1 A single pier successively tested at higher and higher loads by Jersey Central Power & Light Co. withstood extraordinary ground-line moments. The pier took a small permanent set after each test, but the cumulative deflection was little more than 3 in (8 cm) after the fourth loading cycle. Since the measured ground-line moment is so much greater than the current range of practice (shown in grey), a 21-ft-long (6.4-m) by 48-in-diam (1.2-m) pier could be shortened by approximately 6 ft and still meet design load requirements. The savings to a utility could range between $300 and $1000 per foot of pier reduction, depending on type of installation.

HVDC ground electrodes

Ground electrode is the term usually applied to the connection to ground at a dc converter station. In function and design it differs substantially from its ac counterpart, the substation ground grid. For an ac system, the function of the ground is primarily safety and relaying; for a dc system, the ground is usually an important operating component of the system. For a typical bipolar line, the ground electrode provides an electrically fixed reference point for the transmission voltage, a path for the unbalanced current during bipolar operation, and emergency monopolar ground return operation when one-half of the converter terminal is out of service.

For ac systems, grounding methods are generally well established. For dc systems, the available engineering information is scattered in various reports, papers, and designers' project files. A single handbook is needed that will bring together all the existing information, as well as contain advanced design methods. International Engineering Co., Inc., headquartered in San Francisco, has started preparing such a handbook (RP1467). This handbook will provide detailed information on existing HVDC electrodes, including design, siting, testing, and operation. Particular attention will be given to improved siting techniques that rely on public information and aerial surveys. Existing computer programs will be adapted to calculate ground current distribution, potential gradients, and electrode resistance.

When published early in 1981, the handbook will provide in one publication all current engineering knowledge on ground electrodes and will describe the advanced techniques developed during this project. *Project Manager: John Dunlap*

UNDERGROUND TRANSMISSION

Nb_3Ge superconductor development

Having successfully produced over 100 m of high-quality Nb_3Ge superconducting tape, the Los Alamos Scientific Laboratory now hopes to manufacture a high-current-density prototype coaxial transmission cable (RP7855). One objective is to obtain low losses similar to those achieved with the tape (critical current density of 2.4×10^6 A/cm^2 at 13.8 K). This objective was accomplished with a 7-m length of Nb_3Ge tape, 4 to 6 μm thick and 0.6 cm wide, carrying current of over 1200 A.

The overall purpose of this project is to manufacture and test two separate, low-loss, high-current-density Nb_3Ge prototype test sections about 1 m long in a double-double helix configuration. The first cable should have good operating characteristics (13–14 K) and should indicate where improvements can be made in manufacturing the second cable. The second cable will be built and tested after modifications and improvements have been incorporated in the superconductor; a major goal is operation in the 14–16 K range so that hydrogen may be used as the cryogen. Although power loss and current density tests have been conducted successfully on the tapes, the results may differ in the cable with its double-double helix configuration.

The Nb_3Ge tape has operated at higher temperatures and current densities than have been possible with any other superconductor. This may offer substantial reductions in refrigeration, capital, and operating costs for superconducting underground transmission lines of the future. *Project Manager: Mario Rabinowitz*

Losses in pipe-type cables

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

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

Over the past 20 years, significant changes in manufacturing techniques have been introduced. Further, 345-kV cables are in common use, 550-kV cables have been developed, and 765-kV cables are being developed. Because of these changes, it was considered necessary to test whether extrapolation of the Neher-McGrath equations would cover the larger systems.

RP7832-1, jointly funded with DOE and General Cable Corp., was instituted to achieve the following.

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

The project produced several significant findings (EL-1125). For example, it was found that the Neher-McGrath equations are adequate for these systems over their full operating temperature range. Some of the empirical factors were corrected (and one new factor introduced), which improved the accuracy of the equations.

It was also shown that copper conductors with bare strands and with alloy-coated strands exhibit practically identical ac/dc resistance ratios. Both these conductors, however, are sensitive to thermal cycling. Once a single thermal cycle to high temperature has occurred, the ac/dc resistance ratio at lower temperature is permanently increased. This effect is attributed to expulsion of the oil from the interstrand spaces during the thermal cycle, which results in a decrease in the interstrand contact resistance. These measurements were made on laboratory samples with the oil in the pipe at atmospheric pressure. For design purposes, it is considered advisable, for the moment, to use the higher stabilized value of ac/dc resistance ratio.

As expected, aluminum conductors and copper conductors with enamel-coated strands exhibit lower ac/dc resistance ratios and do not exhibit the thermal cycling effect on the ac/dc resistance ratio mentioned above.

The computer program developed provided only limited agreement between calculated and measured values. The attainable accuracy is limited by the nature of boundary conditions and the precision of the detail modeled.

As a follow-on to this work, two other projects have been instituted. RP7832-2 with Pirelli Cable Corp. is investigating four areas: the influence of oil pressure on the resistance ratio variation with thermal cycling; losses in systems with very large conductors; magnetic shielding methods for reducing loss in carbon-steel pipes; and the influence of nonmagnetic pipes on system losses.

RP7832-3 with Cable Technology Laboratories, Inc., is designed to reformulate the analytic expressions derived under RP7832-1. If their accuracy can be improved, these expressions will be suitable for analyzing both conventional and novel systems that may be developed in the future. *Project Manager: Felipe Garcia*

SUBSTATIONS

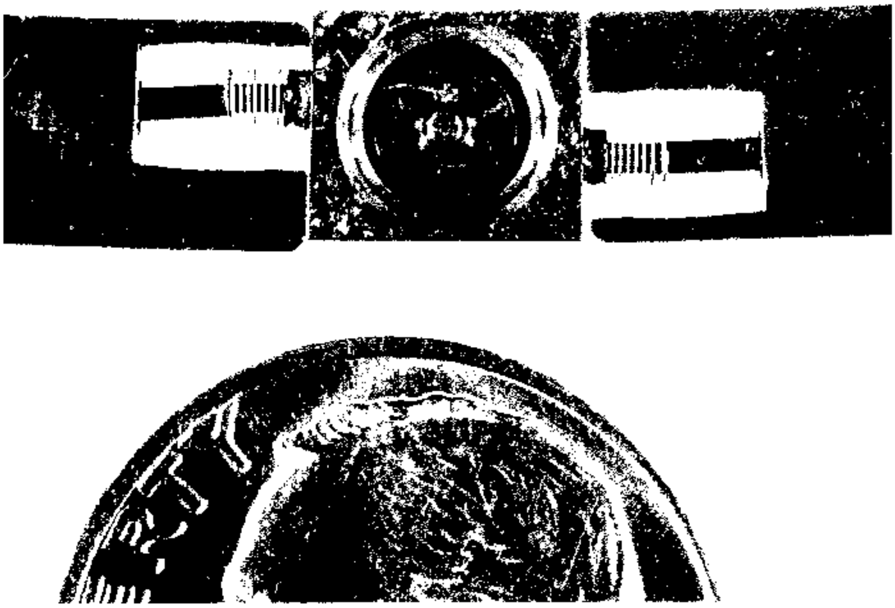
Passive hot spot detector

A new sensor for measuring transformer winding temperatures has been developed by Westinghouse Electric Corp. at its Sharon Transformer Division (RP994-1). The sensor (Figure 2) is a small disk, whose mechanical resonance frequency varies with temperature. Because the disk is very small, it is quickly brought to the same temperature as the transformer conductor when placed in contact with it. The intention is to place the sensor at the hottest spot in the transformer, as the temperature at the hottest spot is the key parameter of interest to transformer operators.

Within the temperature range of interest (−20°C to 200°C), the resonant frequency of the sensor varies about 12 kHz, with a center frequency of about 160–170 kHz. Two ultrasonic waveguides are used to sense the resonant frequency of the disk—one waveguide excites the disk, and the other senses the amplitude of the disk vibration. At ground potential, the frequency at which the maximum energy is transferred through the disk is determined by electronic signal-processing equipment. Fortunately, this is also the frequency at which the disk resonates in its dominant resonating mode and is therefore a direct measure of the disk temperature. A frequency-to-temperature conversion is made, and the temperature value can then be read by the transformer operator. In addition, the electronic equipment includes outputs that can be used for alarms, as well as for tripping the transformer breakers if that should be desirable.

The major developments since the last report on this detector (*EPRI Journal,* November 1978, p. 50) involve the design of the sensor's superstructure, which is used as the connection point of the insulating ultrasonic waveguides, and the design of the

Figure 2 The size of a newly developed temperature sensor for detection of transformer hot spots developed by Westinghouse Electric Corp. under EPRI contract is compared with a dime (the cover removed from the sensing element). Note the ultrasonic waveguides on both sides of the disk and the flexible bellows by which the waveguides are connected to the disk wires.



waveguides themselves. The attachment of the waveguides to the sensor must be sturdy enough to allow handling and installation of the sensor in the transformer, yet sufficiently soft to prevent coupling of ultrasonic energy through the housing itself. One design feature is the flexible bellows used at the point where the waveguides connect to a small wire that makes the final connection to the disk. The waveguides themselves are sectioned. Glass-fiber bundles have been used where sharp corners or high temperatures are encountered. Glass-reinforced fibers are used in long straight sections to avoid the high attenuation of the ultrasonic energy that is characteristic of glass-fiber bundles. This design gives the electronic system designer an acceptable signal-to-noise ratio.

Some manufacturing problems with the sensor itself have also been resolved. Laser welding was found to be necessary to ensure that the temperature sensor is free of leaks. This is an obvious requirement because the sensor must work inside an oil-filled transformer and the presence of oil inside the sensor housing would damp the disk too much.

Southern California Edison Co. will evaluate the sensors for transformer applications. Two complete systems have been built, each using five sensors (four to measure winding temperature and one to measure top oil temperature). One of these systems will be installed in a 15-MVA, 67-kV/12.47-kV transformer. The other is scheduled for installation later. A third system will be used to monitor the temperatures of capacitors as a part of EPRI's compact capacitor project (RP996). *Project Manager: Stig Nilsson*

Fault current damage assessment

Although every effort is being made to find devices that will severely limit fault currents, for many applications it might not be essential to limit the first loop of fault current. For example, there is a question about the effect fault currents of several cycles' duration might have on equipment compared with the effect of one cycle. Conversely, it is not clear what happens when the momentary current rating of one cycle is exceeded. Because the option of preventing fault currents from going beyond the first current zero will afford considerable latitude in current limiter design, it may appreciably reduce the cost and time needed for fault current limiter R&D. Therefore, EPRI has funded a two-year study to investigate the probable damage caused by the first loop of fault current compared with that caused by several cycles of fault current (RP1498).

