Reading the Composition of Coal

ELECTRIC POWER RESEARCH INSTITUTE

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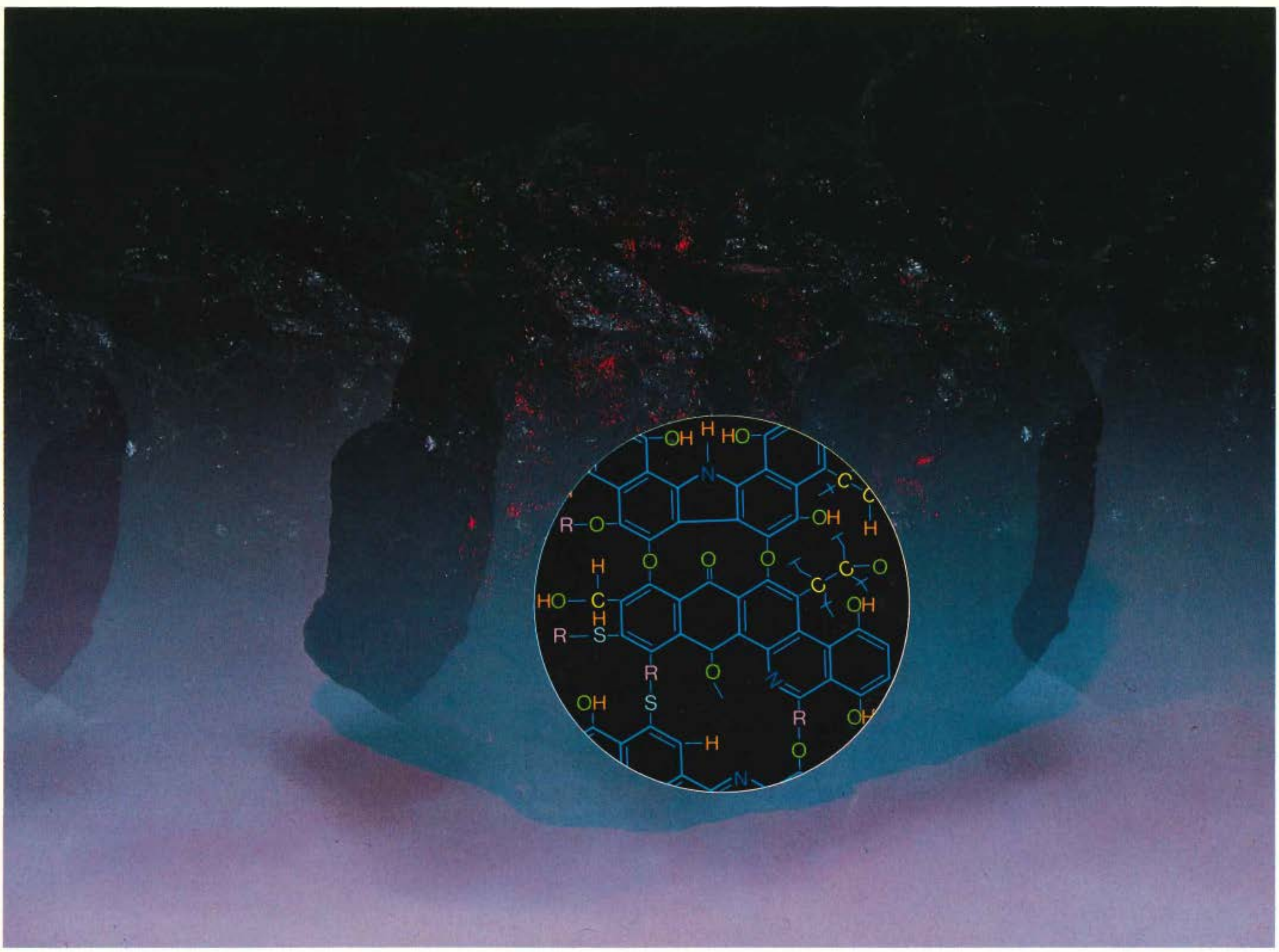

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Cover: Irradiated by a tiny neutron source, atomic nuclei in the organic molecules and mineral matter of coal emit gamma rays distinctive for each element and proportionate to its weight percentage in a constantly moving coal stream.

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Getting to Know Coal Better . . . and Faster

These are exciting and frustrating times for anyone in the energy business. Electric utilities face several hard questions for which there are no good answers, and one of these is, How will we supply electric power needs for the next 10, 20, or 30 years? It's exciting that we have several options to pursue, but it's often frustrating that so many technological, social, and political factors slow our progress.

One of our options is coal. It provides about half the electricity we generate in the United States, and it will play a large role well into the next century. Moreover—even with optimistic assumptions for commercial fluidized-bed combustion, gasification, and liquefaction of coal—conventional pulverized-coal boilers will play that role virtually alone for at least the next 10 years. EPRI's R&D planning assumes a tripling of coal-fired capacity by the year 2000. The outlook is similar elsewhere, too. At a recent energy summit meeting in Venice, representatives of the United States, Japan, and industrialized European nations called for a collective tripling of coal-fired capacity.

One barrier to greater use of pulverized coal for power generation in this country is the deteriorating quality of the coal available to utilities. Not only have average heat contents decreased and ash and moisture contents increased but day-to-day fluctuations in coal composition are getting wider, making it more difficult to operate a power plant reliably.

This month the *Journal* features a technology aimed specifically at the power plant operator's need to know quickly and accurately what is going into the boiler.

CONAC, the continuous nuclear analysis of coal, uses well-established physics in a new application: rapid analysis of moisture, sulfur, nitrogen, chlorine, ash, and ash constituents in a coal stream of up to 50 t/h. How many plant operators have shrugged cynically at the impossibility of knowing what the boiler is seeing, based on data received two shifts later from a 10-g sample analyzed by ASTM wet chemistry procedures?

We can easily see application of CONAC equipment at coal mines, at utility receiving facilities, and in coal-blending operations. In a matter of minutes, data on coal composition are available that can help in predicting slagging and fouling behavior, controlling particulate and SO_2 emissions, and even scheduling thermal outputs from individual boilers to meet dispatch demands. Because of this real-time turnaround of information, corrective actions are feasible, such as changing coal-blending ratios, combustion conditions, or boiler loads. Two prototype CONAC installations are scheduled for testing at utility plants this year and next. The potential saving in annual operating costs could be several million dollars at each plant, resulting from lower fuel costs, decreased maintenance, and higher plant availability.

George T. Preston
Assistant Director
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Authors and Articles

Coal. We talk of a huge resource, using the word as though it denoted a single fuel. But about all it really denotes is the solid form of metamorphosed vegetable matter from the geologic past. Coal isn't even always black. Small wonder that fuel technologists put an *s* on the word; and when they speak of coals, they begin to signal some of the many differences that show up from region to region and mine to mine. But they still miss the changes from seam to seam and from one truckload of Illinois No. 6 to the next.

Reading the Composition of Coal (page 6) picks up on this problem. Ralph Whitaker, *Journal* feature editor, explains why quality variations are an expensive problem as coal flows into utility boilers and introduces a new analytic technique that will deal with the problem on a minute-to-minute basis. Background for the article came from Owen Tassicker, technology manager for EPRI's Coal Combustion Systems Division.

The physics of coal and its combustion products are the basis of developments guided by Tassicker since he joined the Institute in August 1974. His work in electrostatic precipitation began while he was on the electrical engineering faculty of the University of New South Wales from 1962 to 1974. Earlier, on the faculties of the University of Singapore and the Royal Melbourne Institute, Tassicker specialized in automatic control and power systems, and he consulted with many industries and utilities. He holds bachelor's and master's degrees in electrical engineering from the University of Melbourne and a doctorate from the University of New South Wales.

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Because oil can be transported and used in so many ways (even as an international currency), it must be reckoned as a major source of **Energy for Developing Countries** (page 12). But worldwide competition for oil is fiercely inflationary, and the economic consequences in the next 10 or 20 years will depend heavily on energy choices made outside the Third World as well. Which energy fuels and technologies are truly appropriate, where, and why therefore drew the attention of a March 1980 workshop sponsored jointly by EPRI and the international energy program of Stanford University.

Science writer Jack Catron reviews some of the facts, problems, and reasoning presented by speakers and panelists, including Peter Auer, a sabbatical-year consultant to EPRI's Energy Study Center and one of the workshop organizers. Auer has been a professor of mechanical and aerospace engineering at Cornell University since 1966, and he was the founding director (1967–1974) of Cornell's Laboratory of Plasma Studies. Previously he was a research physicist with General Electric Co. for eight years, and he also worked for several national laboratories. Auer is a 1947 Cornell graduate in chemistry and chemical engineering; he holds a PhD in chemistry and physics from the California Institute of Technology.

Tassicker

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When an industrial part is cheap and mass-produced, its lifetime is often unimportant. Even when service reliability enters the picture, it's easy enough to stress a few samples until they fail and then make sure that service conditions never approach the statistical failure level.

None of this applies to the complex one-of-a-kind weldment that goes into the primary coolant circuit of a nuclear power plant. Destructive tests cost too much, and they aren't statistically representative. Overdesign of the weldment


Auer


Dau


Shula

is also costly, and even then it lacks a measurable basis. The same is true of underdesigned operating conditions. Yet service failure and its consequences are clearly unacceptable. **NDE: In-Depth Search for Flaws** (page 16) surveys the developments in nondestructive evaluation (NDE) that are gradually resolving this dilemma of cost and reliability. Nadine Lihach, *Journal* feature writer, gives special attention to NDE techniques for inspecting in situ components to gauge and schedule needs for their repair or replacement. Gary Dau, who manages EPRI's program for NDE development and applications, contributed information and insight.

Dau first came to EPRI in February 1975 as a loaned employee from Battelle, Pacific Northwest Laboratories. He had worked there since 1965, becoming a department manager with principal responsibilities in NDE, but he also devoted a year to research in nuclear waste management. He continued the latter work for 16 months at EPRI. In April 1977 he joined the Nuclear Power Division staff as NDE program manager. Dau earned a BS in mechanical engineering at the University of Idaho and a PhD in nuclear engineering at the University of Arizona.

■

Redundancy exacts a cost when power systems are designed and built, but it produces an offsetting and greater value in service reliability. Not so with redundancy in the information files of multiple data bases. Supposedly identical inputs (but from different sources at different times) are likely to vary, producing inaccurate results in the analyses that flow from the data bases.

Combining Data Base Functions (page 21) puts this problem into context. William Shula, EPRI program manager, reviews how distribution department files are linked in one integrated data base developed under EPRI sponsorship. He also discusses the centralized organization that must be responsible for effectively maintaining those files.

Before joining the Power Systems Department of EPRI's Electrical Systems Division in June 1976, William Shula had been with Texas Electric Service Co. for 27 years, including one year on loan to EPRI as a project manager. After his early field and planning experience, Shula held supervisory posts in distribution design, construction, operation, and maintenance, and for 8 years he headed distribution planning activities for the utility. He is a 1949 electrical engineering graduate of Texas A&M University.

The constituents of coal differ by region, mine, seam—and even by truckload. The effects on power plant operations a
a new analytic instrument will enable plant operators to improve boiler efficiency, reduce pollutant emissions, and veri

READING THE COM

Gasoline is uniform from one tankful to the next. Automobile engines depend on it and refinery processes ensure it. The same is true (or can be, at a price) of petroleum fuels for electric utility boilers.

The coal delivered into a utility boiler silo is another matter. It is essentially the raw product of geochemical processes over time spans up to 500 million years. Unlike crude oil, coal's many organic constituents are randomly locked in solid form and interspersed with mineral matter and strata of rock and earth. It all looks the same to an automated continuous miner as it eats into an underground seam or to a dragline as it takes another bite from an open pit.

Knowing this is not the same as dealing with it. The capital and operating costs of power generation continue to rise with inflation and compliance with environmental standards for coal combustion emissions. At the very least, there is an urgent need to analyze coal shipments so vendors know what they are selling, utilities know what they are buying, and plant operators have some advance notice of the firing properties of the coal reaching their boilers.

New apparatus for coal analysis is now maturing, and it will be available in prototype form for full-scale utility tests late this year. Its name, CONAC, stands for continuous nuclear analysis of coal, a method that blends the principles of nuclear physics with the practicalities of coal technology. Its major features are capacity, speed, and accuracy. Capacity (up to 50 t/h) does much to avoid the inconsistencies that arise from conventional laboratory analysis of small samples. Speed (30 min at most for some coal constituents) ensures that the user has analytic results before burning coal from even the smallest stockpile or silo. And since CONAC's analytic procedure does not affect the coal (a practical necessity with such a large sample size), tests can be run again, if necessary, to verify the results. Such reruns have shown a high correlation with the original test results.

CONAC is expected to play a major role in the efficient use of coal resources, while meeting increasing environmental constraints more reliably and economically. Why this is so becomes evident from a review of the properties of different coals, their practical value, and application. How this is so derives from a review of CONAC and how CONAC can be applied in the sequence of coal mining, cleaning, transport, and use.

Variations in coal

One determinant of coal quality is its heating value, which averages about 12,500 Btu/lb (29 MJ/kg). Quality is also expressed in terms of the weight percent of the coal's moisture content, which is highly variable—as low as 2 wt% or as high as 45 wt%. And it is measured by ash content (the 5–30% of noncombustible mineral matter that becomes ash when coal is burned). Specific

stly, all the way from derating to downtime. But fast readouts from
e specifications that control coal cost—all on a minute-by-minute basis.

elements are also of interest: mainly carbon and hydrogen, which is the fuel itself; sulfur and nitrogen, which become pollutants when oxidized in combustion; and oxygen.

Chemists and technicians are still unraveling this complex structure of coal. The traditional coal names, or rankings—bituminous, subbituminous, lignite, and anthracite—are based largely on age, moisture, and carbon and sulfur content. These coal rankings occur very irregularly in deposits distributed across the United States.