In addition to information on the damage to operating equipment caused by faults, utilities are in a position to provide data on the magnitude, degree of offset, and frequency of occurrence of fault currents. Manufacturers of electrical equipment can also provide information on the effects of fault current magnitude and fault duration from their experience in the design and testing of equipment. *Project Manager: Glenn Bates*

Carrier frequency noise from HVDC converters

Interference in the carrier frequency range from existing HVDC converter terminals is being experienced on carrier equipment directly coupled to ac power systems. The interference bandwidth has generally ranged from 20 kHz to 100 kHz, and its interference effect depended on the proximity of the carrier frequency to the peak noise frequency (approximately 50–70 kHz) and on the electrical distance between the converter terminal and the ac system. Other variables, such as carrier equipment limitations, ambient signal-to-noise ratios, and other noise sources, determine the degree of converter terminal influence, but the conclusion is that certain carrier frequencies in adjacent ac systems will not be usable once a converter terminal becomes operational.

The present solution to carrier interference from HVDC converters is to move the affected carrier channels in the vicinity of the converters out of the problem frequency range (i.e., above 100 kHz). This is not a satisfactory solution because of the expense involved, the lead time needed to obtain a new frequency and obtain clearance for this frequency, and the time required to purchase equipment and install the new system while the existing system is unusable.

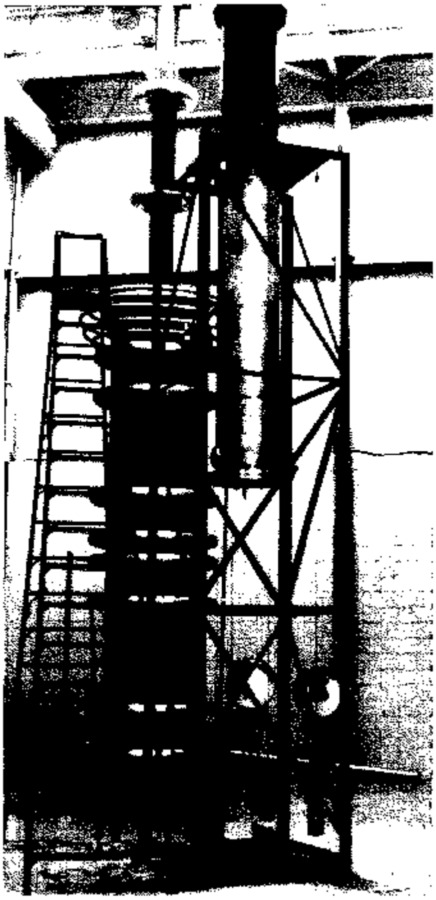
In the future, when a utility plans to install an HVDC system adjacent to an ac system containing carrier systems that could be affected, it may be necessary for the utility to specify acceptable limits of carrier frequency interference. Utilities and suppliers need to understand what solutions are available to meet the specifications, as well as the impact of such solutions on the converter terminal cost. It is desirable to control the noise within the terminal itself (preferably at the source) rather than on the external system.

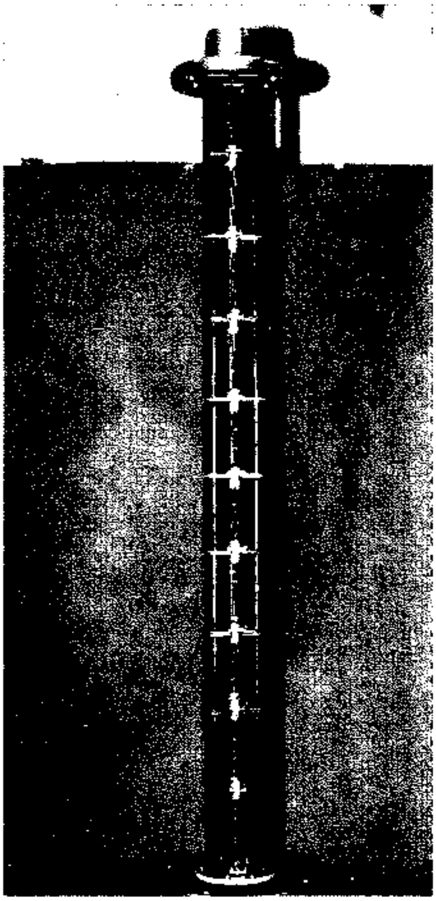
The considerable amount of work that has been done is continuing to increase the understanding of and provide guidelines for interference in the voice frequency and radio frequency range. In the carrier frequency range, however, the problems and solutions have not been fully analyzed.

EPRI recently funded a project with General Electric Co. to obtain a basic understanding of carrier noise generation, develop a noise generation model, verify the model through field measurements, and establish guidelines and measurement techniques for specifying levels of influence (RP1427). General Electric initially developed digital models of the HVDC converter station as a noise generator and is presently verifying the models by comparison with an existing simulator. Impedance and admittance measurements were made at the Square Butte HVDC converter when the line was deenergized; these measurements are being used for model development and verification. Later, measurement of harmonic generation by the energized system will be used to further verify the model.

The model will allow researchers to determine how the converter apparatus and system parameters influence noise production and propagation. In addition, it will be possible to ascertain the degree to which individual components affect the production of carrier frequency noise interference. This, in turn, will permit development of guidelines for procedures, techniques, and cost improvements in the reduction of carrier frequency noise interference. *Project Manager: Gilbert Addis*

Figure 3 Gas-insulated arrester assembly during electrical testing (a) and metal oxide varistor blocks with voltage measurement devices inserted at regular intervals for monitoring during the test program (b).


a


b

Surge arresters for gas-insulated equipment

The use of surge arresters with series-gap construction in gas-insulated stations results in large arrester assemblies. In addition, these arresters require supplementary capacitive grading, precise gas-leakage detection schemes, and elaborate venting systems, all of which result in a very expensive assembly. Furthermore, the sparkover voltage level on faster surges is higher for gapped arresters, and this makes insulation coordination difficult.

The use of a new generation of metal oxide valve blocks for gas-insulated equipment can resolve some of these concerns. A new design for metal oxide blocks, packaged specifically for gas-insulated equipment installation, promises a simple arrester of reduced size and cost. Besides reducing the arrester cost, gapless design has the potential to reduce the insulation requirements and overall substation costs.

A project with Gould–Brown Boveri Inc. and McGraw Edison Co. has therefore been initiated to develop this technology to fulfill the industry's need for systems rated 69–550 kV (RP1421).

Feasibility was successfully demonstrated through recently concluded Phase 1. During this phase, a 2-m-long arrester prototype was built, and extensive tests were conducted to fully reveal its thermal and electrical characteristics. Figure 3 shows this prototype as prepared for tests. The Phase 2 effort will advance this work to full development of a 362-kV arrester suitable for field evaluation, which will be carried out with a host utility yet to be selected. *Project Manager: Vasu Tahiliani*

Silver-sand-fuse fault current limiter

One of the many efforts to develop fault current limiters is a design employing a silver-sand fuse commutation principle, which has been developed through a project with Gould–Brown Boveri (RP281).

This commutation principle involves a simple, oil-filled bypass switch (Figure 4). On opening, sufficient arc voltage is generated to transfer the current into a parallel silver-sand fuse. As the fuse melts, the current is transferred into a current-limiting resistor. The voltage drop across the resistor is also imposed on the fully open bypass switch; however, sufficient time elapses for the switch to deionize and achieve its recovery voltage potential. A single-phase prototype that uses this principle of operation has been designed, built, and laboratory-tested for a 69-kV application.

Without a doubt, the most important requirement of any fault current limiter is reliability. In this design, the reliability hinges on consistent performance of the chemical actuators used to operate the bypass switch and close the fuse switch. This technology of moving a mass at a predesignated speed is quite mature and reliable, and experience with these actuators in laboratory tests has been quite satisfactory.

Comprehensive tests were carried out to alleviate concerns about the weathering effects these actuators may experience. These tests demonstrated that the actuators have a high degree of reliability even after severe weathering conditions have been

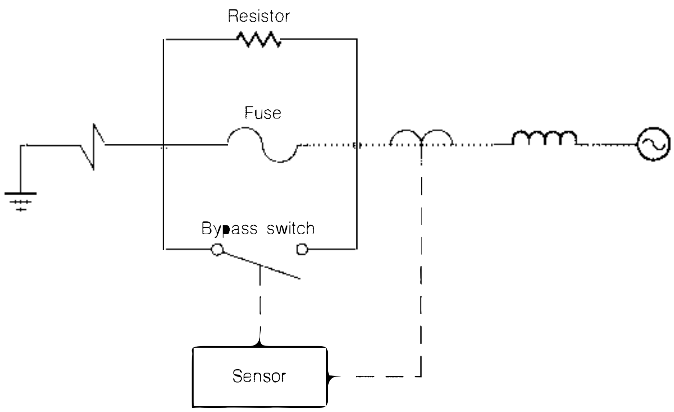


Figure 4 Single-phase representation of the silver-sand-fuse fault current limiter. A fault detected by the sensor triggers the opening of the bypass switch, which generates sufficient voltage to transfer the current to the fuse. As the fuse melts, the current is ultimately transferred to the resistor.

experienced. Further, since the chemical actuators and fuses are all single-shot devices, a practical arrangement employs multiple sets of fuses and bypass switches in the form of six parallel channels, each of which employs a bypass switch and a fuse with its own closing switch. During the course of development and testing, a number of electrical shielding problems surfaced. These obviously had to be addressed through design modifications within the electronic circuitry that controls the firing of the chemical actuators.

This development and the tests have brought about a clear understanding and respect for the stray fields that prevail in a power system environment. In addition to shielding the electronics from the prevailing electrostatic and electromagnetic fields, it is essential to segregate the fields resulting from firing signals within a channel to prevent misfiring in an adjacent channel.

In this recently completed project, the laboratory tests demonstrated the current-limiting capability of this device. However, it was recognized that further development work would be needed before the concept could be applied in the field. Evaluation of the complexity, potential cost, and limitations of the device led EPRI to the decision not to pursue this work to the field demonstration of a commercially acceptable device. *Project Manager: Vasu Tahiliani*

Static VAR generator

The static VAR generator (SVG), built by Westinghouse with EPRI funding, has completed its first year of successful operation at Minnesota Power & Light Co. (RP750). It was recognized that because of its limited size, the SVG would not be able to control the full range of variations encountered at the MP&L substation. However, the device did demonstrate the concept of static VAR compensation on a large utility system in conjunction with other voltage control equipment.

First-year operating experience with the static compensator on the MP&L system was better than expected, considering its limited size. The performance and reliability of the SVG proved successful in several important areas. Its response to system compensation requirements aided in increasing the power transferred on the 485-km, 230-kV interconnection between Manitoba and MP&L's Shannon substation. It also added support to the voltage on the 115-kV line that serves the large motor loads in the taconite grinding mills. The SVG remained fully operational during all system disturbances, and therefore was available to support the transmission system. It operated successfully without thyristor failure for the entire period. The unit was available for operation 97.5% of the time, excluding inspections, tests, maintenance, and planned shutdowns.

To continue the experimental program, a direct-light-fired thyristor switch was fabricated to replace one phase of the existing switch. After testing, the unit was installed in October 1979. In a further step, MP&L is considering the possibility of moving the Shannon SVG to a proposed International Falls substation scheduled for commissioning in 1982. This substation will be located 160 km north of the Shannon site and will provide superior shunt compensation and voltage control, further improving power transfer capability. *Project Manager: Gilbert Addis*

ROTATING ELECTRICAL MACHINERY

Superconducting generator

A project was initiated one year ago to develop and build a 300-MVA prototype superconducting generator that can be driven by an existing steam turbine in a utility power plant (RP1473). If such development is successful, superconducting generators of substantially higher rating could meet the ever-increasing need for machines of reduced size that are also more efficient. Greater reliability, availability, and overall stability are prime project goals. This $19.2-million, five-year effort is centered at the Westinghouse Large Rotating Machinery Facility in East Pittsburgh. The cost of the project is being shared equally by Westinghouse and EPRI. To date, the largest operating generator of this type has been a 5-MVA machine built and laboratory-tested by Westinghouse. The 300-MVA superconducting machine is intended for actual utility operation after a period of initial factory testing.

Superconductivity is a property of certain metal alloys that at very low temperatures carry a loss-free flow of electric current. When this technology is applied to electric power generators, the result is a potential reduction of 50% or more in electric losses normally incurred during the generation processes.

Other potential advantages of the superconducting generator are lower capital cost and increased system reliability. The machine will be more compact than conventional generators, and therefore it will require less construction material. Manufacturers will also be able to fully assemble the generator in a controlled fabrication environment, eliminating difficulties that have arisen in the past with some generators that required additional fabrication on site.

This feature is seen by researchers as a plus for increasing unit reliability.

Also viewed as potential advantages are enhanced stability brought to the electric power system and greater adaptability to high-voltage transmission lines, which are expected to become more prevalent in the future.

A superconducting generator is much like a conventional generator in that it produces electricity by the interaction of the magnetic fields surrounding two sets of windings. The difference between superconducting and conventional generators is found in the field winding. In a conventional generator, the field winding is made of copper and is cooled by air, hydrogen, or water. It operates at temperatures of about 82°C (180°F), and at these temperatures, it experiences resistance to the flow of current, resulting in electric losses.

In a superconducting generator, the rotating field winding is made of an alloy that becomes superconducting when it is cooled with liquid helium to a temperature of 4 K (−452°F). At this extremely low temperature, there is no resistance to the flow of current and, consequently, no electric field winding losses.

The superconducting quality is also responsible for the strengthened rotating magnetic field of the generator, which will ultimately increase the stability of the entire electric system and thus reduce the probability of power outages. It also allows the stationary armature winding to be designed to operate at much higher voltage levels than possible with conventional machines. A prototype machine should be under test on an actual utility system by 1984. *Project Manager: James Edmonds*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

EFFECTS OF POWER LINES AND POLES ON BIRDS

Power lines and poles can have adverse effects on bird populations. For example, there are cases of large birds being electrocuted by power lines, birds sometimes collide with lines, and the flight patterns of certain species seem to be affected simply by the presence of power lines. These events are very difficult to quantify, however, and the effect on total bird populations is difficult to evaluate. Nevertheless, power line builders are being required to produce increasingly detailed information about the possible impact of power line installation and operation. Two EPRI-funded projects, RP1002 and RP1636, are seeking answers to questions on how power lines and poles affect birds.

Raptor mortality

The potential danger of power lines to birds of prey (raptors) and such other large birds as vultures and great blue herons has been noted for several years. For example, golden eagles use utility poles as perches from which to hunt and are often electrocuted by contact with lines. Cooperative studies by power companies, the National Audubon Society, the National Wildlife Federation, the U.S. Fish and Wildlife Service, and the U.S. Forest Service have revealed that protective devices could be installed on poles to reduce eagle mortality. However, installing the devices on all or most poles in bird habitats would be quite expensive.

Preliminary findings indicated that 98% of eagle electrocutions could be prevented by modifying just 2% of the poles. Identifying these poles, however, is a formidable task. The problem was sufficiently complex to warrant a research project, which is now nearing completion at Brigham Young University (RP1002). Field data have been gathered for three seasons (1977, 1978, and 1979) at 25 separate line sections in six states—Idaho, Wyoming, Utah, Colorado, New Mexico, and Nevada. The data describe vegetation, prey base, raptor densities, raptor mortalities, age class of electrocuted birds, topography, altitude, prevailing winds, season when electrocutions occurred, nearest roads, power line configuration, line voltage, and soil.

Investigators have concluded that although raptors in general are seldom electrocuted by power lines, certain populations of eagles may be significantly affected. As a result of this research, it will be possible to identify with a good deal of accuracy the poles that attract eagles and that should therefore be modified, thus mitigating the problem in the most cost-effective way. Details of the research procedure are described in the following paragraphs.

Vegetation data were collected by three techniques, two of which are modifications of the canopy-coverage method of vegetation analysis. One of these methods involves the placement of 40 plots, each 1-m (39-in) square, at random along each transect (8-km [5-mi] section of power line). The second involves estimates of cover 61 m (200 ft) to either side of the power line at each pole. Both techniques require visual estimation of the percentage of canopy cover in each of several size categories. The third technique involves the measurement and identification of shrubs in a 9.3-m^2 (100-ft^2) circle around the poles. Shrubs are the plants of primary concern, since they are useful both as cover and as browse for the small mammals that are the main food source for many raptors.

Data on prey species were gathered by walking transects along and parallel to each power line. These areas were studied primarily to determine rabbit populations, but the presence of various rodent colonies (e.g., white-tailed prairie dogs and Townsend's ground squirrels) was also noted. The number of rabbits was recorded, along with the location and species of each animal. In addition, information on the species and size of the shrubs used by rabbits for their forms was recorded.

Relative raptor densities and power pole use patterns were calculated from the number of defecations and castings around each pole and by observations of live birds in the area. The location, species, and sex, where possible, of the birds were noted, as well as the weather conditions and time of day when the observations were made.

Raptor mortalities were determined, and if possible, the cause of death was classified as electrocution, shooting, or collision with a power line. The degree of decomposition of each carcass was noted and the date of death estimated. Birds were classified by age class (juvenile, subadult, adult), if possible, with plumage as the criterion.

A clinometer and a range finder were used to determine the distance between poles and the position and elevation of the poles in relation to one another and to nearby topographical features. These data were collected to identify the physical characteristics of those poles that appear to be preferred by raptors. Field observations about the types of roads at the sites and their use will help determine the extent of human disturbance, including shooting.

Collisions and behavioral effects

Interest in other effects of overhead transmission lines on bird populations has increased in recent years, and such effects have become an important consideration in the siting of some lines. A number of potential impacts have been identified, including collision mortality and changes in behavior because of the presence of lines, electromagnetic fields, audible noise, and visual coronas. The lack of useful data from previous studies and the absence of a standard research approach have frustrated both engineers who are responsible for routing transmission lines and biologists who are trying to evaluate the significance of the problem.

Several utility companies have received inquiries from regulatory agencies about how existing and proposed lines may affect birds. The lack of quantitative data became especially apparent, for example, during hearings on Pacific Power & Light Co.'s proposed 500-kV transmission line from Midpoint, Idaho, to Medford, Oregon. The company incurred significant delays in construction of the line when the Oregon Public Utilities Commission required an extensive study of birds in the Klamath Basin. The permit to build along the proposed route was subsequently denied by the U.S. secretary of the interior, and further delays were incurred as studies attempted to locate an acceptable route.

In early 1978 the National Power Plant Team of the U.S. Fish and Wildlife Service and the Oak Ridge Associated Universities held a workshop in Oak Ridge, Tennessee, on the effect of transmission lines on birds in flight. Although the questions raised at the start of the workshop were not adequately answered, the workshop summary defines the problem: "Transmission lines are a source of mortality to bird populations. However, at this time, we have not assimilated the data on the percentage of population mortality, the effects of scavengers on bird death counts, or the actual number and biological significance of collisions with transmission lines. Further studies of the effects on populations are needed if we are to understand the complete scope of this question of avian mortality."

As a follow-up to the workshop, the Edison Electric Institute (EEI) convened a meeting in Washington, D.C., in March 1978 to discuss an industry approach to the problem. Representatives of electric utilities, DOE, EPRI, EEI, NRC, the U.S. Fish and Wildlife Service, and the National Audubon Society attended, as well as representatives invited from the academic community. It was decided that EPRI was the appropriate organization to carry out the needed research.

Methodology studies

EPRI's goal in this research is to develop and apply methodologies for studying bird behavior and assessing collision mortalities that are related to overhead transmission lines (RP1636). The research will be coordinated with and will complement ongoing research sponsored by government agencies and the electric power industry. As a first step, EPRI commissioned the preparation of two documents: a review of the effect of overhead wires on birds and an overview of ongoing and planned research, including an analysis of future research needs.

The project, a two-phase study, started in January 1980 and is scheduled to run for two to three years. At this time, funding has been approved only for Phase 1, which entails development of a methodology and field evaluation of observation techniques. Following the successful completion of Phase 1, Phase 2 will initiate the collection of data on bird behavior and collision mortalities at selected transmission line sites. Phase 1 has been divided into five tasks.