The proportions of various elements vary with the coal category. Bituminous coals (found primarily in the East) typically have a sulfur content between 0.7 and 4%. Lignite coals (mostly in the West) seldom exceed 1.5% sulfur. But even in one part of the country, at a single mine, the coal can vary widely over a 24-h period. For example, a coal may have a nominal 2.6% sulfur content but vary from 2 to 4%, while the heating value averaging 12,500 Btu/lb may range from 11,800 to 13,200.

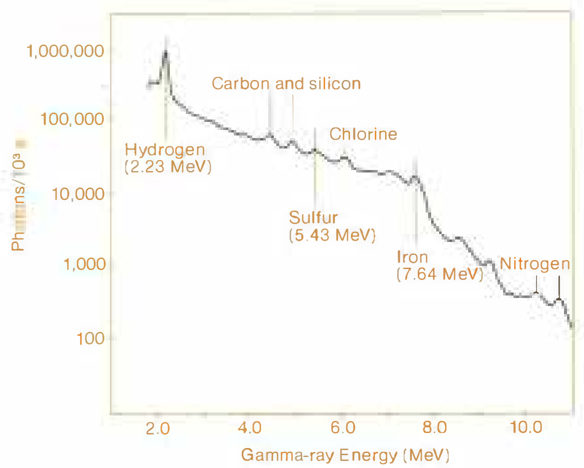
In short, nature did not leave coal in tidy packages, nor endow us with a quality-controlled product. This is awkward enough for the regulatory agencies that must set power plant emission standards. It is distinctly troublesome for the utilities and plant operators that must comply with such standards, because both thermodynamic and cost efficiencies (like emission standards) are based on the concept of a uniform fuel.

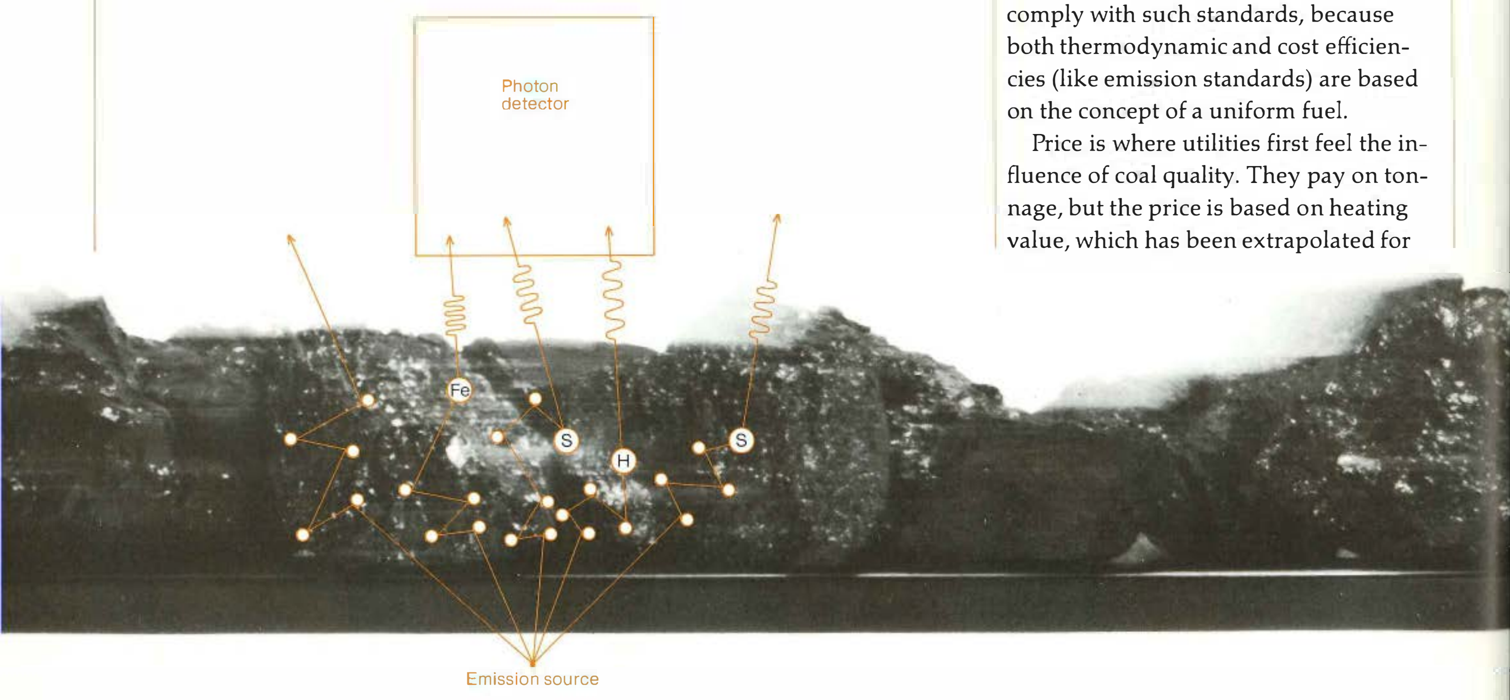
Price is where utilities first feel the influence of coal quality. They pay on tonnage, but the price is based on heating value, which has been extrapolated for

The "fingerprint" of an East Ohio coal is its distinctive gamma spectrogram (top), produced by the detection and counting of photons released from atomic nuclei in the coal as it passes over a small source of neutron emissions (bottom).

Energetic neutrons are slowed by random collisions with atomic nuclei, permitting many of them to be absorbed. This nuclear activation yields gamma-ray impulses, or photons, with energy levels that are specific for each element.

For this spectrogram, a sodium iodide crystal acts as a scintillation detector, converting the gamma photons to proportionate photons of visible light. Passed through a photomultiplier and an electronic amplifier, the photons are counted. Cumulative counts over time, derived from a moving coal stream of known flow rate, represent the percentage weights of constituent elements, singly and in various combinations. Resolution accuracy is proportional to the time interval over which counts are recorded (1000 s for this spectrogram).





many truckloads, carloads, or an entire shipment from the results of small-sample laboratory analysis that follows a lengthy ASTM procedure. The price today is equivalent to about $1.00–$1.70/10^6 Btu (depending on sulfur content, another pricing factor). Moisture content strongly influences tonnage, however. Because moisture content also varies widely, a utility may not get all the heating value it expects on the basis of small-sample tests.

Regular and rapid analyses of coal deliveries are therefore vital to cost-effective power plant operation. But for an installation such as TVA's Kingston plant (which receives as many as 600 truckloads daily from 30 or so mines), accurate and timely sampling and traditional analysis are nearly impossible.

Quality and performance

Heating value and moisture content together determine how much energy can be obtained from a coal when it is fired in a boiler and thus determine the amount of electric power derived from the generator. From burner to busbar, the performance index is heat rate, measured in Btu/kWh. Other factors of plant operation, in turn influenced by other coal properties and constituents, also affect heat rate.

Air quality standards on emissions and emission controls are major plant operating factors. The sulfur and nitrogen percentages in coal have a direct bearing on exhaust-stack concentrations of their oxides. Adjustments of fuel-air mixtures and temperatures and the use of stack gas scrubbers reduce oxide emissions, but at a penalty in heat rate and power generation cost. This penalty can be minimized by accurate advance knowledge of coal constituents and, at times, by blending high-sulfur coals (generally cheaper) and low-sulfur coals (which cost more). This is the practice, for example, at Detroit Edison Co.'s Monroe plant, and it indicates the importance of rapid sulfur analysis of the two coals used to make a blend with an acceptably low sulfur content and price.

The ash content of coal compromises plant performance because of the measures that must be taken to limit particulate emissions. There is also the cost of collecting the waste ash for disposal. Ash in large volume, diffused as fine particulate matter, is an environmental, health, and esthetic hazard.

Electrostatic precipitators or fabric filters remove more than 99.5% of all fly ash before it reaches the power plant stack; this is a necessary and accepted penalty in efficiency and cost. Fly ash is 80% of the total ash produced in coal combustion. The other 20%, most of it known as bottom ash, is routinely captured in hoppers below the boiler furnace.

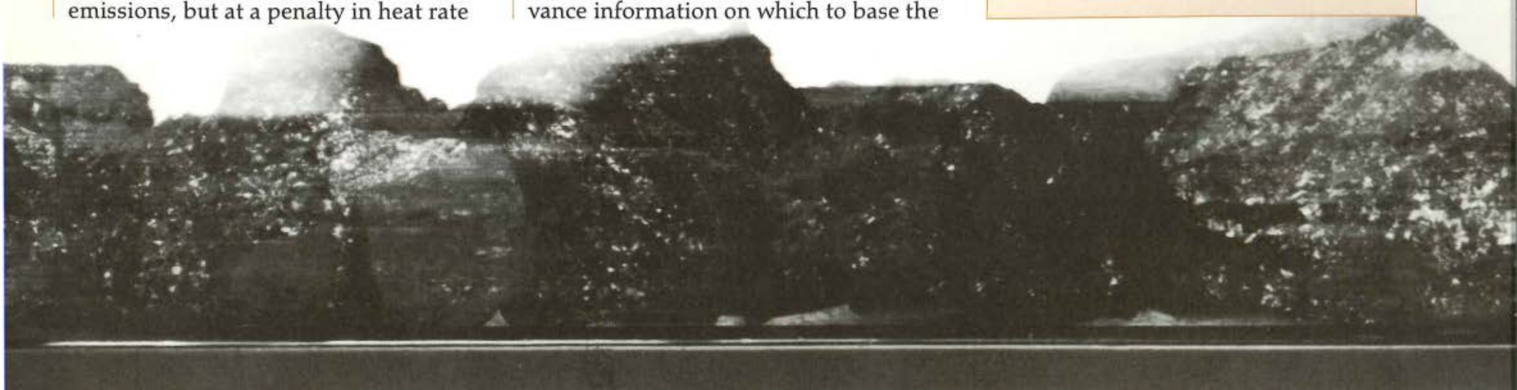
However, if a coal's mineral character suddenly changes for the worse, molten slag is formed instead of solid ash, fouling and corroding heat-transfer surfaces in the boiler. At best, the consequence is derated thermal and electric output, caused by plugging of boiler tubes; at worst, it may be a costly forced outage, with perhaps 600 t of glassy slag to be pried loose or blasted out. Variable ash is therefore a major problem for power plant operators, unless they have advance information on which to base the

DIRTY COAL: CLEAN IT OR COMPENSATE FOR IT?

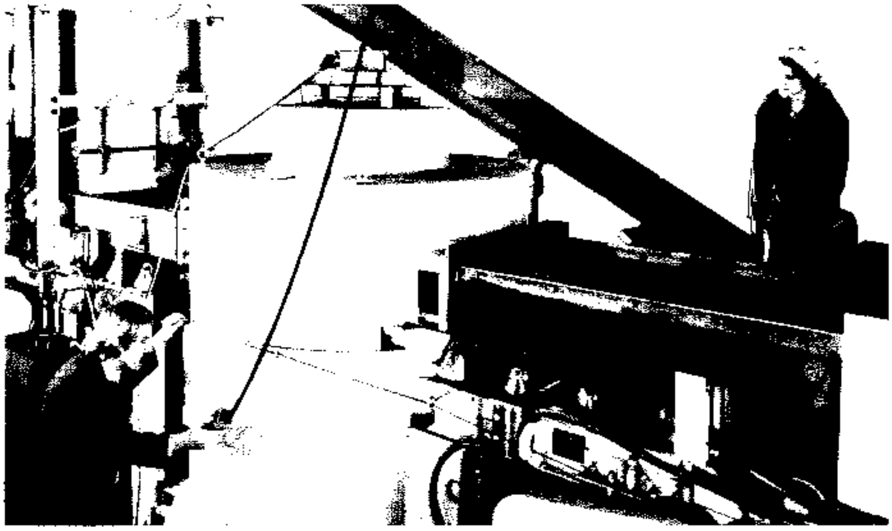
Perhaps 20% of the 500 million tons of coal mined for utilities each year (about two-thirds of U.S. production) undergoes rudimentary beneficiation to reduce the dirt and mineral ash fractions. The rest is run-of-mine. The only universal coal treatment is pulverizing to a granular consistency before the coal is blown through burner nozzles in streams of primary combustion air. Coal-cleaning techniques are being adapted and developed under utility-sponsored research (*EPRI Journal,* June 1979, pp. 7–13), but they are expensive, historically justified only in the steel industry, where consistently high-quality coal is required for coking. Until these techniques mature or become economically feasible, the coal available to utilities (or even to any one utility from a single captive mine) will remain a complex and highly variable substance.

A further aggravation today is that coal quality in general is declining. This results in part from exhausting the best reserves. It also results from economic influences that have stimulated automated mining procedures that are less costly but less selective.

In such circumstances, instruments and techniques for coal analysis, if fast enough and accurate enough, can provide coal users the insights they need to compensate for fuel variations and their effects on boiler efficiency, maintenance, and power cost.



One of the first sulfur meters to see service is this unit designed and built by Science Applications, Inc., and Kennedy Van Saun. It is now being tested at the Monroe plant of Detroit Edison Co., where coals of different cost and sulfur content are blended for economy and compliance with environmental emissions standards.



addition of excess air (with a consequent reduction in firing temperature) and the shedding of load, for which the utility's system dispatcher must compensate by calling on other units or plants.

Getting fast answers

Variations in coal quality are a fact of life, but the adverse effects can to some extent be averted if coal composition is thoroughly and accurately known soon enough. In contrast to ASTM analytic methods used to date, CONAC apparatus (and at least one other new instrument) yields more information, yields it more accurately, and in practical terms, yields it immediately.

The long-sanctioned ASTM procedures for sampling and analyzing coal are not in question because they are inaccurate. In fact, correlations between ASTM and CONAC results are generally quite satisfactory, particularly for small, discrete samples. The problem is one of adequacy in the real world where enormous volumes of coal are consumed at great rates. Here, changes in quality can outstrip the pace of methods available to detect them. The problem is accentuated by the small size of samples employed in ASTM analysis. A 2–3-g sample does not faithfully represent the 30,000 t of coal fired daily at the Monroe plant, for example. For this reason, uncertainty creeps into the ASTM test results.

ASTM analysis involves manual sampling and a tedious test sequence. This may easily take 2–3 days; in practice, with normal laboratory workloads, the time span may be 7–10 days. Further, chemical analysis destroys the test sample and findings cannot be verified quickly, even with the duplicate samples that are routinely cut from the originally submitted lot. These circumstances are now seen as shortcomings because of the sharply higher value of power plant availability, fuel economy (heat rate), and compliance with environmental standards. There is a new premium on continuous and timely analysis of coal quality.

CONAC relies on the prompt neutron activation of coal. Experiments on minerals, ores, cement, oil deposits, and coal have been conducted at several centers in the United States and abroad since the 1960s. The 1980s will be the decade of commercialization and widespread application of prompt neutron activation analysis (PNAA) in the coal industry.

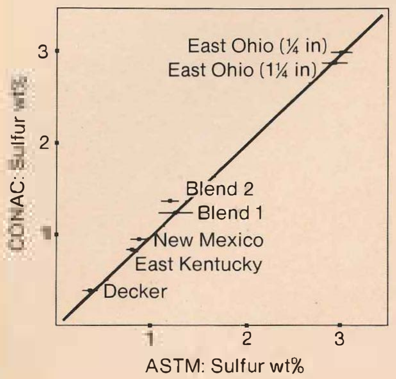
PNAA "fingerprints" coal elements by the gamma-ray frequencies emitted under neutron bombardment. For any given element, the number of emissions in a stated time span is an index to the weight percent of that element in the coal.

CONAC employs a small specimen of radioactive californium (^{252}Cf) as the neutron source. Its energetic neutrons are slowed as they bounce among the coal molecules. As they become sluggish, some are captured in various atomic nuclei. At the instant of such neutron capture, a photon of energy, a gamma ray of frequency that is distinctive for each element, is emitted.

Detection of the gamma ray is the next essential step in CONAC's operation. Sodium iodide (NaI) and germanium-lithium (Ge-Li) crystals are used, sometimes a hybrid of both. NaI crystals are large and highly sensitive, obtaining many counts in a short time, but their resolution is low. They are favored for sulfur detection. Ge-Li crystals have high resolution and thus are useful when other elements are of interest. Electronics to amplify and count gamma impulses and a microcomputer to enhance and array the data for presentation complete the unique CONAC capability.

Other sensors and detectors are also needed because PNAA identifies and measures only atomic elements, not molecular compounds. Moisture determination, for example, requires special components. CONAC correlates moisture level with the attenuation of microwaves passed through the coal stream. This permits the derivation of the moisture percentage. Heating value is a computer-derived output, based on measured amounts of carbon, sulfur, hydrogen, and moisture. (A separate generator of 14-MeV neutrons, such as a small accelerator, will be required to measure oxygen content directly; this measurement is not possible by ASTM analytic procedures. Such an MeV device is under study.)

Comparative ASTM and CONAC analyses for sulfur content reveal the consistency of CONAC analysis by prompt neutron activation technique. ASTM analyses of as many as 10 duplicate samples of several coals by different laboratories yield ranges of values for sulfur content (horizontal scale). Repetitive CONAC analyses of duplicate samples yield almost no variation in values (vertical scale).



CONAC's measurement of many elements (in addition to carbon, hydrogen, sulfur, and nitrogen) has far-reaching importance for plant operators as they seek to avoid slagging episodes. Fractions of silicon, iron, aluminum, calcium, titanium, sodium, potassium, and (with a 14-MeV neutron generator) magnesium are measured. The computer converts these to equivalent quantities of acidic silica (SiO_2) and alumina (Al_2O_3) and basic calcium oxide (CaO); it thereby calculates a figure of merit familiar to operators as the slagging index.

Putting hardware in place

The theory of PNAA techniques seems thoroughly workable for coal-fired utilities and their suppliers. The apparatus may take several forms. CONAC, sponsored by EPRI and jointly developed by Science Applications, Inc. (SAI) and Kennedy Van Saun (KVS, a subsidiary of McNally-Pittsburg Manufacturing Corp.), is the most comprehensive. A prototype unit is now being readied for TVA and probably will be installed at the 1723-MW Kingston plant early in 1981. It will be placed in a transfer house, directly ahead of a conveyor that feeds the plant fuel stockpile, and arranged for the continuous diversion of up to 30 t/h of coal for analysis and return to the main fuel stream.

A mechanically similar PNAA unit, also by SAI and KVS but simplified for sulfur determination alone, has completed its commercial acceptance tests. Known as a Nucoalyzer sulfur meter, it is now being installed at the coal-blending facility of Detroit Edison's Monroe plant and should begin operational tests this summer.

Another Nucoalyzer unit, this one to analyze coal from individual truckloads, is also being developed by SAI and KVS for TVA. It will be installed in the truck weighing and sampling section at the Kingston plant. Coal samples will be extracted from each shipment by an auger, crushed, and analyzed on a small-batch basis. During its early operation, PNAA will be paralleled by ASTM analysis to verify the correlation between the two methods.

Still another version of CONAC is being designed for routine laboratory testing of batch samples of coal (up to 100 lb). Union Electric Co. is considering such units for use at its 978-MW Sioux and 1110-MW Labadie power plants.

MDH, Inc., another manufacturer, is developing PNAA instrumentation for the 1000-MW Homer City power plant in Pennsylvania (owned jointly by Pennsylvania Electric Co. and New York State Electric & Gas Corp.). Using a NaI crystal detector, this system is expected to be in place late in 1980, with testing to begin early in 1981. (Homer City is also the site of EPRI-sponsored R&D in coal-cleaning techniques and apparatus.)

Controlling plant performance

How fast will these PNAA devices provide results? Almost instantaneously. Neutron bombardment is continuous, as is the emission of photon energy impulses at distinctive gamma-ray frequencies to be detected and counted for each coal constituent. Precision, however, demands a prescribed minimum number of impulses for computer analysis. All reported counts are rolling averages, compiled and computed over time. For some elements, such as hydrogen and sulfur, the counting time is 1–5 minutes; for others, such as sodium, it is as long as 30 minutes.

In calendar time, the PNAA tests by various host utilities should establish technical and operating feasibility, as well as reliability, within a year or two. Economic dividends should also be quickly demonstrated at Detroit Edison's Monroe plant. Systemwide benefits to utility operations will take longer to demonstrate.

As individual plant performance is more accurately tailored to the exact character of its incoming coal quality, thermal efficiency and cost economy will become more controllable on an hour-to-hour basis. Furthermore, advance analysis of fuel will permit prediction of coal-fired plant performance.

Performance is already predictable for gas-fired, oil-fired, and nuclear power plants because their fuels are uniform in quality. CONAC will bring the same prediction capability to coal-fired plants despite nonuniform fuel quality. When such information also becomes available at system load control centers, it will be possible to select the most cost-efficient energy mix at any time from among power plants of all types. This ability to select (dispatch) coal-fired plants on a par with other generating units will most effectively mark CONAC and other rapid analytic instruments as money-savers, if not money-makers, in the production of electricity from coal. ■

Further reading

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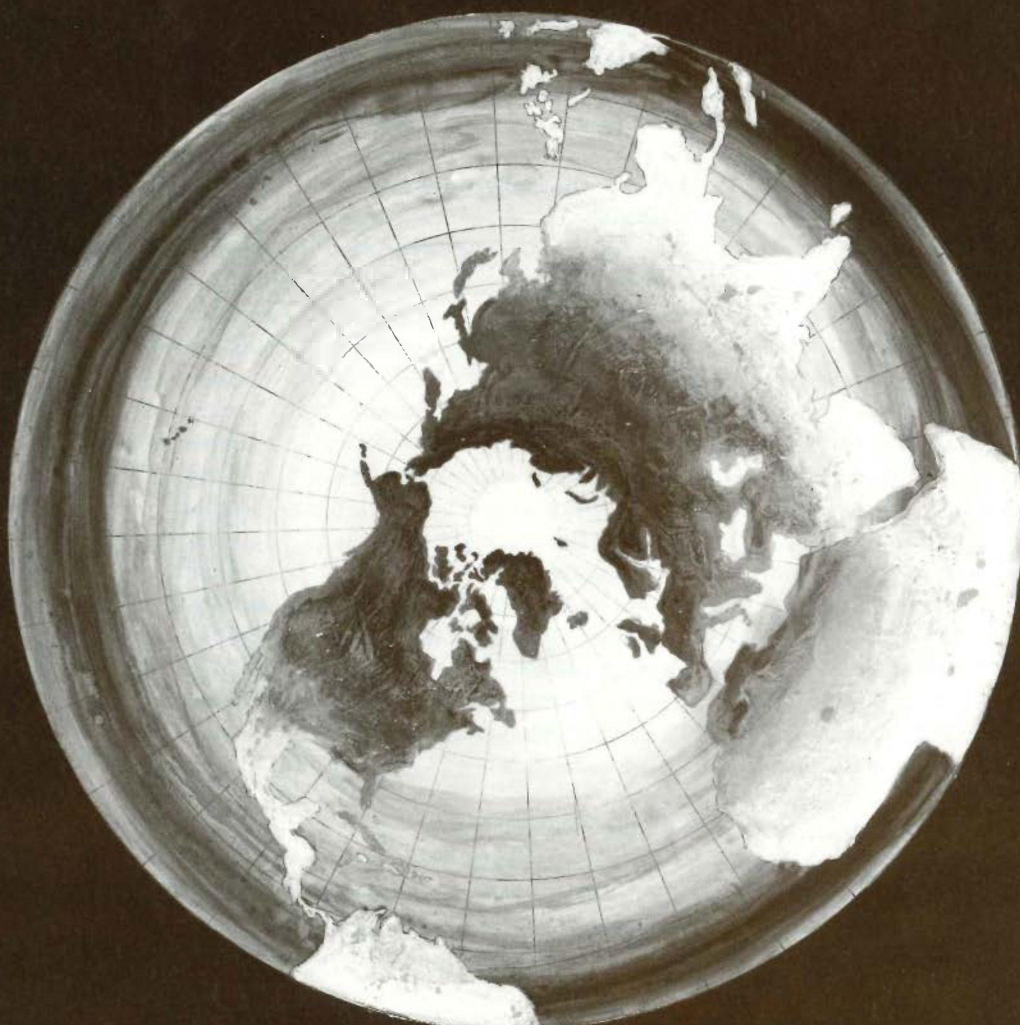
ENERGY FOR DEVELOPING COUNTRIES

The emerging industrial nations weathered the 1973–1974 energy crisis better than expected but will face new and varied adjustments to spiraling energy prices in the 1980s. This was one of the few points of consensus reached at a recent workshop on the energy problems of the Third World.



Throughout the Third World contrasting cultures lie compressed within national boundaries. A few steps along a major thoroughfare may span centuries of development. The contrasts are particularly striking in the uses made of energy. Within a few miles, a city family may be cooking the evening meal in a microwave oven, while those in surrounding villages use small kerosene stoves and tribesmen in the hills sit around open fires.

The most striking and important differences in energy use arise among the nations themselves. Some less developed countries (LDCs) have abundant domestic energy resources. Some can compete for supplies on the world oil market. But others remain at a subsistence level, relying on donated fuels and firewood.

To better understand the complex energy problems of the LDCs and the likely effect of the U.S. energy policy on them, EPRI and the Stanford International Energy Program jointly sponsored a workshop March 18–20. Entitled "Energy and the Developing Nations," the workshop was held at the Hoover Institution of Stanford University, with 80 participants and observers attending. Speakers and panelists discussed both conventional and unconventional energy supplies, changes in energy demand, and the growing problem of how poorer countries can pay their energy-related debts.

A consensus seemed to emerge among participants that LDCs had survived the energy crisis of 1973–1974 better than had been expected, but that new problems will face LDCs as they try to cope with spiraling energy prices during the 1980s. There was also agreement that the best thing the United States could do to ease energy shortages in the developing world would be to reduce its own massive oil imports. Beyond these two broad areas of unanimity, lively debate surrounded discussions of forecasts and policy alike.

Comparison of energy use patterns between the industrial countries and the LDCs is tricky. According to Lincoln Gordon of Resources for the Future, Inc., who presented the conference overview address, average purchasing power in LDCs is actually twice as large as one would expect from simple comparisons of per capita wealth at official exchange rates. He also commented that recent studies suggest traditional fuels, such as firewood, account for as much as 35–40% of total energy consumption in developing countries, and the efficiency with which fuels are used is much lower than in industrial countries.

Gordon concludes that as countries develop industrially their use of energy does intensify, but not nearly so much as previously suggested. "Levels of per capita use in the industrialized countries are almost nine times those of the developing countries, while the intensity of energy use (measured by useful energy consumption per million dollars of real gross domestic product) is about twice."

Adapting to oil prices

What happens, then, as oil prices rise? Up to a point, LDCs may be able to adjust better than industrial ones. Because their economies are not yet so energy-intensive and because of their greater flexibility in substituting labor or traditional fuels for commercial energy, LDCs have shown remarkable resilience in the face of oil price shocks. In response to the quadrupling of petroleum prices in 1973, as well as other factors, the economic growth rates of industrial countries fell from 5.4 to 2.9% a year, but those of the LDCs only declined from 6.7 to 5.3% a year.

Now, however, the ability of LDCs to adapt to further price increases may be stymied. The price of kerosene has risen beyond the reach of many low-income families. Extensive deforestation is removing a major source of traditional fuel. OPEC countries have not continued to raise their petroleum production levels. And some countries are reaching the limits of their credit. Gordon sees a "hidden development crisis" beginning as countries start sacrificing imports of the essential capital goods and raw materials needed for further economic growth.