▫ Task 1 involves the selection, development, and field testing of various surveillance techniques. The investigators will evaluate the use of binoculars, range finders, spotting scopes, night viewing devices, and radar for observing birds under a variety of climatic conditions. An attempt will be made to develop the means to quantify a number of variables related to bird movement in the vicinity of overhead transmission lines.

▫ Task 2 will validate surveillance data on collisions by comparing the data with counts of dead and injured birds obtained by ground searches. Also as part of this task, a controlled experiment will be conducted to quantify scavenger and investigator success in locating dead birds.

▫ Task 3 concerns data management and analysis. As it is expected that a large quantity of data will be collected because of the many variables being considered in this study, a methodology will be developed for storing, retrieving, and manipulating the raw data to produce relevant information.

▫ Task 4 involves evaluating the appropriateness and feasibility of developing a predictive model that can be used by utilities in future routing decisions.

▫ Task 5, the development of standard procedures and analytic methods, is aimed at creating a uniform approach to data collection, management, and analysis. The procedures will be published in a handbook that will be available to utility and government biologists working on future projects.

Phase 2 will consist of field studies at selected sites to determine the incidence and magnitude of mortality resulting from direct wire collisions under various weather, habitat, seasonal, and diurnal conditions; and the occurrence and significance of alterations in flight patterns and habitat use caused by overhead transmission lines. Funding for Phase 2 is contingent on the success of Phase 1; a detailed work statement has not yet been prepared, but the full range of hardware and procedures developed in Phase 1 will be used in collecting these data.

A limited number of sites, probably no more than two, will be chosen for the Phase 1 studies, which focus on evaluating equipment and methodology. Phase 2 studies could involve a number of sites in different flyways or other areas of bird concentration. *Project Manager: John W. Huckabee*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

STEAM GENERATOR THERMAL HYDRAULICS

The severe problems affecting PWR steam generators result from complex interactions involving steam generator chemistry, materials, and thermal-hydraulic behavior. An important part of the effort to solve these problems is characterization of their thermal-hydraulic aspects. This research has recently identified new support plate hole geometries that minimize the potential for dryout, chemical concentration, and corrosion (and hence denting). Research is continuing on the thermal-hydraulic aspects of corrosion phenomena and is being broadened in the areas of mechanical damage, moisture carry-over, and development and verification of computer codes.

A number of problems have been experienced with PWR steam generators. These include corrosion phenomena, such as cracking, pitting, wastage, and denting of tubes; mechanical phenomena, such as water hammer, vibration, cavitation, and tube fretting and fatigue; and functional phenomena, such as excessive moisture carry-over in the steam. The problems are widespread. Tube denting has occurred in 23 units, tube wastage in 18 units, and tube cracking in at least 4 units. Water hammer has been reported in at least 20 units and excessive moisture carry-over in several others. It appears to be only a matter of operating time before a unit experiences one or more of these problems.

Solving the problems (i.e., arresting damage and identifying corrective action for current and future units) requires understanding the complex interactions of steam generator chemistry, materials, thermal-hydraulic behavior, and design details. As part of its total effort toward this end, the EPRI Steam Generator Project Office is evaluating the thermal-hydraulic aspects of the problems. Because the most severe problems experienced to date have been corrosion-related, thermal-hydraulic work has been focused in that area. However, additional work is being initiated to study mechanical and functional phenomena and the problems they create.

Corrosion phenomena

In U-tube recirculating steam generators, a two-phase mixture of water and steam flows through the tube bundle region on the secondary side. Testing under Project S118 shows that if conditions exist that cause a local region to dry out (i.e., all the water to vaporize), aggressive chemicals can concentrate and deposit there. The goals of the following research are to identify the conditions that lead to dryout and chemical concentration and to find methods for eliminating those conditions.

Tube–Support Plate Crevice Tube denting occurs when carbon steel tube support plates exhibit fast linear corrosion at the locations where the tubes pass through them. The corrosion product occupies a greater volume than the original support plate metal and squeezes down on the tube, deforming it. If corrosion continues, gross deformation and eventual cracking of the support plate and tubes result. Ongoing tests (S118) show the following.

- With heat fluxes and support plate hole geometries typical of operating steam generators, dryout can occur at the location where the tube contacts the support plate.

- The degree of dryout is largely independent of fluid quality, mass flow rate, and system pressure, but it increases with average heat flux.

- Support plate hole geometries that minimize contact between the tube and the support plate and open up adjacent flow areas make the crevice more resistant to dryout.

Work is continuing in this area to assess improved support plate hole geometries and their susceptibility to sludge accumulation and subsequent dryout (S180). Additional work is planned to evaluate the feasibility and effectiveness of using an insulating sleeve inside a tube to reduce the heat flux in a local region and hence the tendency toward dryout and denting (S114).

Sludge Piles Sludge accumulations 12 in high or more have been measured on the tubesheets of operating steam generators. It is in the region of such sludge piles that wall thinning of steam generator tubes sometimes occurs when phosphate water chemistries are employed. Laboratory testing with synthetic and real sludge has shown that dryout occurs within 1 in of the top of the sludge pile (S119-1). Further testing is under way to determine the mechanisms of boiling and chemical concentration in these sludge piles in an effort to identify techniques for controlling or reversing concentration (S171-1).

Tube-Tubesheet Crevice In some steam generators the manufacturing process leaves a crevice between the tube and the tubesheet hole in the upper part of the tubesheet. Dryout and chemical concentration may occur in this crevice, leading to tube denting and cracking. Several steam generators have experienced tube cracking in this region. Work is currently under way to confirm the postulated mechanisms of dryout and chemical concentration in the crevice and to evaluate methods for flushing the crevice by soaking or by alternately soaking and boiling (a technique being tried by the Japanese) and introducing neutralizing chemicals into the crevice (S119-2).

Mechanical phenomena

Vibration Clearances exist between steam generator tubes and support plates; such clearances are required for manufacture. Fluid flowing parallel to, perpendicular to, or at some intermediate angle to the tubes induces tube vibration. This vibration may cause a tube to hit or slide against support plates and/or adjacent tubes, resulting in local wear damage (i.e., loss of tube and support plate metal). Because the movement between the surfaces is oscillatory and usually of small amplitude, the rubbing process is termed *fretting*. Fretting causes tube metal loss, and fretted regions are sensitive to fatigue cracking.

No fatigue cracking has yet been observed in U-tube steam generators; however, tube cracks that were apparently propagated by a large number of cycles have been found in once-through steam generators. This may signal a new problem generic to steam generators. Currently, there is insufficient quantitative information on the mechanisms of vibration induced by two-phase flow in complex geometries, fretting, high-cycle fatigue, and corrosion fatigue to explain what has been observed, let alone calculate the potential for vibration-related damage in steam generators over a lifetime of 40 years.

To fill this void, work is being initiated to develop detailed design information in the areas of steam generator tube vibration, fretting, and high-cycle and corrosion fatigue (S153, S174-2, S110).

Erosion and Cavitation There are no consistent, easily accessible design and evaluation criteria on the phenomena of erosion-corrosion, solid-particle impingement, and cavitation in PWR steam generators. However, there is evidence that such phenomena may have caused tube damage observed in a once-through steam generator, and again this may signal a problem generic to steam generators. Thus work is being started to assemble in a usable form the available technical information on the occurrence and prevention of erosion-wear, erosion-corrosion, cavitation, and resulting fatigue-limit reduction in PWR steam generators.

Water Hammer Water hammer has occurred in feedwater piping for feed ring–type steam generators and can potentially occur in the preheat section of economizer-type steam generators, which are now under construction. Water hammer is thought to be caused in this way: (1) feed flow is interrupted, and susceptible regions fill with steam; (2) when feed flow resumes, a volume of steam is trapped and rapidly collapses because of heat transfer to the colder feedwater; (3) the rapid collapse of the steam volume creates a pressure differential that accelerates a slug of water through the susceptible region; (4) the accelerating slug of water impacts (hammers) a barrier.

Because of the complex nature of steam pocket formation, the lack of data on direct-contact condensation rates, and uncertainties regarding liquid slug length and interface geometry, water hammer forces cannot be accurately predicted. Therefore, current practice involves a combination of design modifications and operating guidelines to prevent formation of steam pockets, as well as testing to verify that water hammer will either not occur or not cause damage if it does occur.

Excessive moisture carry-over

U-tube recirculating steam generators are intended to deliver dry saturated steam. The moisture content of the steam, or moisture carry-over, is limited to 0.25 wt% to prevent damage to turbines. Steam generators contain moisture separators to remove enough moisture from the steam produced in the tube bundle to keep carry-over at the steam generator outlet below 0.25 wt%.

The design of moisture separators for steam generators has been a trial-and-error process of limited success. Moreover, modifications made to operating steam generators to increase the moisture content of the water-steam mixture in the tube bundle (in an attempt to prevent dryout in crevices) have sometimes overloaded the separators and caused moisture carry-over in excess of 0.25 wt%.

Work is currently under way to characterize the mechanisms of moisture separation and associated flow fields and to develop predictive techniques to permit a quantitative approach to separator design and evaluation (S122, S135, S172, S173).

Code development and verification

Characterizing the thermal-hydraulic aspects of steam generator problems is only part, albeit the most important part, of the effort in the thermal-hydraulic area. Accurate computer codes must be developed to calculate local thermal-hydraulic conditions leading to corrosion damage in steam generators, to calculate the forcing functions for potentially damaging mechanical phenomena, and to predict such functional details as moisture carry-over. Such codes are needed to assess the effectiveness of corrective action for known problems, to detect incipient problems in operating units, and to facilitate the design of future steam generators to avoid the problems.

Work in this area is concentrated on assessing the 3 three-dimensional, two-phase thermal-hydraulic steam generator codes currently available and an advanced code, URSULA, being developed by EPRI's Nuclear Power Division. Preliminary results indicate that the codes agree in calculations of average conditions, such as circulation ratio, but do not agree in calculations of local conditions in specific areas. Comparisons are continuing in order to determine the extent of the differences and their causes and to determine where corrections are required (S129, S130, S131).

There are plans to verify the codes by comparing their predictions of local thermal-hydraulic conditions with results of small-scale tests, measurements of local conditions in model steam generators, and the more global measurements from actual operating steam generators. To speed up this process, initial emphasis is being placed on reducing data already available and on collecting data from experiments that have already been constructed and instrumented. *Program Manager: J. F. Lang*

NEW EQUIPMENT FOR ISI DATA ANALYSIS

A new portable device has been developed for EPRI that uses state-of-the-art microprocessor technology to analyze data from the in-service inspection (ISI) of nuclear power plant components. At the heart of the device are two computers that work in parallel to control the acquisition of ISI data and to analyze the signals and interpret them for the operator. Special high-speed, arithmetic-logic chips are used to allow real-time interpretation of the data. The device has proved extremely useful in laboratory investigations and is now undergoing field evaluation, which will last for about one year. After that, workshops will be presented by EPRI's nondestructive evaluation (NDE) center to introduce this new technology to the utilities and service groups who will deploy it in the field. Once in field service, the equipment should greatly enhance the reliability and precision of ISI data interpretation and considerably reduce man-rem exposure and inspection time.

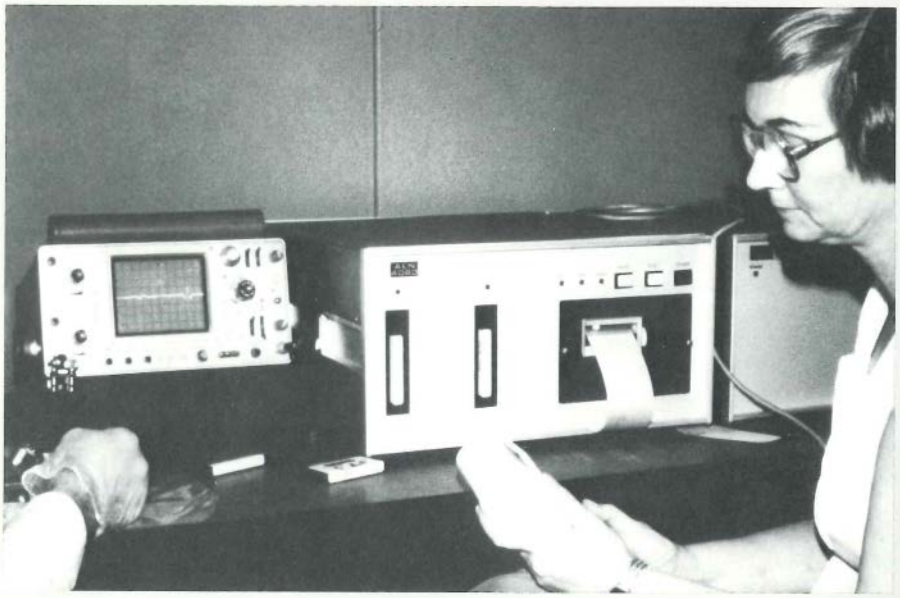
Manual inspection, whether eddy current or ultrasonic, requires that an operator perform a number of somewhat incompatible tasks. The operator must move the probe along the object, make adjustments on the flaw detector instrument, check the probe's contact with the component, and at the same time monitor the flaw detector's output screen, which is often located in a very awkward position. This demanding procedure tires the operator and reduces the productivity and reliability of an inspection. A detailed evaluation of flaw parameters is even more demanding and stressful.

In recognition of these facts, a program was initiated to develop the equipment and analysis routines necessary to increase inspection reliability by automating the measurement operations. On the basis of an earlier project that demonstrated the feasibility of performing an automatic analysis of ultrasonic signals (RP770), it was decided to proceed with a two-part development effort (RP1125-1). One objective of the project was to develop the analysis routines for the interpretation of ISI data, and the second was to develop the equipment necessary to enable automatic acquisition and interpretation of data in the field. A description of the hardware that resulted from the second effort follows.

The original design specifications were that the automatic processing equipment accept information from conventional flaw detection equipment now deployed in the field, that the hardware be easily transportable by hand and by air, and that it remove as much of the responsibility for data interpretation from the operator as possible. From the start, it was assumed that an automatic mechanical scanner that moved the transducer about the test component would be used to gather position information believed necessary for a highly precise interpretation. Another specification was that the portable analysis equipment be capable of automatically controlling the data acquisition device so that man-rem exposure would be reduced in nuclear applications. The resulting instrument more than met the original goals.

Figure 1 is a photograph of the finished product, and Figure 2 is a block diagram illustrating its various functions. The equip-

Figure 1 The portable automatic signal-processing unit (right) can analyze and interpret flaw data more accurately and reliably than manual inspection methods. The unit is shown processing data from an ultrasonic instrument (left) but can be easily modified for use in eddy-current inspections as well.



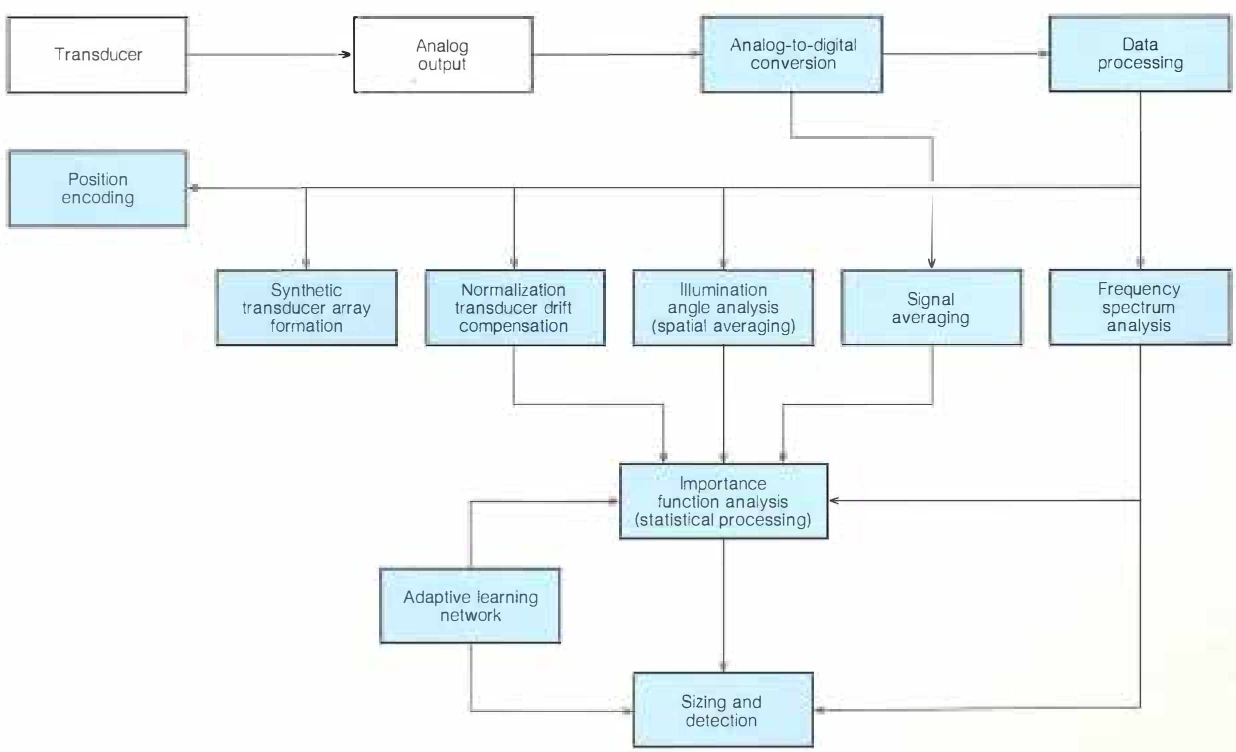


Figure 2 The shaded blocks represent signal-processing steps performed by the new ISI equipment. In each of these steps, the equipment significantly improves on the signal identification of conventional approaches.

ment is generic in nature and can be programmed to perform different data acquisition and analysis routines by inserting different magnetic tape cassettes of machine instructions. The same hardware can be used for both eddy-current and ultrasonic inspection with only minor modifications.

In addition to providing automatic analysis and interpretation of ISI data, the hardware has other features that offer improvements over conventional technology. It provides a complete record of the inspection, including the original raw signal and its position coordinates, a calibration curve of the transducer used to generate the data, and such information as operator name, plant name, date, and weld or component identification. This record permits a complete replay of the inspection and preserves the raw information for use with any improved analysis techniques that may be developed later.

All communications with the instrument are through a miniature hand-held computer terminal that uses English in a question-and-answer mode for the required operating instructions. All data on the magnetic cassettes will be in a form compatible with a large computer operation for either additional analysis or storage in a central archive. The transfer of data from the analysis unit to a large mainframe computer will be through a built-in conventional phone module.

The equipment has three operating modes. In the first, strictly a data acquisition mode, it controls the data-gathering device, records the raw signal and position information, and stores the data for later analysis. In the second mode, a real-time analysis of the data is added to these acquisition activities. The third mode provides the capability to perform detailed off-line analysis of any particular part of the inspection. Because of the many different mathematical routines in the analysis network, this mode requires a highly sophisticated user.

At the present time, data acquisition and interpretation instructions are being developed for three specific nuclear plant applications: ultrasonic inspection of BWR feedwater nozzles, ultrasonic inspection of stainless steel pipe welds, and eddy-current inspection of steam generator tubes. A fourth effort is aimed at coupling this analysis technique with a method of acquiring position information from a manually operated ultrasonic transducer. Preliminary evaluation of the hardware and the analysis instructions have been completed, and rigorous field evaluation and qualification are under way. The prime contractor for this project is Adaptronics, Inc. Subcontractors are the Southwest Research Institute; Battelle, Pacific Northwest Laboratories; and Battelle, Columbus Laboratories. *Project Manager: Gary J. Dau*

DESIGN RULES FOR BWR CARBON STEEL PIPING

In 1970 BWR designs began to specify the use of carbon steel for piping systems that were previously stainless steel. In the latest BWR-6 standard plant, carbon steel is used extensively; except for the main recirculation water lines and parts of the control-rod-drive hydraulic system, virtually all primary pressure boundary piping is made of carbon steel. Although stress corrosion cracking (SCC) and corrosion fatigue have never been observed in carbon steel BWR components, the increased use of carbon steel in the BWR-6 has stimulated interest in the behavior of carbon steel in BWR environments. Thus research has been initiated to formulate design stress rules that will ensure the continued successful performance of carbon steel for the design life of the BWR.