The crunch is likely to intensify. Not only will petroleum prices probably keep rising but the volume of oil exported may well decline. Fereidun Fesharaki, a research fellow at the Resource Systems Institute of the East-West Center in Honolulu, cited several reasons why OPEC countries may cut back oil production: The original hopes of exporting countries for quick modernization and industrialization have now faded away, while those with surplus funds invested abroad have faced inflation, declining value of the dollar, and increasing insecurity of their assets. Meanwhile, political pressures are mounting in many of the countries to conserve their natural resources.

Thus Fesharaki, who was formerly the energy adviser to the prime minister of Iran and a delegate to the OPEC Ministerial Conferences, expects to see OPEC exports decline from 28.28 million barrels a day in 1979 to 22 million in 1985 and 17.29 million in 1990. Even this forecast of a nearly 40% cutback in available supplies he calls "relatively optimistic" because it assumes increasing Iraqi production, relatively steady Iranian production, and a large Saudi production.

Even if OPEC exports held constant, however, shortages of oil would arise because of increasing demand by LDCs. Robert Copaken of the U.S. Department of Energy told the conference that consumption growth rates for commercial fuels in LDCs are expected to continue to exceed those of industrial countries by 2–4% a year. This would increase their share of the total world consumption from around one-fifth in 1980 to one-quarter by 1990. Oil production by non-OPEC countries may increase, according to Copaken, but exports will again be limited by the rate at which producer countries can absorb financial surpluses. One problem is that the social infrastructure needed to run a modern state takes time to develop. "You can build schools overnight, but you can't raise literacy overnight."

The impact of higher energy prices and potential shortfalls on the world economy will be exceedingly complex. Jean Louis Waelbroeck of Université Libre de Bruxelles commented that in the past the result has been an international tug of war to reduce the effect of expensive oil by inflation and devaluation. "This is a game that countries have played with much gusto in recent years," he said. "The slide of the dollar, for example, has wiped out debts that greatly exceeded the foreign aid given by the United States since the war."

But such tactics cannot be continued indefinitely, Waelbroeck warned. "The result is a vicious circle of inflation, which appears to multiply by several fold the initial impact of energy prices." On the other hand, the amount of funds removed from circulation by OPEC countries has the effect of reducing the world's volume of economic activity. Next year, according to Waelbroeck, this reduction of funds will be about 1% of world GNP and thus make a powerful contribution to global recession.

Individual countries will feel the effects of this cycle of inflation and recession according to their own domestic resources and their position on the scale of development. Bijan Mossavar-Rahmani of Rockefeller University believes non-OPEC LDCs should be considered in three groupings: 14 net exporters of oil, 9 large importers, and 72 with net imports of less than 100,000 barrels a day.

The status of the first group, which includes such countries as Oman, Brunei, and Mexico, is clear. Higher oil prices not only have increased their income but have enlarged their effective reserves by making previously inaccessible fields commercially viable. The second group consists mainly of countries that have already become partially industrialized and have commercial loans available to finance further energy purchases (for example, Brazil). The majority of countries in the third category have per capita GNP levels of less than $400 a year, and many are experiencing increasing difficulty in financing petroleum imports. Because of such different abilities to obtain energy, Mossavar-Rahmani concludes that the gap between the world's richest and poorest countries is likely to increase.

This point was made in a slightly different way by Alan S. Manne of Stanford University, co-organizer of the conference. Based on modeling studies that separate LDCs into various groups, he concludes that the oil-importing LDCs will be more seriously affected than industrial countries by higher prices and declining supplies of petroleum. If energy supplies grow by 3.3% a year, industrial countries could reach their full potential GNP growth through 1990, with non-OPEC LDCs achieving 94% of their potential. But if supplies grow by only 1% a year, industrial countries could still maintain 95% of their economic growth, while non-OPEC LDCs would be limited to 83% of their potential.

How much individual countries can mitigate such negative impacts by adopting better energy policies became a subject of intense argument at the conference. Helen Hughes of the World Bank took the optimist's position that the main factors influencing an LDC's economic future would be its own decisions on how to use energy and expand trade. By acting quickly to allow their economies to adjust to rising oil prices, while avoiding ideological extremes, many LDCs were actually able to benefit from past price increases. And if political breakdown of the Middle East can be avoided, she believes that LDCs can continue vigorous development.

Countries that will suffer will not necessarily be those with high debts to pay for imported oil, according to Hughes, but rather those with few exports to help pay off the debt. Debt service as a percentage of total exports has held fairly constant for LDCs as a group during the 1970s, and it can continue to remain stable through the 1980s provided political disasters can be avoided.

A contrasting and far more pessimistic point of view was offered by David A. Deese of the Center for Science and International Affairs at Harvard University. Again looking at the oil-importing LDCs, Deese notes that the majority depend on foreign oil to meet 90% or more of their needs for commercial energy. It is precisely these countries, rather than the Middle East oil producers, that show the greatest potential for disrupting international security. And instead of expecting the growth of international trade that Hughes sees as imperative for further peaceful development, Deese believes that the current economic squeeze may lead to another round of protectionism.

To centralize or not?

Of the policy decisions facing LDCs as they try to counter rising oil prices, perhaps none has gained more attention or become more controversial than the choice between centralized and decentralized energy systems, particularly those based on renewable resources. Several speakers explored various aspects of this difficult question.

The association of renewable energy resources, such as solar power, with a decentralized energy delivery system is a natural one, according to José Goldemberg of the University of São Paulo, Brazil. And "the attraction of a long-lost bucolic life exerts, of course, a strong attraction in the minds of many proponents of this soft path." But the fact is that for the half of humanity inhabiting the rural areas of LDCs, life is generally "very difficult, unhealthy, and full of hard work and drudgery." As a result, there is great pressure in LDCs for urbanization, for life in a slum often represents a substantial improvement over rural subsistence.

Goldemberg thus concludes that a policy of building decentralized energy sources might improve rural living conditions, but it does not enjoy a clearcut advantage over a policy of encouraging urbanization and centralized energy. In either case, more energy is definitely needed to improve standards of living. "Although city dwellers usually use more energy than villagers, this does not mean that rural life is less energy-intensive than urban life. It merely illustrates the fact that most villagers lead a miserable life, consuming little more than is needed to stay alive," he said.

The real question, according to Goldemberg, is how much of an LDC's energy needs can be supplied through the use of domestically available renewable resources, whether these are decentralized or not. Most LDCs, he believes, can achieve significant gains in this direction. Renewable resources accounted for 35% of energy consumption in 1975 and will probably grow a few percent by 1995, with inefficient technologies being replaced by modern methods of using solar energy and other sources.

The identification of decentralized energy systems with renewable resources as the best policy option for LDCs has already led to some spectacular failures. "Anyone who has lived or traveled outside the cities in the Third World has seen the ruins of biodigesters or the skeletons of windmills long since abandoned," said James W. Howe of the Overseas Development Council. To succeed, rural energy programs must be introduced with the full cooperation of the villagers who must use the equipment and keep it repaired. The challenge can be met, but a time-consuming process of building educational services and support networks will be needed, just as it was in the agricultural programs of the last decade.

A case study of how one LDC is introducing energy conservation and renewable resources was presented by Lee Schipper of the Lawrence Berkeley Laboratory. In work sponsored by the Beijer Institute of Stockholm, Schipper studied the complex mix of traditional and commercial energy resources in Kenya. He learned that three-quarters of the energy used in Kenya is from wood and charcoal, but government policy is now aimed at conserving wood for other purposes. Because of such policy decisions and the increasing scarcity of traditional fuels, he found that a major tire manufacturer has just hired an engineer to find ways of reducing process energy use, most new office buildings in Nairobi have elaborate shading systems to keep direct sunlight off windows, and a solar equipment manufacturer reported that business was booming, with orders from a school, a hospital, and a condominium soon to be completed.

China, on the other hand, provides an example of a rapidly industrializing country vigorously exploiting energy-intensive development. The supposed Chinese model of decentralized energy systems based on methane biodigesters and tiny hydrogenerators has now been largely abandoned, according to Thomas Fingar of Stanford University's U.S.-China Relations Program. "Coal, petroleum, and electric power have emerged as areas of preeminent importance," he reported. Government credibility suffered from the failure of the biogas generators, so now "China's leaders and economic theorists are extolling the importance of economies of scale and the need to build a conventional energy system."

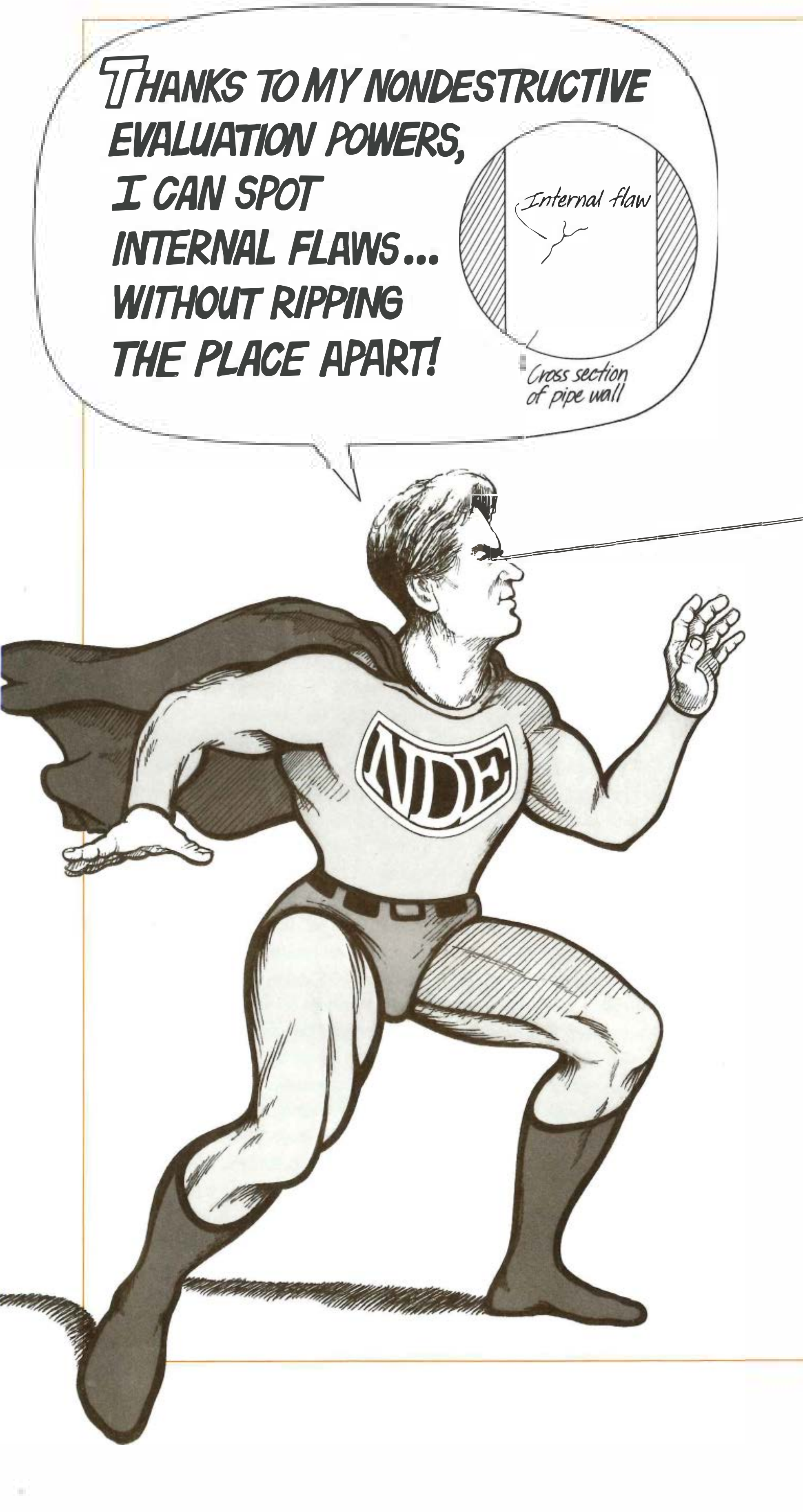
Although small, decentralized energy systems may help rural development, they contribute little to national economic growth as a whole, EPRI Vice Chairman Chauncey Starr told the conference. If capital is severely limited, as it usually is among LDCs, the best return on investment will come from centralized energy sources, coupled with a policy of urbanization. Small systems can then be used primarily to make rural life more tolerable until an urban industrial infrastructure has been developed.

Starr concludes that any energy development strategy of LDCs must be linked to a program of technical leadership and energy conservation by the industrialized countries. By using such high-technology sources as nuclear energy, the technically advanced and capital-rich nations can minimize resource competition with LDCs.

This theme was elaborated during an interview with Peter Auer, a professor at Cornell University who is on sabbatical at EPRI and a co-organizer of the conference. Auer commented that the reason the conference was organized was the interest in the growing interdependence of the United States and LDCs on all matters concerning energy. "How we behave in the world oil market affects them and vice versa."

An underlying theme of the conference was to give an international dimension to policy decisions affecting energy problems. "It would do no good for us to try to find a general solution for the developing world. Rather, American strategy must include a new partnership with LDCs to help them develop their energy resources, while we try to reduce our own dependence on imported oil. In particular," he said, "the United States must avoid trying to develop energy technology for developing countries at home and then hope to market it abroad —appropriate technology must be a joint venture."

As several speakers observed, far more is at stake in this partnership than industrial development among the LDCs or continued economic growth among the technically advanced nations. International stability is also involved. The lack of a coherent policy for reducing oil imports on the part of the American government came in for particular criticism at the conference. One point of general agreement seemed to be that U.S. policy has not allowed the market to reflect the cost of oil imports accurately enough to force a large reduction in oil consumption. What effect this lack of action may have on the stability of countries struggling to obtain energy for economic development remains to be seen. But the bottom line of conference discussion was quite clear—energy for development is also energy for peace. ■



Across the United States, technicians regularly probe nuclear power plants with ultrasonics, X rays, eddy currents, and other nondestructive diagnostic tools. Their quarry is any flaw in any welded joint that might affect the plant's integrity and, consequently, its safe and economic operation.

The flaw information that this examination reveals, together with other information on stress, temperature, and materials properties, is factored into fracture mechanics analyses. The results of these analyses tell engineers whether a component should be run, repaired, or retired. If this nondestructive evaluation (NDE) process shows repair is unnecessary, the plant can resume operation. If repair is required, it can either be done immediately or, if deferrable, scheduled for a later, more convenient outage.

Without NDE to alert engineers to potential problems, a utility has almost no choice but to repair component failures as they happen. The penalty is unexpected outages—repairs at these times cost far more than repairs made at scheduled outages because of the increasingly expensive cost of replacement power. While NDE can be used at any power plant, there are legal reasons for its use at nuclear power plants: NRC regulations and ASME standards demand periodic in-service inspection of welds in pressure vessels, pipes, valves, and other components subjected to the high pressures and temperatures of the nuclear power plant's primary coolant system.

There are obviously strong economic, safety, and regulatory reasons for NDE at nuclear power plants. Although nondestructive component examination has been greatly improved over the past several years, further research is warranted to improve NDE's efficiency and lower its costs. Ultrasonic signals, for example, can be misinterpreted by even a skilled operator. X rays of plant components can take hours to complete, and heavy radiography equipment can be difficult to maneuver within the confines of a power plant. Further, experienced NDE technicians have been in great demand and short supply ever since the advent of product liability lawsuits in various industries created a need for their skills.

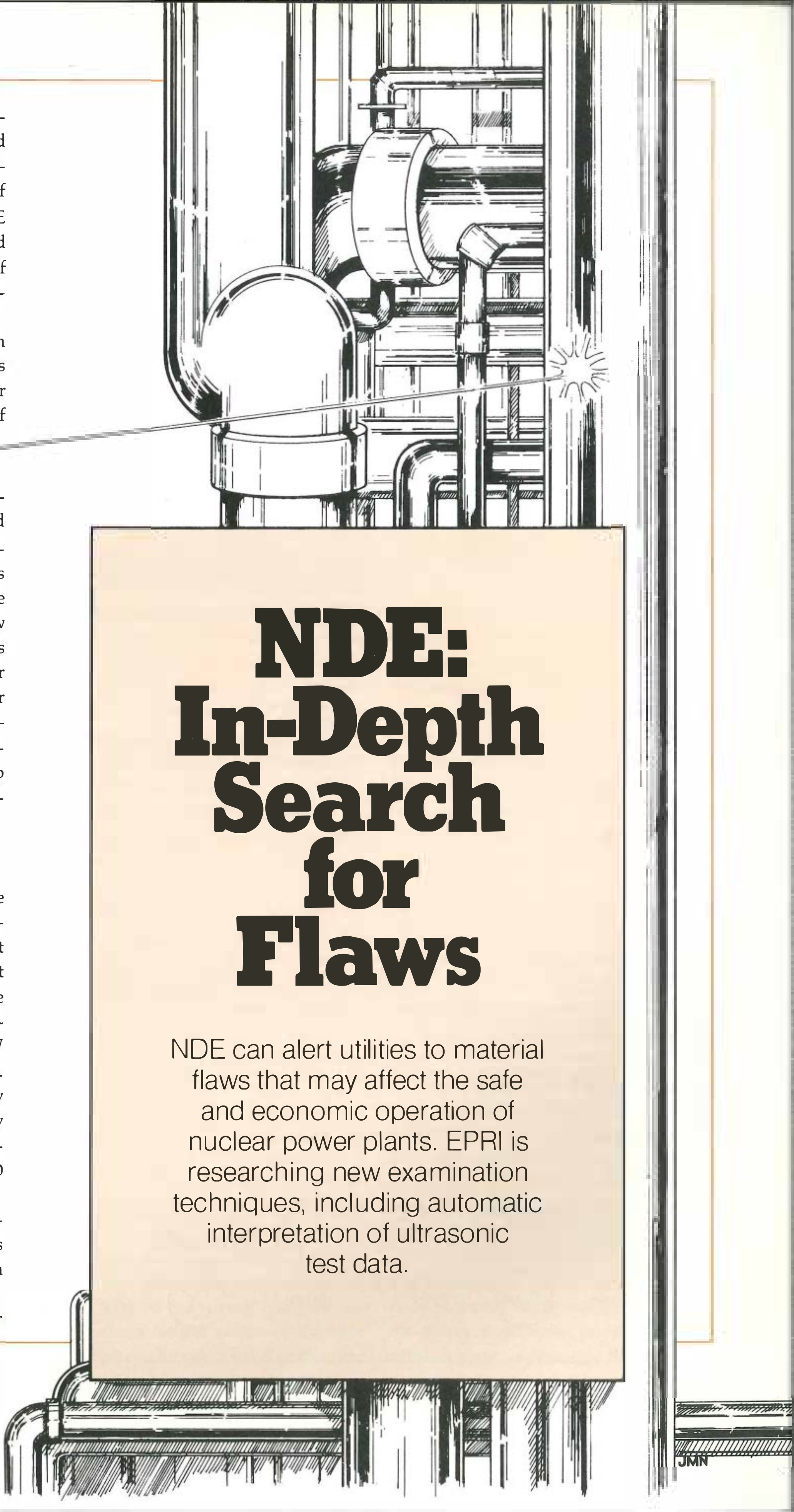
With these and other limitations in mind, the NDE program within EPRI's Nuclear Power Division is searching for improved NDE techniques and ways of developing well-trained NDE technicians. The technology is being expanded in several directions—hardware necessary for inspection and data analysis is being perfected; software to guide the hardware is being developed; flaw samples to verify inspection techniques are being fabricated; an NDE center scheduled for completion late this year will ensure that field-qualified equipment gets out to the utilities; and training programs at the center will develop skilled technicians to operate the equipment.

Incentives for better NDE

Program Manager Gary Dau explains the arithmetic behind EPRI's research: If better inspection techniques can prevent just one day of outage during one year at a nuclear power plant, that plant can save an average of $25/MWh (e) in replacement power costs alone. For a 1000-MW plant, this amounts to $600,000 a day. Multiply that by the approximately 50,000 MW of installed nuclear capacity in the United States today, and the electric utility industry can save about $30 million in just one year.

"In the past," comments Karl Stahlkopf, head of the Systems and Materials Department, "replacement power from oil was not a big consideration."

"But today," notes Division Director



NDE: In-Depth Search for Flaws

NDE can alert utilities to material flaws that may affect the safe and economic operation of nuclear power plants. EPRI is researching new examination techniques, including automatic interpretation of ultrasonic test data.

Milton Levenson, "as the cost of oil climbs ever upward, the cost of replacement power is a completely new incentive."

"If NDE is properly administered, it doesn't cost money; it saves money," concludes Robert Zong, NDE subcommittee chairman of EPRI's Nuclear Systems and Materials Task Force.

Better NDE techniques and better-trained technicians can not only save replacement power dollars but can also reduce personnel exposure to the radioactive portions of a nuclear power plant. When an inspection procedure is streamlined and a technician is trained to do exactly what needs to be done, the number of man-hours required for the inspection is reduced, according to David Gaines, another member of the NDE subcommittee.

Recent advances in computer technology and fracture mechanics analyses coincide with the push to improve inspection techniques. The microprocessor revolution of the past few years has made available increasingly efficient, inexpensive, fast, and lightweight equipment to facilitate in-field data analysis and interpretation of such inspection techniques as ultrasonics and eddy currents. With portable electronic equipment, technicians, who up until now have had to rely on manual analysis and interpretation of inspection signals, can use computer-aided systems to identify flaw characteristics instantaneously and more accurately.

The accuracy of fracture mechanics analyses has also advanced considerably in recent years, enhancing the effectiveness of NDE inspection, according to Stahlkopf. Until the recent development of improved fracture mechanics techniques, fracture analyses tended to be overly conservative because the behavior of flaws under such operating conditions as high pressure, temperature, and stress was imperfectly understood. As a result of these conservative analyses, some plant equipment was needlessly replaced or repaired. But engineers can now factor actual operating conditions into their analyses and thereby maximize equipment lifetime.

Automation

Perhaps the most critical area of EPRI's NDE research is automatic interpretation of ultrasonic and eddy-current test data. Ultrasonics are routinely used for testing pipes and pressure vessels; eddy currents, which cannot penetrate to the same depths as ultrasonics, are used to inspect steam generator tubing. Interpretation of inspection data is now done by well-trained, highly experienced technicians. But the ability of technicians to interpret the large amounts of complex data that ultrasonic or eddy-current examinations generate is not as comprehensive and rapid as that of electronic equipment.

An ultrasonics technician searches for flaws by moving a transducer in a back-and-forth motion across a weld. The transducer emits high-frequency sound waves that travel through the component being inspected. When the waves encounter a flaw, the amplitude of the reflected waves change. The technician studies these changing signals as they appear on an oscilloscope and interprets them in terms of flaw location, size, and characteristics. But signals can be easily misread. Stainless steel, for instance, is characterized by large grains whose return signals can mimic those of flaws. Electronic interpretation of these data can provide a much more detailed evaluation than is possible by operator interpretation.

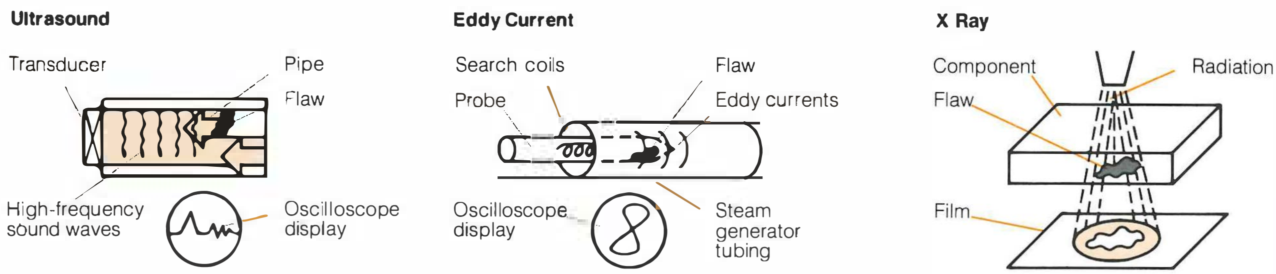
Eddy currents pose a similar problem. Generated by an alternating current in a

Today's Examination Techniques

Ultrasound is used to inspect pipes and pressure vessels. A transducer emitting high-frequency sound waves is moved back and forth across a weld. The waves travel through the weld, and when they encounter a flaw, the amplitude of the reflected wave changes. The technician studies the signals as they appear on an oscilloscope and interprets them for flaw information.

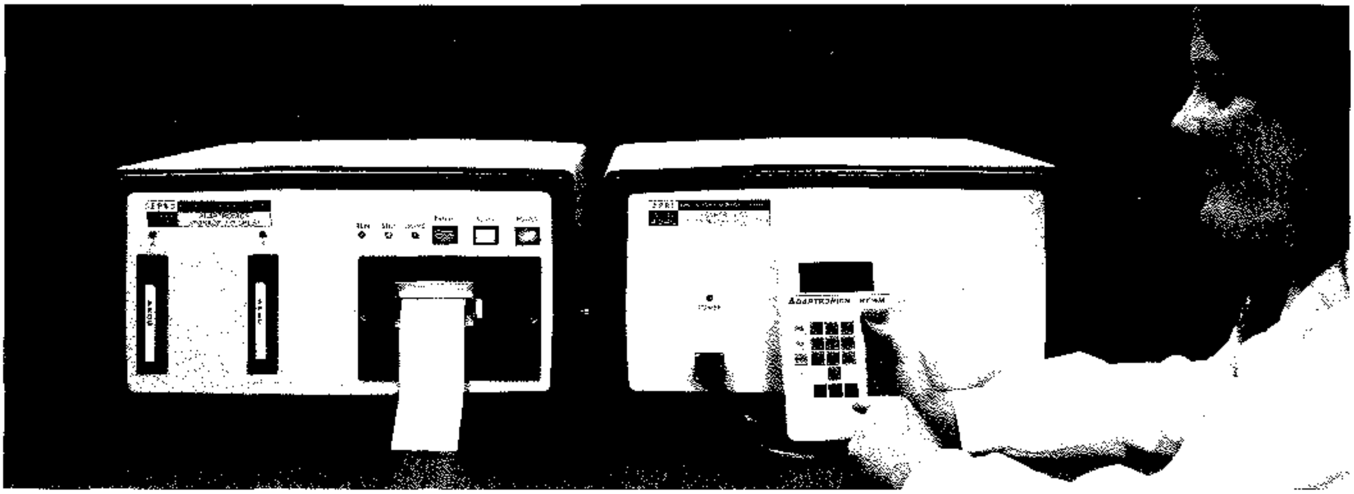
Eddy currents are used to inspect steam generator tubing. A probe with search coils is inserted into the tubing; an alternating current flows through the coils, and this alternating current induces eddy currents in the tube. The eddy currents in turn induce a voltage across the coils. Any change in eddy currents caused by a flaw alters the voltage. The technician observes voltage signals on an oscilloscope for flaw information.

X rays are useful for detecting certain types of flaw, but because of present equipment limitations, this technique is used mainly to confirm findings made by ultrasonics. To X-ray plant components, penetrating radiation is beamed through the material in question, and the images of flaws appear on film.



Tomorrow's Examination Techniques

Today's NDE technician studies the ultrasound or eddy-current signals on an oscilloscope and interprets them in terms of flaw information. A device developed by EPRI and Adaptronics, Inc., will not only perform ultrasound and eddy-current inspections but will also analyze and interpret the data from those inspections, thereby providing a more accurate and rapid inspection. The system is composed of two microprocessors; the first controls a mechanical scanner that guides the transducer; the second analyzes and interprets the resulting data. A readout tape sums up flaw location, size, and other information for the technician.



probe, eddy currents flow through the material, and flaws register as pockets of resistance. Again, the technician does his own interpretation of return signals; in this case, voltage and current fluctuations. And again, nonflaw conditions, such as changes in geometry, can be misinterpreted as flaws.