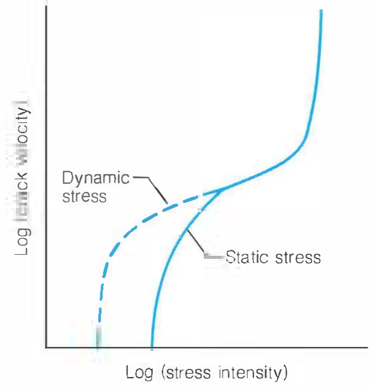
The design rule philosophy is based on the assumption that very small flaws exist from the first day of construction. The growth of these flaws into cracks can be predicted by the science of fracture mechanics, which has shown that crack growth is a function of stress intensity—itself a mathematical function of crack geometry, stress, and the geometry of the component containing the crack. The design stress rules provide stress-related guidelines that will prevent existing flaws from growing to a critical length within the lifetime of a BWR component.

Figure 3 illustrates the typical relationship between crack growth and stress intensity under static and dynamic stress. Dynamic stress reduces the stress intensity required for crack growth. This effect has been observed in EPRI-sponsored research at General Electric Co. on carbon steel in BWR-like environments (RP1248-1) and will be an important consideration in the final formulation of design stress rules.

This research has also shown that crack growth can be affected by the frequency of dynamic stress fluctuation. For example, Figure 4 shows that the crack growth per cycle is significantly greater at low frequencies than at higher frequencies. However, the crack growth per unit of time is greater at the higher frequencies.

Although the precise stress rules for carbon steel in BWR environments have not yet been fully quantified, observations of practical value have been made. These ob-

Figure 3 The relationship between crack velocity and stress intensity. Stress intensity is a mathematical function of crack geometry, stress, and the geometry of the components containing the crack. Research has shown that dynamic stresses can reduce the stress intensity required for crack growth in carbon steel in BWR-type environments.



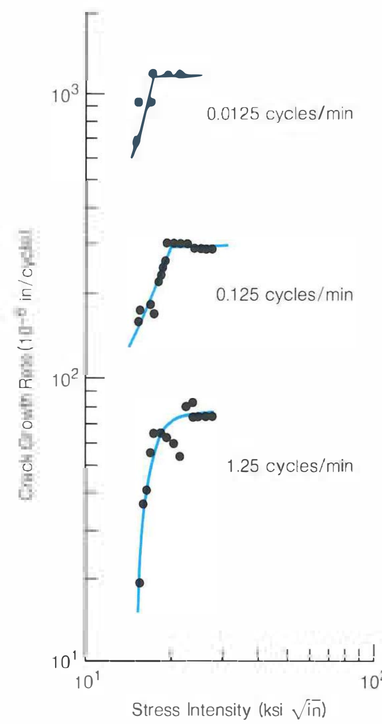


Figure 4 The crack growth rate per cycle in carbon steel is presented as a function of the stress intensity range for three frequencies of the cyclic stresses. The environment is high-purity water at 288°C containing 8 ppm dissolved oxygen. Except for the high oxygen content, the environment is similar to a BWR environment. The ratio of minimum to maximum stress intensity is 0.5 for all three frequencies.

servations pertain to stress and to the other two parameters that affect crack growth: the metallurgical condition of the material and the environmental conditions.

In general, the SCC of carbon steel requires greater stress than the intergranular SCC of sensitized type-304 stainless steel. For example, in full-scale environmental testing of carbon steel pipe welds and type-304 stainless steel pipe welds at stresses equivalent to 250% of their respective allowable design stress levels, carbon steel outperformed type-304 stainless steel by more than a factor of 20. The testing environment was high-purity water at 288°C (550°F) containing 8 ppm of dissolved oxygen. Except for the high oxygen content, this environment is similar to that of an operating BWR. The oxygen content in an operating BWR environment is about 0.2 ppm at equilibrium conditions.

The susceptibility of carbon steel to SCC does not appear to be associated with any specific metallurgical condition. Rather, SCC occurs at geometric stress concentrators, such as notches, the weld counterbore, and the weld fusion line. For comparison, intergranular SCC in type-304 stainless steel pipe welds is confined to the weld-heat-affected zone.

Laboratory experiments and environmental pipe tests have shown that the environmental (water chemistry) conditions likely to occur in a BWR are sufficient to facilitate SCC in carbon steel. This is true for both startup conditions and steady-state operating conditions (288°C and 0.2 ppm oxygen).

It needs to be emphasized that the three essential conditions for SCC—stress, metallurgical susceptibility, and facilitating environmental conditions—have to be present simultaneously for SCC to occur. Therefore, the presence of environmental conditions that will facilitate SCC does not necessarily mean that SCC will occur. However, if the environment is sufficient to facilitate SCC and the metallurgical condition is susceptible to SCC, stress becomes the controlling factor that determines whether SCC will occur. Thus stress-related design rules are of considerable value in ensuring the continued reliable performance of carbon steel in BWRs. *Project Manager: Michael J. Fox*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP101-1	Epidemiological Study of the Three Mile Island Accident	5 years	200.0	Pennsylvania Department of Health *L. Sagan*
RP434-38	Electric Utility Rate Design Study	4 months	25.0	Putnam, Hayes & Bartlett, Inc. *R. Malko*
RP468-3	Transient Phenomena in Coal-Fired Magneto-hydrodynamic Generators	21 months	495.8	Stanford University *A. Lowenstein*
RP703-1	Benefits of BWR Oxygen Control	18 months	171.0	General Electric Co. *J. Danko*
RP844-2	Commercial Solar–Load Management Experiment	3 years	184.0	Public Service Co. of New Mexico *G. Purcell*
RP1066-5	Stability Analysis of Steam Generator Computer Codes	5 months	40.0	Jaycor *J. Sursock*
RP1084-6	Potential Application of Energy Storage Devices in Small Utilities	6 months	53.8	Burns & McDonnell *T. Yau*
RP1090-2	Heat Storage Instrumentation and Data Verification	9 years	335.0	Niagara Mohawk Power Corp. *R. Mauro*
RP1129-5	Baghouse Gas and Dust Flow Modeling	15 months	287.4	Dynatech R/D Co. *R. Carr*
RP1199-8	Analytic Prediction of Circulation and Vortices at Intakes	4 months	43.3	Worcester Polytechnic Institute *A. Ferreira*
RP1253-5	Sphere Pac Ceramic Fuel in a Safeguarded Fuel Cycle	11 months	22.1	Oregon State University *R. Williams*
RP1253-6	Engineering Aspects of LWR Life Extension	8 months	119.6	International Energy Associates Ltd. *M. Lapides*
RP1258-4	Absorption-Stripping Pilot Plant Analytic Program	6 months	19.2	Radian Corp. *D. Stewart*
RP1265-3	Failure Cause Analysis: Turbine Bearing Systems	2 years	589.1	The Franklin Institute *J. Parkes*
RP1265-10	Preliminary Approach to Root-Cause Analysis of Power Plant Equipment Problems	8 months	47.3	Science Applications, Inc. *J. Parkes*
RP1266-20	Human Factors Design for Fossil-Fired Boiler Systems	7 months	122.6	Whitston Associates *J. Dimmer*
RP1277-2	Transmission Line Wind Loading Research: Analytic Model	18 months	234.9	GAI Consultants, Inc. *P. Landers*
RP1317-1	Environmental and Safety Assessment of Selected Battery Energy Storage Systems	1 year	125.0	Bechtel National, Inc. *R. Wyzga*
RP1318-1	Validation and Calibration of the EPA Integrated Assessment Model	18 months	325.0	TERA Corp. *P. Ricci*
RP1394-5	Induction Heating Stress Improvement	3 months	25.0	IHI Heavy Industries Co., Ltd. *M. Fox*
RP1398-4	Metallurgical Characteristics of Turbine Rotors and Disks Related to Stress Corrosion Cracking	3 years	648.7	Transamerica Delaval, Inc. *M. Kolar*
RP1398-5	Cracking of Steam Turbine Disks	20 months	946.2	Southwest Research Institute *M. Kolar*
RP1400-5	Construction of EPRI Coal-Cleaning Test Facility	20 months	9123.0	Roberts & Schaefer Co. *D. Trerice*
RP1412-8	Preparation of Deashed H-Coal Residual Fuel Oil	6 months	69.5	The Lummus Co. *N. Stewart*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1454-1	Gadolinium Benchmarks	16 months	259.6	General Electric Co. *B. Zolotar*
RP1480-1	Review and Evaluation of Energy Supply Projects	23 months	210.6	SRI International *J. Eyssell*
RP1530-1	Development of Method to Evaluate Bulk Transmission System Reliability	2 years	470.8	Power Technologies, Inc. *N. Balu*
RP1547-1	BWR Fuel Rod Simulator	1 year	129.3	Westinghouse Canada, Ltd. *M. Merilo*
RP1554-8	Crack Opening and Stability Analysis for Flawed Stainless Steel Piping	15 months	265.3	General Electric Co. *R. Jones*
RP1574-1	Impurity Segregation in Stainless Steel	1 year	119.5	General Electric Co. *M. Fox*
RP1615-3	Water Resource Constraints on Energy-Related Activities	1 year	40.0	Lawrence Livermore Laboratory *D. Geraghty*
RP1649-4	Protection of Induced-Draft Fans From Erosion Damage	1 year	201.3	Westinghouse Electric Corp. *J. Stringer*
RP1685-3	Coal Ash Disposal Manual Update	1 month	15.0	GAI Consultants, Inc. *D. Golden*
RP1689-2	Survey of Outages of Steam Surface Condensers and Associated Systems	13 months	98.7	Stone & Webster Engineering Corp. *I. Diaz-Tous*
RP1699-1	Preliminary Engineering Design and Cost of Advanced Compressed-Air Storage Systems	1 year	216.0	United Engineers & Constructors, Inc. *W. Stevens*
RP1702-2	Analysis of Fission-Product Migration and Release Experiments	15 months	40.0	Science Applications, Inc. *H. Ocken*
RP1704-1	Assessment of Maintainability of LMFBR Designs	15 months	390.0	ETA Engineering, Inc. *J. Matte III*
RP1704-2	Assessment of Operability of Prototype Large Breeder Reactor Designs	15 months	697.4	General Physics Corp. *K. Winkleblack*
RP1704-4	Assessment of Inspectability of LMFBR Designs	14 months	449.0	Rockwell International Corp. *J. Matte III*
RP1705-1	Work Performance Under Heat Stress	5 months	54.3	Pennsylvania State University *H. Parris*
RP1707-3	Threshold for Radiation Damage to Electrical Equipment	10 months	18.5	Georgia Institute of Technology *G. Sliter*
RP1725-1	Transient Thermal-Hydraulic Systems Analysis Using the TRAC Computer Code	1 year	200.0	Jaycor *G. Strikantiah*
RP1728-1	Engineering Evaluation of Projected Utility Solid-Waste Disposal Practices	9 months	270.3	Michael Baker Jr., Inc. *D. Golden*
RP1731-1	Reflux Boiling and Natural Circulation Heat Rejection Tests	1 year	92.9	SRI International *J. Sursock*
RP1745-1	Increased Efficiency of Hydroelectric Power	8 months	174.8	Shawinigan Engineering Corp. *A. Ferreira and T. Schneider*
RP1747-1	Demand 80: National Energy Demand Forecasting Model	1 year	75.7	Applied Forecasting & Analysis, Inc. *L. Williams*
RP7876-3	Development of Impermeable Dielectric Cements Based on Silica Polymers	2 months	25.0	Southwest Research Institute *M. Rabinowitz*

New Technical Reports

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

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

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

Standing orders for free copies of reports in EPRI program areas or Technical Summaries of reports for each EPRI technical division may be placed by EPRI member utilities, libraries of U.S. national, state, and local government agencies, and the official representative of any foreign organization with which EPRI has an information exchange agreement. For details, write to EPRI Communications, P.O. Box 10412, Palo Alto, California 94303.

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

ADVANCED POWER SYSTEMS

The Role of Personnel Errors in Power Plant Equipment Reliability

AF-1041 Final Report (TPS77-715); $4.50

The effects of personnel errors on the equipment availability of a cross section of fossil fuel power plants are quantified. The data are based on a questionnaire, personal interviews, and the trouble memos of two utilities. The report indicates that personnel errors are responsible for at least 20–25% of all failures in power plant generation systems. The contractor is Failure Analysis Associates. *EPRI Project Manager: Jerome Weiss*

Comparative Assessment of Marine Biomass Materials

AF-1169 Final Report (TPS77-735); $5.75

This study assessed potential marine biomass sources and their preprocessing requirements. A priority list of marine plants was developed on the basis of maximum potential organic yields, maximum potential calorific yields, and chemical composition (including seasonal variations in ash and water content) and was used to estimate maximum potential yields from U.S. coastal waters. Assuming meaningful physical and nutrient constraints and no mechanical nutrient upwelling, the yield could be as high as 30×10^{15} Btu/yr. Preprocessing schemes were compared by evaluating energy consumption for each step. The contractor is Science Applications, Inc. *EPRI Project Manager: Dwain Spencer*

Metastable Phenomena in Hydrogen Degradation of Low-Alloy Carbon Steels

AF-1176 Interim Report (RP838-1); $2.75

Chromium-carbon clustering phenomena, carbide formation in low-alloy carbon steels, and the role of these phenomena in hydrogen attack were investigated. In carbonization experiments in which pure iron and iron-chromium alloys were exposed to atmospheres of varying carbon activities at 600° and 700° C, the solubility of carbon in the alloy ferrite was in excess of that in pure iron. This finding substantiates the existence of a metastable condition in which the carbon atoms cluster around the chromium atoms and assume a higher thermodynamic activity. The contractor is Pennsylvania State University. *EPRI Project Managers: Ramaswany Viswanathan and Roger Richman*

Simulation of a Texaco Gasifier: A Steady-State Model

AF-1179 Final Report, Vol. 1 (RP1037-1); $3.50

This volume describes a steady-state model of a Texaco entrained gasifier; a dynamic model will be developed in the next phase of the project and reported in a second volume. The gasifier is represented by a perfectly stirred tank reactor in combination with a plug flow reactor. The model includes both gas- and solid-phase reactions, interphase mass and energy transfer, and wall heat loss. Coal particle size distributions may be used. In tests with actual data on four different coals, good agreement between predicted results and actual observations was obtained. The contractor is Texaco, Inc. *EPRI Project Manager: George Quentin*

Economics of Retrofitting Power Plants for Coal-Derived Medium-Btu Gas

AF-1182 Final Report (TPS78-773); $5.75

Capital and operating cost estimates are presented for retrofitting two types of existing 500-MW (e) power plants to burn medium-Btu gas derived from developmental Texaco and Combustion Engineering oxygen-blown coal gasification processes. The two types of plants selected for analysis are relatively new natural-gas-fired boiler plants and oil-fired combined-cycle units. It was concluded that engineering evaluations should be conducted on additional retrofit options. The contractor is Bechtel National, Inc. *EPRI Project Manager: Edwin Force*

Coal Slurry Feed Pump for Coal Liquefaction, Phase II

AF-1189 Final Report (RP775-1); $4.50

This report presents the detailed design of a slurry feed pump for commercial-size coal liquefaction plants, including a hydraulic design, thermal analysis, and structural analysis. (The complete set of detailed drawings and manufacturing and test plans are available to authorized individuals through EPRI.) The pumping design requirements were 5000 gal/min (0.3 m^3/s), 3000 psi (20.7 MPa), at 500°F (260°C). The contractor is Rocketdyne Div., Rockwell International Corp. *EPRI Project Manager: H. H. Gilman*

Thorium-Cycle Hybrid Reactor Design Study

ER-1195 Technical Report (RP473); $4.50

This report describes the potential for producing fissile uranium from thorium. Data indicate that near-term, beam-driven tokamak fusion-fission devices could produce abundant amounts of ^{233}U—from 1.5 to 4 t/yr, depending on the details of the blanket design. Factors affecting this rate include tritium production rates, blanket neutron multiplication, and the desired amount of blanket thermal power. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Noel Amherd*

COAL COMBUSTION SYSTEMS

Continuous Nuclear Assay of Coal: Progress Review and Industry Applications

FP-989 Final Report, Vol. 8 (RP983-1); $4.50

This is one of several volumes describing the development of a continuous on-line nuclear analyzer of coal. A small source of neutrons is used to excite gamma emissions from coal nuclei. These emissions are captured by solid-state detectors and analyzed by a minicomputer to determine the elemental composition by weight, together with such derived quantities as Btu/lb. The development of such an analyzer will help utilities control coal quality, comply more effectively with emission regulations, and schedule and optimize power system load flows. As part of work in this phase, various mechanical configurations of neutron source, detector, and coal were evaluated. The contractor is Kaiser Engineers, Inc. *EPRI Project Manager: Owen Tassicker*

Coal-Water Slurry Systems for Oil-Design Power Plants

FP-1164 Final Report (RP1180-4); $3.50

A conceptualized system was evaluated for preparing a coal-water slurry and burning it in utility boilers originally designed for oil. The technical status of the following system elements was reviewed: coal selection, mechanical coal cleaning, chemical coal desulfurization and ash reduction, slurry preparation and transportation, combustion, and boiler modifications. The assessment found that each element of the fuel production process had been tested independently of the others and only on a limited basis. Costs are discussed. The contractor is Combustion Processes, Inc. *EPRI Project Manager: Steven Drenker*

Monitoring the Fixed FGD Sludge Landfill, Conesville, Ohio: Phase I

FP-1172 Final Report (RP1406-2); $7.25

This is the first in a series of reports evaluating a full-scale disposal system that uses the IU Conversion Systems, Inc., process to treat flue gas desulfurization sludge. In this phase, background information was reviewed and geohydrologic investigations were conducted to formulate a long-term monitoring program that will determine if full-scale applications of the process (1) reflect laboratory- and pilot-scale results, (2) provide environmentally acceptable disposal methods, (3) cause operating problems for the utility, and

(4) meet current and future regulatory agency requirements. The contractor is Michael Baker Jr., Inc. *EPRI Project Manager: Dean Golden*

Evaluation of Ozone Treatment in Air Conditioning Cooling Towers

FP-1178 Final Report (RP1260-4); $5.25

Air conditioning cooling-tower systems that use ozone to treat circulating water were surveyed to determine if ozone averts scale deposition on heat transfer surfaces. The performance of these systems and the implications of using ozone treatment in electric power plants were examined. Makeup and circulating water samples were taken at four sites and were analyzed for general mineral content, including parameters that affect chemical scaling. The effectiveness of ozone treatment in controlling mineral scale deposition was confirmed. The contractor is Brown & Caldwell. *EPRI Project Manager: Winston Chow*

ASTM Leachate Test Evaluation Program

FP-1183 Final Report (RP1260-6); $3.50

This report describes testing to determine the precision of proposed ASTM methods for leaching of waste materials and to compare these tests with proposed EPA tests. Two ASTM shake-extraction procedures were evaluated, and the March 1978 version of the EPA toxicant extraction procedure was performed for comparison. There was a high degree of variability in the results from 21 laboratories testing the same material with a given test method. Results indicate that all three test methods are unsuitable for use in determining whether a waste is hazardous or not. The contractor is Engineering-Science, Inc. *EPRI Project Manager: Dean Golden*

ELECTRICAL SYSTEMS

Study of Lightning Current Magnitude Through Distribution Arresters

EL-1140 Final Report (RP1141); $5.75

The current magnitude of lightning surges discharged through distribution arresters was determined from arrester gap etchings caused by the surges. Inspection of the gaps revealed that two distinct types of etchings had been produced. These gaps were compared with gaps produced in the laboratory by 8×20 μs surges and surges of longer duration. All arrester data were statistically analyzed and are presented in the form of tables and graphs. The contractor is The Detroit Edison Co. *EPRI Project Manager: H. J. Songster*

Vacuum Arc Commutator for Resistive Fault Current Limiter

EL-1187 Final Report (RP993-2); $4.50

A triggered, vacuum arc commutating switch was evaluated for use as a component in a resistive fault current limiter for application at transmission voltages. Reliable turn-on was demonstrated. Reliable interruption in the range from 5 to 6.5 kA was obtained, with maximum values up to 9 kA. Transient recovery voltage capability was demonstrated up to 20 kV. Parallel shunt capacitance increases the interruption ability, particularly at higher source voltages. The contractor is Gould–Brown Boveri Inc. *EPRI Project Manager: Joseph Porter*