EPRI and Adaptronics, Inc., have developed a system that can not only perform ultrasonic and eddy-current inspections, but can also analyze and interpret the data from those inspections, thereby providing a more accurate and rapid inspection. This system consists of two microprocessors. The first controls a mechanical scanner that moves the transducer to gather data; the second microprocessor analyzes and interprets those data. With appropriate modifications, the system can be put to work in either ultrasonic or eddy-current inspections.

Data acquisition and interpretation instructions for this system are now being developed for three applications at nuclear power plants: ultrasonic inspection of BWR feedwater nozzles; ultrasonic inspection of stainless steel pipe welds; and eddy-current inspection of steam generator tubes. A pattern-recognition technique called adaptive learning is used to train the microprocessor to recognize important flaws. To do this, signals from sample flaws of known dimensions are recorded and analyzed, thereby establishing guidelines for identifying each signal. When these guidelines have been established, the relative importance of each new flaw discovered is determined by comparing the new flaw with the known flaw data.

The sample flaws that the adaptive learning technique is based on occur infrequently at power plants, so researchers must fabricate many of the flaws they base their work on. In the past, saw-cuts and machined notches served the purpose, but today's research demands samples grown under real stress and corrosion conditions. Accordingly, EPRI contractors (including General Electric Co.; Battelle, Pacific Northwest Laboratories; and Ishikawajima-Harima Heavy Industries Co., Ltd.) have developed a variety of flaw-growing techniques. Corrosion in stainless steels is duplicated by the application of a chemical solution to a component, according to M. E. Lapides, project manager. Mechanical stress can also be applied for a more complex defect. Thermal fatigue cracks of the type that have been found in BWR nozzles are simulated by using gas heaters on one side of a nozzle and then cycling cold water through the nozzle every 30 seconds for as many as 20,000 cycles. Samples such as these provide a good data base for EPRI's new inspection system.

While this advanced inspection system is being perfected, EPRI is developing a simpler signal-processing device for more immediate ultrasonics applications. A technician equipped with this portable device performs his usual inspection, moving the transducer himself and watching the oscilloscope for important signals, according to Lapides. But the technician can augment his own judgment with analyses from the portable unit.

X rays are another vital focus of EPRI's NDE research. Although X rays are useful for detecting specific types of flaws, they have certain limitations and are today used mainly to confirm findings made by ultrasonics. A powerful radiation source is required to overcome a nuclear power plant's background radiation and to penetrate dense components, yet such powerful X-ray equipment can be too heavy and bulky for practical use within a plant. Lightweight X-ray sources must therefore be used, but because these sources are less powerful, exposure times are extended (sometimes to several hours) and undesirable personnel exposure to background plant radiation is extended as well. Through contractor Schoenberg Radiation, Inc., EPRI is developing a high-power, lightweight X-ray source. The X-ray mechanism of this portable source weighs only 150 lb (68 kg), compared with 3000 lb (1.36 Mg) for a conventional source with equivalent strength. The new equipment will be able to X-ray plant equipment in minutes, minimizing personnel exposure to plant radiation. Laboratory tests have already been successfully conducted on a prototype, and field tests will begin by the end of 1980.

While ultrasonics, eddy currents, and X rays account for most of the NDE at power plants, EPRI researchers are also delving into other promising inspection techniques. Optical inspection, for example, is an alternative way to detect surface flaws that may be invisible to the unassisted eye. In one optical technique, light is shone on the surface to be inspected; the light reflected is measured in terms of electric signals. Surface discontinuities that may indicate flaws reflect light at different intensities from the rest of the component's surface.

EPRI and Science Applications, Inc., are currently researching a diode-array imaging camera that will measure these differences in signals. This camera might also be used in conjunction with dye penetrants, yet another optical inspection method for surface flaws. Liquid penetrants containing dyes or fluorescent materials are applied to a prepared surface; capillary action draws the penetrant into any surface flaws. The penetrant is then wiped off, and a developer applied. This developer lifts the penetrant from the flaws for the technician's interpretation.

Dye penetrants, however, are messy and require considerable surface preparation before the penetrant can be applied. If water alone is applied to the surface instead of a dye penetrant, according to Lapides, the water should reflect light back to the camera at different wavelengths wherever there is a surface change, enabling the technician to identify a possible flaw. Colored filters might enhance the effect.

Although today's inspection techniques seek out existing flaws, future techniques might be able to detect flaws as they occur because high-frequency sound waves are given off as a flaw grows. Sensors mounted on a component can pick up these acoustic emissions on a continuous basis, and technicians could thus be alerted to flaws as they develop. But the problem here, as explained by Dau, is that researchers don't yet know how to interpret the resultant sound waves. Researchers at the National Bureau of Standards (NBS) are now striving to understand the physics behind these signals and hope to develop formulas that will express the relationship between the emitted acoustic energy and the flaw. Meanwhile, through a four-year joint effort with NBS, sensor calibration techniques have been developed so that acoustic emission data gathered with different equipment in different laboratories can be compared easily.

NDE Center

The EPRI NDE program doesn't stop at research into diagnostic techniques. "Having a report on a bookshelf doesn't do a utility much good," says Dau, "nor does a prototype in a laboratory have much practical value. Utilities need field-ready equipment and procedures and trained technicians." EPRI's NDE Center, now under construction at University Research Park, Charlotte, North Carolina, and scheduled to open its doors in late 1980 with a professional staff of about 30, should provide that essential capability.

At the center, the results of EPRI research will be translated into equipment and procedures that utilities can use in the field. Here, researchers will quantify the performance of inspection systems; modify prototype systems for field use; evaluate inspection systems on full-size plant components; and develop the performance data bases necessary for realistic inspection requirements.

The center will also train technicians to use the new equipment and procedures. "Much of this training will consist of applying NDE techniques to full-size mockups, components, or even specimens with service-induced defects," points out Dau. During training, real-life constraints of limited access and radiation exposure will be simulated. Once technicians perfect their inspection techniques at the center, costs and radiation exposure on the real job should be reduced.

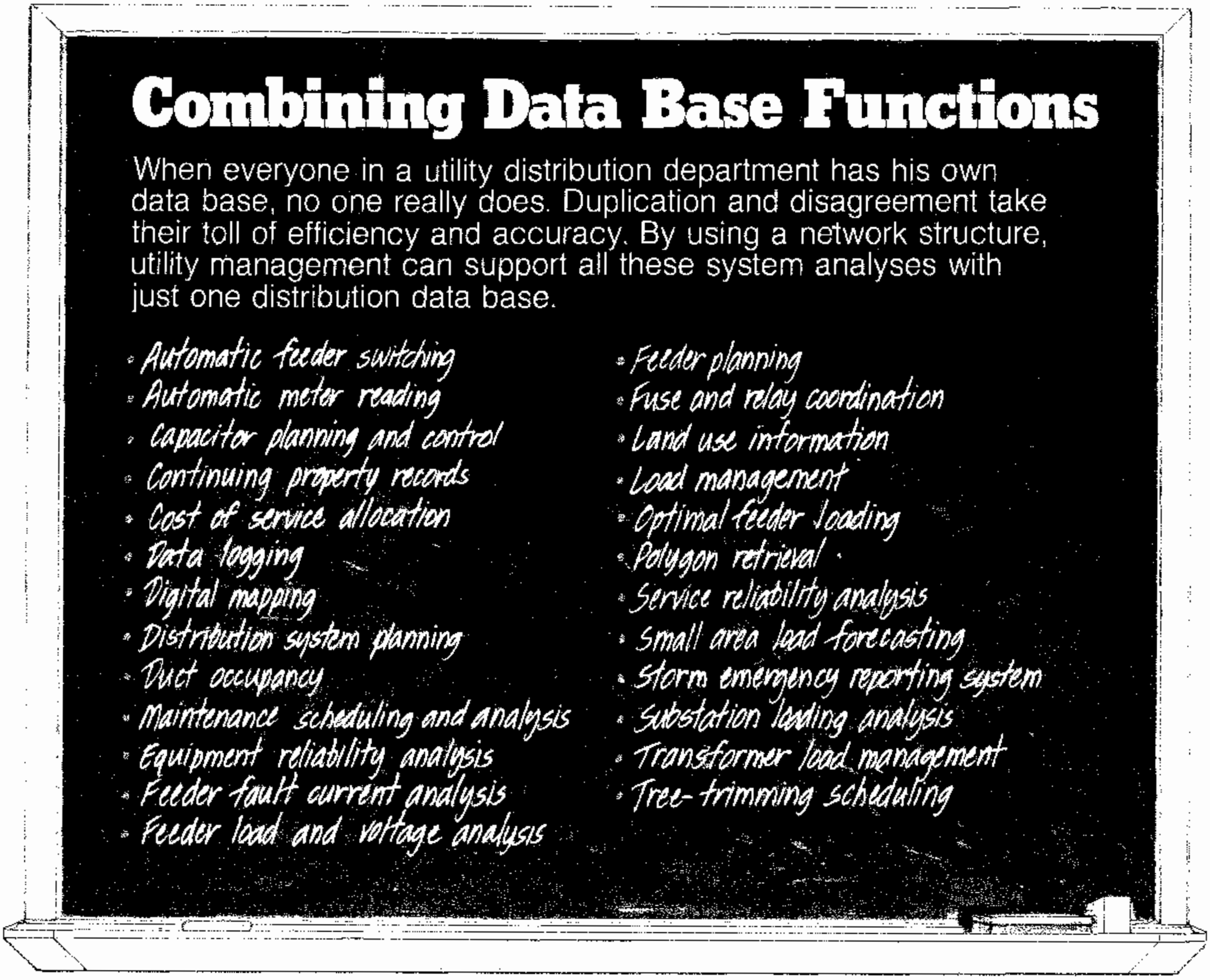
Human resource development is another of the center's priorities. The supply of qualified technicians in this relatively new field is limited, and the shortage is expected to increase with time. Most utilities now rely on contractors to provide NDE technicians at inspection time, and as the demand for NDE technicians grows, the utility industry may have to compete with other industries for the available talent.

To help solve the problem, the center plans to encourage colleges and universities to educate candidates for NDE careers with specific emphasis on power plant inspection. The exact way to accomplish this is still in the planning stages, according to Dau, but the center will work with interested schools to devise appropriate programs.

The savings in replacement power, scheduling convenience, and personnel radiation exposure that EPRI's NDE program can provide go beyond the primary coolant system in nuclear power plants. Regulatory requirements are an incentive for NDE in that area, but improved NDE can benefit other parts of the nuclear plant, and certainly other types of power plants as well. And EPRI results are sure to have application in other fields, such as the pipeline and aerospace industries. More and more, engineers are finding out that the extra effort of NDE can pay off handsomely.

Combining Data Base Functions

When everyone in a utility distribution department has his own data base, no one really does. Duplication and disagreement take their toll of efficiency and accuracy. By using a network structure, utility management can support all these system analyses with just one distribution data base.



by William E. Shula

Charged with the operation and maintenance of systems that are constantly expanding, utility distribution engineers and managers more than occasionally wish things would slow down. Then they could get ahead of the game—give more attention to forecasting, look even further ahead (and more accurately) at the alternatives for system additions, do more reliability analyses to avoid at least some of the outages, or even map the system with timeliness and precision.

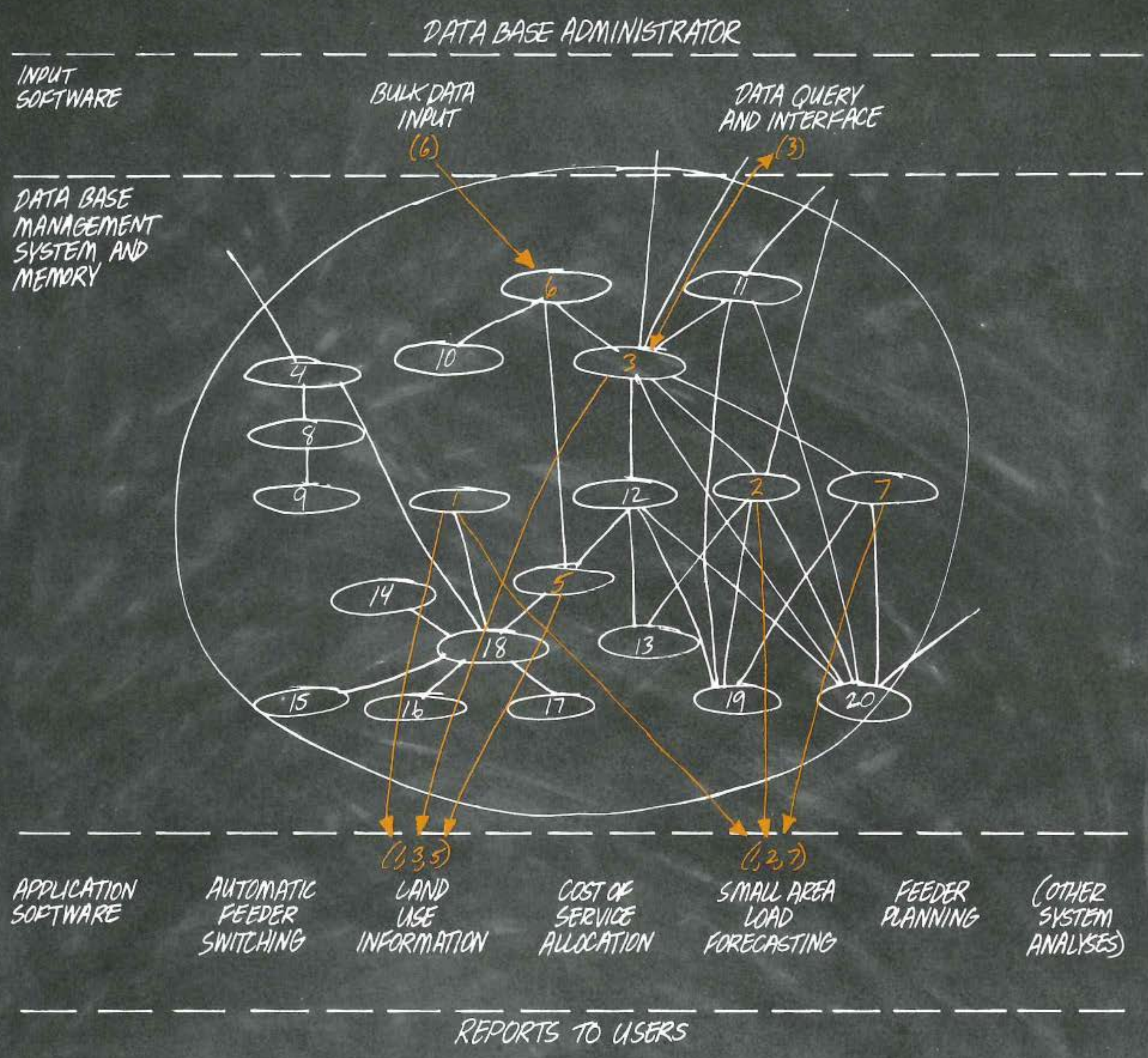
"Someday we've got to get organized," runs the resigned comment. Certainly most distribution engineers would agree on the value of an organized body of system data. This, by definition, is a distribution data base. Furthermore, if computerized, it could be the single up-to-date source of information on any component of an entire distribution system at the press of a button. It would provide what people expect of computers: accurate, quick, and convenient information at relatively low cost. The computer could also be programmed to analyze maintenance needs, fuse and relay coordination, transformer loading, feeder voltage profiles, and optimal schedules for tree trimming. The list is endless.