Research Into Load Forecasting and Distribution Planning

EL-1198 Final Report, Vol. 2 (RP570-1); $12.00

Two small-area load-forecasting methods were selected and each was written into a production computer program for utility use. The simplest program, TREND, uses advanced time-series trend analysis methods with many curve form options. It requires six years of historical electrical demand data by small area. The second program, MULTIVARIATE, requires both control and demand data by small area. A clustering procedure is used to linearize the process before the MULTIVARIATE parameter estimation. In addition to two years of historical data, the program requires estimates of future control data. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: W. E. Shula*

ENERGY ANALYSIS AND ENVIRONMENT

Economic Modeling of Electricity Production From Hot Dry Rock Geothermal Reservoirs: Methodology and Analyses

EA-630 Final Report (RP1017); $5.25

This report describes the development of an analytic methodology for assessing alternative modes of generating electricity from hot, dry rock (HDR) geothermal energy sources. The methodology is used in sensitivity analyses to explore relative system economics. It is more complex than conventional approaches for evaluating geothermal systems because it must take into account the many critical operator-controlled variables in HDR systems. A computerized, intertemporal optimization model was used to determine the profit-maximizing design and management of a unified HDR electric power plant. The contractor is the University of New Mexico. *EPRI Project Manager: Richard Urbanek*

The Integrated Forecasting Model

EA-1119 Interim Report (RP1108-1); $3.50

The current status and methodology of the integrated forecasting model are described and the results of a preliminary base case are given. An integrating framework was achieved that can generate a single, internally consistent forecast of energy prices and quantities on the basis of supply and demand submodels and information from diverse sources. The main frame of an analytic tool for use in special R&D analysis was provided, and the principal requirements were identified for its construction. The contractor is Decision Focus, Inc. *EPRI Project Manager: Lewis Rubin*

Energy Transition Strategies: A Progress Report

EA-1180 Interim Report (RP1014); $5.75

This report presents three papers prepared as part of a project examining different aspects of the long-term problem of transition from scarce to abundant energy resources. The papers are "A Decision Analysis of the U.S. Breeder Reactor Program," "Alternative Models of Energy Demand," and "Exhaustible Resource Models: The Value of Information." The summary abstracts four other papers produced by the project. The contractor is Stanford University. *EPRI Project Manager: Victor Niemeyer*

ENERGY MANAGEMENT AND UTILIZATION

Combined Thermal Storage and Transport for Utility Applications

EM-1175 Final Report (RP1199-3); $7.25

The technical and economic aspects of transporting heat from conventional central station steam power plants to distant user networks via large, closed-loop thermal pipelines are analyzed. Results indicate that heat extracted at temperatures available from LWR plants and transported as hot water over distances up to 50 km can be delivered at a cost that is competitive with heat generated locally by natural or synthetic gas or oil-fired boilers. The contractor is General Electric Co. *EPRI Project Manager: W. A. Stevens*

Performance Monitoring of a Passive Solar-Heated House, Stockton, California

ER-1177 Interim Report (RP1191-3); $3.50

This report describes the data acquisition system used in monitoring the performance of Pacific Gas and Electric Co.'s passive solar demonstration home in Stockton, California. Details about the data logger, the sensors, and the installation procedure are given. The house is briefly described, and some of the problems encountered in the project are discussed. The contractor is the Berkeley Solar Group. *EPRI Project Manager: Gary Purcell*

Hydrogen Production Using Solid-Polymer-Electrolyte Technology for Water Electrolysis and Hybrid Sulfur Cycle

EM-1185 Final Report (RP1086-3); $5.75

A comparative evaluation was made of the technoeconomics of hydrogen production using General Electric Co.'s solid-polymer-electrolyte (SPE) technology in two advanced processes: water electrolysis and Westinghouse Electric Corp.'s hybrid-sulfur-cycle water decomposition. The principal conclusion is that the SPE-based hybrid-sulfur-cycle process shows no technological or economic advantage over existing (SPE-based) water electrolvsis systems for the production of hydrogen. The contractor is General Electric Co. *EPRI Project Manager: B. R. Mehta*

Parametric Performance Evaluation and Technical Assessment of Adiabatic Compressed-Air Energy Storage Systems

EM-1188 Final Report (RP1199-1); $6.50

This report presents a review and evaluation of adiabatic compressed-air energy storage (ACAES) systems, using as a basis the ACAES studies performed by the UK's Central Electricity Generating Board. The performance of several potentially attractive ACAES system configurations was estimated and analyzed, and the technological requirements of the major turbomachinery of these configurations were assessed. The contractor is United Technologies Research Center. *EPRI Project Manager: W. A. Stevens*

Impact on Transmission Requirements of Dispersed Storage and Generation

EM-1192 Final Report (RP917-1); $5.75

Statistical data reflecting national average utility characteristics (such as generation mix, transmission component costs, and transmission configurations in terms of MW-miles for each voltage class) were incorporated into a base case. Transmission expansion planning studies were conducted by using the base case for four market penetration levels of dispersed fuel cell or battery storage power plants. Results show that dispersed fuel cell and battery power plants could achieve transmission savings ranging from $66 to $133 per kW of their generating capacity. The contractor is Systems Control, Inc. *EPRI Project Manager: Timothy Yau*

NUCLEAR POWER

Limiting-Factor Analysis of C–E Nuclear Plants

NP-1137 Final Report (RP894-2); Vol. 1, $12.00; Vol. 2, Part 1, $18.00; Vol. 2, Part 2, $14.25

A limiting-factor analysis of the Maine Yankee nuclear plant was made on the basis of a detailed study of 2.5 years of mature plant operation. This study is one of four by EPRI to define the factors that limit the availability of nuclear power plants. Field engineers stationed at the plant site for 18 months gathered data, which were then analyzed by computer to quantify the lost generation caused by various systems and components. Vol. 1 summarizes the analysis and presents results and recommendations. Vol. 2, in two parts, presents the appendixes. Part 1 describes the computer programs and codes used and presents detailed results of data bases on operational power outages and plant modifications. Part 2 presents detailed results of data bases on time lost during fuel shuffling, reactor coolant and cavity water radioactivity levels, plant maintenance, and refueling. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: R. E. Swanson*

Limiting-Factor Analysis of High-Availability Nuclear Plants

NP-1138 Final Report (RP894-3); $12.50

Unit 1 of the Oconee nuclear plant was used as the reference for a plant-availability limiting-factor analysis; additional information on plant outages was obtained from other plants. The operations and maintenance data were assigned to one of 48 systems and components; refueling data were assigned to one of 17 work events. Limiting factors for operation, maintenance, and refueling were calculated. Recommendations for improvements were made. The contractors are Babcock & Wilcox Co. and Duke Power Co. *EPRI Project Manager: R. E. Swanson*

Limiting-Factor Analysis of High-Availability Nuclear Plants

NP-1139 Final Report (RP894-4); Vol. 1, $8.25; Vol. 2, $12.00; Vol. 3, $4.50

Vol. 1 presents a limiting-factor analysis of Unit 3 of the Turkey Point nuclear plant. Each significant power reduction was investigated, quantified, and categorized. Results show that the major factors limiting productivity are refueling outages, maintenance activities, and problems with steam generators, the main turbine, the main condenser, and plant valves. The appendixes are given in Vol. 2. These include computer codes, a computer list of all activities performed that require shutdowns or power reductions, a table of long-term power losses, refueling data, a computer list of plant modifications, plant layout observations, and recommendations for instrumentation and analysis to diagnose long-term power losses. Vol. 3 is a supplementary report that provides more detail on productivity losses from problems with key valves. The contractor is Combustion Engineering, Inc. *EPRI Project Managers: W. L. Lavallee and R. E. Swanson*

EVAP User's Manual

NP-1190-SR Special Report (RP620); $3.50

The computer code EVAP calculates the national economic value of an advanced electric power system—the liquid metal fast breeder reactor—under conditions of uncertainty in electricity demand and availability of technologies. This user's manual describes the capabilities and limitations of EVAP, the calculation method, input preparation, and output, and it gives detailed operating instructions. Also included are references, appendixes of sample data, and a glossary. *EPRI Project Manager: Jay James*

Nuclear and Large Fossil Unit Operating Experience

NP-1191 Final Report (RP771-4); $11.25

Operating data were analyzed and summarized for 159 nuclear and large fossil generating units that are typical of units recently started up or are now being designed and constructed. Representative data are included for nuclear units through June 1978 and for fossil units through December 1977. Contributors to outages are categorized according to impact on plant performance, and the history and present conditions of major contributors are discussed. The contractor is The S. M. Stoller Corp. *EPRI Project Manager: W. L. Lavallee*

Operation and Design Evaluation of Main Coolant Pumps for PWR and BWR Service

NP-1194 Final Report (TPS78-776, TPS78-789); $4.50

This study identifies the major causes of forced outages resulting from operating problems with primary coolant pumps in PWRs and primary recirculating pumps in BWRs. The results indicate that additional analytic methods are needed to evaluate various aspects of current pump design in order to develop more reliable designs. The contractor is Energy Research & Consultants Corp. *EPRI Project Manager: Thomas Libs*

Categorization of Cable Flammability: Laboratory Evaluation of Flammability Parameters

NP-1200 Interim Report, Part 1 (RP1165-1); $4.50

Cable samples were burned in laboratory tests, and measurements were taken of smoke capacity, mass loss, and heat release rates. Three cables representing high, intermediate, and low fire hazards were selected for larger-scale fire testing. Limited qualitative correlations were made between these laboratory-scale data and IEEE-383 cable ratings, ASTM-E84 tunnel test data, and data on larger-scale tests available in the literature. The flammability parameters obtained are discussed, as well as the interaction between cable conductors and polymer insulating and jacket materials. The contractor is Factory Mutual Research Corp. *EPRI Project Manager: R. E. Swanson*

Simulation of a U-Tube Steam Generator With COBRA–IV and COBRA–TF

NP-1211 Final Report (RP1121-1); $3.50

This report describes a full-scale simulation of a Combustion Engineering System-80 U-tube steam generator with the COBRA computer code. Both steady-state and transient conditions are considered in comparing the results of the Battelle COBRA–IV homogeneous-equilibrium code with those of a newly developed two-fluid, two-phase flow model, COBRA–TF. The details of formulating code input to simulate primary and secondary flows are discussed. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: Henry Till*

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

NONPROFIT ORGANIZATION
U.S. POSTAGE
PAID
PERMIT NUMBER 7577
SAN FRANCISCO, CALIFORNIA

EPRI

ADDRESS CORRECTION REQUESTED

March 1980