But where to start? How does one go about compiling an inventory of more than 10,000 items per square mile, much less arranging it electronically and logically so it can respond to even the 20 or 30 most important management needs? Such a data base must be more than responsive; it must be flexible (looking to the future), easily accessed, frequently updated, and most important, reliable.

These needs were recognized over two years ago, when EPRI funded a 20-month project for development of a generic dis-

Functional relationships govern the configuration of this network-structured data base developed for utility distribution system analyses. Information files in the computer memory are linked by a data management system so that inputs to any file (e.g., 6) automatically update all related files. Users' application software provides access only to selected files (e.g., 1, 3, and 5; or 1, 2, and 7), but the management system again automatically ensures that data from all functionally related files are taken into account.

The key to success with this data base is centralized responsibility for data inputs (e.g., 6) and for analyzing and maintaining accurate functional linkages (e.g., 3) in the management system.



tribution data base. Boeing Computer Services, Inc., contracted to survey utility industry practices, design a data base to fit the most general circumstances and needs, and provide an evaluation rationale for utilities to follow in deciding whether to adopt the data base. The project was completed late last summer; the final report was published in three volumes—*Distribution Data Base Design* (EPRI EL-1150).

Selecting analytic functions

Survey data, as well as a literature search, were Boeing's point of departure. Forty-five U.S. utilities were queried, and all responded with summaries of distribution activities desired or already programmed to use base data maintained on a computer. There were nearly as many candidate functions (44) as utilities polled, but none of the cited data files had the comprehensive scope needed to serve all the needs of a distribution department. The ten functions that led the list were submitted by 33% or more of the utilities surveyed.

- Transformer load management (62%)
- Primary feeder fault current analysis (57%)
- Construction cost estimation* (52%)
- Primary feeder load and voltage analysis (50%)
- Service reliability analysis (43%)
- Secondary network analysis (43%)
- Area substation loading analysis (40%)
- Customer profile* (33%)
- Construction management* (33%)
- Crew activity analysis* (33%)

Asterisks mark four functions that despite their evidently wide use cannot be implemented because their data are not naturally stored in a generic distribution data base. Fifteen other candidates were also disqualified when subjected to the four criteria that evolved in Boeing's research: (1) a function must be a responsibility of the utility's distribution department; (2) it must be one that can be programmed; (3) it must be widely applicable among utilities; (4) its program must draw solely on the data base that describes the distribution system alone.

Many candidate functions satisfied the first three criteria but failed the fourth because some portion of their data requirements lacked a connection with the data requirements of the others. The four asterisked functions were dropped for this reason; another example is inventory control and replacement planning. To perform these analyses requires two data bases and their independent justification.

Along with descriptions of distribution functions and their respectively limited data bases, the utility survey elicited two areas of frequent problems encountered in devising and using data bases: gathering and updating data, and defining interdependencies between data elements. The former signals the importance of logical input procedures. The latter signals the essential interconnection that was recognized to be the heart and soul of a successful generic design.

Data base in network form

A single data base of any size must have a logical internal design if it is to be useful. Most reported attempts to use data effectively were frustrated by duplication. This is a natural result when files are established piecemeal for the preparation of various reports. Such data files overlap. Compiled in separate files, their information quickly becomes obsolete in varying degrees, engendering confusion or even conflict among users and their reports.

This shortcoming is traceable to the absence of interconnections; piecemeal data bases lack any means of ensuring that every change will show up in all related files. For Boeing and EPRI, therefore, the early conclusion was to organize the distribution data base as a network in which interactions of all related components, events, or functions are clearly defined. Instead of repeating a data entry in several inherently competing files, which poses awkward logistical and supervisory problems, the entry is made once in a master data base, and repetition is provided by the relationships or connections built into the data base architecture.

So conceived, the network-structured data base is also a complete description of the distribution system itself. Thorough application of logic in designing the data base establishes this criterion and forces this result. Separate vertical files of data, restricted in their content and purpose, inherently fail to reflect the nature of the system. Therefore, the conclusion was that the distribution data base should be in network form. This was the most important output of the data base research effort. But then came the question of maintaining the base. How difficult is this?

Responsibility is the key concept in updating and revitalizing any computer-based system. Considering only the memory content and the means for accessing and using it (or changing it), distribution department members hold the support responsibility. Typically, these are suppliers of data, applications programmers, and users. The data base itself is only a foundation, and a number of consistent and appropriate input and output actions are the lifeblood that keeps it healthy and responsive. Hardware is part of this support only in the matter of choosing and placing the specific accessories needed by responsible individuals.

Keeping the distribution data base healthy means keeping it reliable. This primarily means keeping the data up to date, and only one person should be in charge. A distribution department manager may find that setting up the organizational structure of a support system is the most difficult task. The organization responsible for the data base may be in another department. Capability is built into the data base design, responsiveness is built into its software, but its accuracy must be the responsibility of one person or, at most, a small group.

The group leader must know (or be able to learn) the needs of the users and understand those needs in the sometimes limited context of a computer environment. This person is in the middle and should be multitalented. A likely title for the group leader is data base administrator, and it should go to a person in whom management can place complete trust.

No utility will want to program an entire range of functions simultaneously. Cost is one reason. A more practical reason is the time it takes the system's contributors, programmers, and users to learn how to use each function.

From a theoretical standpoint, the order of implementation doesn't matter, so long as programming conforms to the logical data base design. There is good reason for selecting certain functions at the outset, however; those functions that have the most extensive linkages throughout the data base should be chosen first. Digital mapping and small area load forecasting are good examples, as are any of the electrical system analytic functions. If the data base responds accurately in support of these, it should have no trouble with any of the others.

Justifying the system

Data base systems require a high initial investment—about $200,000 to $300,000 to start even a modest system. One western utility is investing $5 million to digitize the mapping of its entire service territory. But a happy compromise can and should be reached. The bulk of any utility's investment will be devoted to the data base design, systematic data collection, and system software and hardware. As the generic design is included in the final report of Boeing's research for EPRI, that cost element will be minimal.

Although the highest costs come at the front end, simply to complete the installation, benefits accrue only as functions are implemented. This encourages going with as many functions as possible as early as possible. So management will tend to seek a stream of benefits to offset the initial shock of the investment. But while it is important to avoid having a data base and no functions, it is equally important to avoid imposing extensive changes on an organization and seeing it descend into chaos. Thus the data base should be implemented only as fast as the distribution department can assimilate it.

To some extent, the network data base can be justified in the name of "doing the job right." Earlier systems, functions, and piecemeal data files were installed almost at random. Although their incremental costs were thus lower than they would have been by doing the job right, their final costs may be greater. Standalone systems are often characterized by redundant or inconsistent data; they can also lead to jealously guarded data empires and a pervasive lack of cooperation. Because the costs of these problems are diffuse and not easily pinpointed, initial costs become the easy basis of comparison, and they are greater for a network-structured data base. Management should recognize this and be prepared for it.

Boeing's survey of utilities revealed that data bases are most clearly justified if functions or reporting requirements that originate outside the utility can be identified. Examples are reports of assets within tax districts, reports of reliability indexes, and the costs of providing service to customers. These reports are required, and the only thing that matters to management is how to produce them at least cost. The simplest and most direct way to justify investment in a distribution data base, therefore, is to concentrate on the external requirements whose underlying data will form a significant portion of the data base.

Costs and benefits associated with internal functions and analyses are less easily assessed. In an essential sense, they are discretionary. As every cost-benefit analysis is really an examination of options, one option always to be considered is that of letting things continue as they are.

On the other hand, there is little doubt that a well-organized distribution data base makes a handsome addition to any utility's list of cost-cutting resources. The design recommended by EPRI's research should virtually eliminate the need for utilities to invest in studies of basic system architecture. The new design was purposely made independent of computer hardware, software, and user practice. Given this documented concept of a network data base that conforms to distribution system characteristics in the field, utilities can confidently adapt it for their own practice at their own speed. ■

TLM: AN EXAMPLE OF DATA REQUIREMENTS

The most popular function (in the utility survey) that a data base would be required to support is transformer load management. TLM is a methodology used to determine the size of each distribution transformer according to the load it must handle. If a transformer is too large for its customers, its margin of capability and investment represents unnecessary cost. If a transformer is too small, service may be unreliable because of low voltages and excessive transformer failures. Correctly sized transformers minimize the cost of serving customers.

As the peak load of a distribution transformer is not readily available, proper sizing is accomplished by relating customer usage (kWh) readings to estimated peak kVA. The equations used in this method are derived by recording actual kVA readings for a small sample of customers and then statistically relating these load readings to customers' kWh readings.

The data required to support TLM are the transformer size, transformer location, the number of customers connected, and the customers' respective kWh readings. This information is generally available from customer billings. The distribution data base provides an accurate and efficient means to access this data and carry out the TLM program.

Accelerating Synfuels Development

The Energy Security Act of 1980 is intended to launch a synthetic fuels industry and to spur development of alternative energy resources. Financial assistance to meet the national production goals will be channeled through the U.S. Synthetic Fuels Corp.

For more than a year, Congress has been shaping a legislative package to help free the nation from its dependence on imported oil. The thrust of the legislative proposals has been to accelerate the development of synthetic fuels and other alternative resources.

The synfuels effort began a year ago March when amendments to the Defense Production Act were introduced in the House of Representatives, setting a national production goal for synthetic fuels and giving the president the authority to purchase such fuels for national defense. Synfuels fever intensified throughout the spring and summer of 1979 with passage of the House bill in June, introduction of synfuels legislation in the Senate, and a message by the president on July 15 calling for the creation of an independent energy security corporation to invest $88 billion in the production of synthetic fuels. Throughout the fall, the Senate considered several key approaches to synfuels development and passed its bill, which incorporated many aspects of the president's proposals. In November a House-Senate conference committee convened to resolve differences between the House and Senate bills. The conference committee worked until June of this year, considering not only the synfuels provisions but also initiatives dealing with such matters as solar energy, acid rain, and the Strategic Petroleum Reserve that were added to the Senate bill.

In June the conferees reached agreement on a bill and both houses of Congress passed the Energy Security Act of 1980 conference report by large margins. President Carter signed the bill into law on June 30 at the White House, saying, "This is a proud day for America. . . . The keystone of our national energy policy is at last being put in place."

The Energy Security Act launches a synthetic fuels industry in the United States by establishing a national production goal for synthetic fuels, providing $20 billion initially (and possibly $68 billion in four years) in various forms of financial assistance to the private sector to meet this goal, and creating an independent government corporation to oversee the process. The new law also authorizes $5 billion in initiatives in a number of other energy areas.

The electric utility industry and EPRI have a direct interest in this new synfuels effort. Because of a continuing need for liquid, gaseous, and solid fuels, utilities may play a role in providing a market for some synthetic fuels. On behalf of the utilities, EPRI is supporting a major R&D effort to produce clean liquid, solid, and gaseous fuels from coal for electric power production and with DOE is participating in the development of the H-Coal and Exxon Donor Solvent coal liquefaction projects. During the course of House and Senate committee consideration of the synfuels bills last summer, EPRI officials testified on key technical aspects of the synfuels proposals (*EPRI Journal*, September 1979, pp. 30–32).

Synfuels Provisions

A major portion of the Energy Security Act deals with efforts to accelerate the development of synthetic fuels on a commercial scale. Declaring that the "achievement of energy security for the United States is essential to the health of the national economy, the well-being of our citizens, and the maintenance of national security," the law states that the purposes of the synfuels provisions are "to improve the nation's balance of payments, reduce the threat of economic disruption from oil supply interruptions, and increase the nation's security by reducing its dependence on imported oil." To do this, the law establishes a national goal for a synthetic fuels production capability of 500,000 b/d of crude oil equivalent by 1987 and 2 million b/d of crude oil equivalent by 1992 from domestic energy sources. Synthetic fuel is defined in the law as any solid, liquid, gas, or combination of such that can be used as a substitute for petroleum or natural gas and is produced by chemical or physical transformation (other than washing, coking, or desulfurizing) of the following domestic resources: coal, including lignite and peat; shale; tar sands, including certain heavy oil resources; and water, as a source of hydrogen through electrolysis. Mixtures of coal and combustible liquids, including petroleum, are also included in the definition.

To oversee the program to meet these production goals, the law creates the United States Synthetic Fuels Corp. as an independent government organization, free of many of the constraints placed on the departments and agencies of the executive branch. The key function of USSFC is to provide financial assistance through various mechanisms to the private sector to bring about the commercial production of synthetic fuels. Because of this, USSFC is expected to function much like a private corporate entity, such as a bank or similar financial institution.

USSFC will be run by a seven-member board of directors appointed by the president with the advice and consent of the Senate. The USSFC chairman will also serve as its chief executive officer, responsible for the corporation's management and direction. The law provides seven-year terms for the directors. The chairman will serve in his position full time; the other directors may serve full or part time. That determination will be made by the president for each director at the time of appointment. No more than four of the directors may be members of any one political party.

Congress has restricted USSFC to employing no more than 300 full-time professional employees (with the exception of corporation construction projects) and has set a ceiling of $35 million in annual appropriations for administrative purposes. With certain exceptions, the directors, officers, and employees of USSFC are not to be subject to laws relating to federal employment.

The new law also establishes a six-member advisory committee to the board of directors, composed of the secretaries of defense, energy, and the treasury, the administrator of the Environmental Protection Agency (EPA) and the chairman of the Energy Mobilization Board (if and when EMB is created.)

USSFC is authorized to carry out its financial assistance to the private sector in two phases. Phase 1, funded at $20 billion, is basically designed to demonstrate the commercial viability of a variety of synthetic fuel technologies. It will last four years, beginning with enactment of the legislation, and will focus on building the information base needed for the second phase of the effort, as well as providing a limited amount of fuel toward the overall production goal.

During the first phase, USSFC will issue solicitations to the private sector for proposals on the types of financial assistance private companies would need to construct commercial-size plants to demonstrate such technologies as aboveground shale retorting, coal gasification, and coal liquefaction. The Energy Security Act authorizes USSFC to provide the following categories of financial assistance in descending order of preference: purchase agreements, price guarantees, and loan guarantees; loans; and joint ventures. In considering proposals for financial assistance, the act stipulates that USSFC must take into account such factors as the diversity of technologies; the potential cost per barrel or unit production of synthetic fuel from the proposed project; the overall production potential of the technology, considering potential for replication, the extent of geographic distribution, and potential end use of the resource; and the potential of the technology for complying with applicable regulatory requirements. If no satisfactory proposals are submitted, USSFC could then initiate construction of government-owned, contractor-operated plants.

At the end of the four years, USSFC

will take the information gathered from the first phase of the effort and put together a comprehensive production strategy that will outline the recommendations of the board of directors on how to achieve the national synthetic fuel production goals. The strategy will include reports on the findings from the facilities funded in Phase 1. Findings should include information on the economic and technical feasibility of each facility; the environmental effects associated with each facility; and recommendations concerning the specific mix of technologies and resource types to be supported during Phase 2 and subsequent phases. USSFC must submit its comprehensive production strategy to Congress, which must, in turn, approve it by joint resolution. If approved, Phase 2 could allow USSFC to spend up to $68 billion to carry out the comprehensive production plan.

The Energy Security Act anticipates that USSFC will be fully operational within the next few months. Until that time, however, the act provides for a fast-start interim program, using existing federal departments and agencies to speed up the development and production of synthetic fuels to meet national defense needs. The act amends the Defense Production Act of 1950 to allow the president to contract for, or make a commitment for, the purchase of synfuels for national defense purposes. It also allows the president to issue loan guarantees and make direct loans for such purposes. Once USSFC becomes fully operational, these authorities are placed on a standby basis for possible reactivation in times of serious energy supply shortages. Other standby authorities granted to the president are the authority to install additional equipment, facilities, processes, or improvements in government-owned plants; install government-owned equipment in privately owned facilities; and construct government-owned, contractor-operated synthetic fuel projects.

Other Energy Initiatives

In addition to the major synfuels provisions of the Energy Security Act, the law also contains initiatives to spur the development of other energy resources. Among these are provisions that

- Require the secretaries of agriculture and energy to prepare a plan for maximizing biomass energy production and use. In addition to establishing goals for the production of other forms of biomass, this plan would be designed to achieve a total level of alcohol production and use within the United States of at least 60,000 b/d by December 31, 1982. Both secretaries are authorized to issue loan guarantees, price guarantees, and purchase agreements for biomass energy projects.

- Establish the Office of Alcohol Fuels within DOE.

- Direct the secretary of energy to prepare a municipal waste energy development plan and authorize the secretary to commit, make, and guarantee loans for construction of municipal waste energy projects. Price support loans and price guarantees are also authorized for the operation of such projects.

- Establish the Office of Energy from Municipal Waste within DOE to perform research, development, demonstration, and commercialization activities.

- Direct the secretary of agriculture to establish up to 10 model demonstration biomass energy facilities to exhibit the most advanced technology available for producing biomass energy.

- Direct the president to submit to Congress energy targets for net imports, domestic production, and end-use consumption of energy for the calendar years 1985, 1990, 1995, and 2000.

- Establish under the secretary of energy a three-year program to demonstrate energy self-sufficiency through the use of renewable energy resources in one or more states within the United States.

- Create the Solar Energy and Conservation Bank in the Department of Housing and Urban Development to provide subsidized loans for energy conservation and installation of solar equipment in residential or commercial buildings. The bank would have the same powers as the Government National Mortgage Association.

- Delete the prohibition in the National Energy Conservation Policy Act against utility financing of residential energy conservation measures, thus permitting utilities to undertake lending programs subject to state law. Utilities are also allowed to supply and install conservation measures if done through independent suppliers and contractors.

- Establish a program within DOE to encourage up to four demonstrations of residential energy efficiency plans involving utilities and state and local governments.

- Establish a new loan program to assist the geothermal industry in exploring for and confirming the economic viability of geothermal reservoirs.

- Create the Acid Precipitation Task Force (to be chaired by the National Oceanic and Atmospheric Administration, the Department of Agriculture, and EPA) to prepare a comprehensive research plan to identify causes and effects of acid precipitation and possible actions.

- Direct the head of the Office of Science and Technology Policy to contract with the National Academy of Sciences to carry out a comprehensive study on the level of carbon dioxide in the atmosphere and submit a report within three years.

- Direct the president to begin filling the Strategic Petroleum Reserve at an average rate of 100,000 b/d. ■

EPRI's Role in Railroad Electrification

Electrification could reduce transportation oil consumption by 2–3%, but the incentives for conversion will have to be forged by the federal government.

Although EPRI can play a significant R&D role for the electric utility industry in the electrification of the nation's railroads, EPRI and federal officials agree that little is likely to happen unless the government makes electrification a national priority and backs that policy with funding. This was the consensus of a recent conference in Palo Alto at which representatives of EPRI and the U.S. Department of Transportation (DOT) exchanged views on the issues involved in railroad electrification.

Fewer than 1% of U.S. railroads are electric. In Europe, electric railroads are common; 99% of all rail lines in Switzerland, for example, are electric. Electrification is of interest to U.S. utilities for two primary reasons. Existing rail corridors offer a potential right-of-way for power lines through joint use of towers. Increased activity in coal transport adds to the economics of this conversion, possibly reducing future transport costs.

DOT officials acknowledge that electrification has not held the incentive required for either the railroads or the utilities to overcome basic obstacles to large-scale conversion. Costs, for example, are relatively high. In a recent Conrail study, it was estimated that $1.2 billion would be needed to electrify only a small portion of Conrail routes in the Northeastern corridor.

Although railroads already provide a relatively efficient means of transportation, electrification of those corridors handling 95% of all U.S. rail traffic would result in a reduction of 2–3% of the oil used in all transportation modes. And as oil prices increase, electrification will become even more cost-effective.

Among the technical issues of concern to EPRI is the development of a methodology that would help individual utilities assess various load and supply requirements caused by railroad electrification. Related technical topics are being investigated, such as telecommunication interference and the sharing of overhead wire rights-of-way. Economic issues to be studied include assessing ownership options, calculating costs, and pricing electricity.

Federal officials said this is the first of a series of conferences planned with various utility and railroad groups to sound out industry concerns and help shape DOT recommendations. It was suggested that EPRI consider collaborating with DOT on well-defined, small-scale research projects that would be of common interest. ■

ANS Tribute to Comar

The American Nuclear Society bestowed its Special Award on the late Dr. Cyril Comar, who was director of EPRI's Environmental Assessment Department prior to his death on June 11, 1979. The award was presented June 10 to Dr. Comar's widow, Mildred, during the society's annual meeting in Las Vegas, Nevada.

The citation read, in part, "Over a period of more than 35 years as a researcher, professor, and administrator, Dr. Cyril Comar published several books, wrote over 200 scientific papers, and trained innumerable students. Few have devoted as much time and effort and contributed as much to the field of radiological environmental protection and control."

Dr. Comar was born in Dudley, England, in 1914 and received degrees from the University of California at Berkeley and Purdue University. Prior to joining EPRI he was affiliated with the University of Florida, Cornell University, and the Oak Ridge National Laboratory.

ANS is a nonprofit organization dedicated to the peaceful application of nuclear power and has more than 13,000 members worldwide. ■

Contamination Detector Improves Cables

Machinery used to ensure quality control in food processing is being converted into equipment that will remove contaminants from the insulation material used in power cables. Researchers recently demonstrated this new adaptation in equipment at EPRI's Waltz Mill Underground Cable Test Facility in Pennsylvania, where six representatives of the cable industry viewed and bid on a new device—the contaminated-pellet detector. Alcoa was the high bidder and plans to incorporate the detector in its power cable manufacturing operations.

"This equipment will have great impact on improving the quality of distribution cable and extruded dielectric transmission cable," commented Bruce Bernstein, EPRI project manager for development of the detector. "It will help the power cable industry provide superior quality high-voltage cables and thus save time and money by minimizing the replacement of aged cables."

The polymeric material that is used to insulate the conductors in power cables is generally composed of high molecular weight, low-density polyethylene. Before being extruded over a conductor in the cable preparation process, the insulation material is in the form of polyethylene pellets. If contaminants, or foreign bodies, are mixed with the polyethylene pellets as they are converted into insulation, these impurities cause high stresses to develop later inside the insulation wall of the power cable. When voltage is applied to the cable, these contaminants reduce the integrity of the insulation and can lead to premature cable failure.

The object of EPRI research directed by the Electrical Systems Division was to develop equipment that could remove contaminated pellets and foreign bodies from a fast-moving stream of polyethylene pellets. To remove the pellets, the project subcontractor, Food Technology Corp. of Rockville, Maryland, adapted a modified optical detection and removal system that has been used in the food-processing industry for removal of unripe or spoiled vegetables from the canning process.

The optical detector locates the contaminated pellets and causes a signal to trigger a gas ejector downstream from the pellet. Defective pellets and other foreign contaminants are then blown away from the others and are deposited in a separate container. Equipment developed on this project can process about 250 pounds of polyethylene material each hour.

The Waltz Mill demonstration of this new technology was arranged by Spencer Bailey, EPRI's project administrator, and coordinated by Bruce Bernstein and John Shimshock, EPRI's Waltz Mill project manager. ■

Effects of High-Voltage Lines on Health

One of the important issues related to the siting of overhead transmission lines involves potential adverse health effects on people exposed to the lines' electromagnetic (EM) environment.

EPRI studies being conducted under the direction of Robert Kavet are designed to determine if EM fields from transmission lines produce deleterious health effects. Studies are under way to determine the effects of ac electric fields on mammals. The dose of electric fields is designed to simulate close-to-maximum exposures humans would experience under high-voltage lines. The duration of animal exposures being tested, however, is considerably longer than would be anticipated for human populations.

Other studies are focusing on specific biological systems. These include honeybee hives in a field near a 765-kV ac line, chick embryos in an incubator specially designed to receive chronic ac electric field exposures, endocrine tissue in a culture exposed to an ac field, and crops in a greenhouse that has been equipped with overhead electrodes.

EPRI is also supporting an investigation of the possible effects of electric interference with pacemakers, as well as epidemiological studies of utility linemen and switchyard workers. Work on the effects of exposure to dc line environment is also under way.

EPRI is expending more than $6 million in this research area. ■

Electric Vehicles Moving Closer

Electric vehicles are still down the road a bit as practical transportation alternatives, but research under EPRI auspices is accumulating valuable real-world data for assessing EV performance in utility fleet applications.

As part of an EPRI-sponsored project that began in 1978, Southern California Edison Co. has tested eight state-of-the-art EVs and will complete tests on three more later this year. All these vehicles are converted gasoline-powered units, and most of them are small trucks or vans—the kind commonly used in stop-and-go delivery applications. Twenty-one different road tests have been conducted, including 1000 miles of actual city street and highway driving.

The overall objective of the project is to develop a data base on performance and other characteristics of EVs that are available either commercially or as preproduction prototypes. These data will be used in selecting vehicles for a pilot demonstration by the Tennessee Valley Authority and in aiding utilities that are interested in buying EVs for their own use.

"For certain applications, electric vehicles available today, using lead-acid batteries, may be perfectly acceptable," notes EPRI Technical Manager Ralph Ferraro. "The key element in selecting suitable vehicles," he adds, "is to determine from the existing data which vehicles are most compatible with the user's own selection criteria."

For the future, EV prospects look promising. Even setting aside the likelihood of a major battery breakthrough, which could extend the range of EVs, the advent of public recharging outlets, hybrid vehicles, and electrified highways could make these vehicles much more viable.

Although reliability has also been a major shortcoming of EVs (with failures ranging from burned-out motors to loose wires), the recent tests indicate significantly fewer component failures. Ferraro says that the gains in reliability have been primarily due to improved quality control by the manufacturers.

EPRI has provided TVA with 10 Volkswagen Electro-Transporter vehicles for testing this year. When another qualified EV manufacturer is identified by EPRI, additional vehicles will be purchased for testing. ■

CALENDAR

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

OCTOBER

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

13–16
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

30–31
Turbine-Generator Nondestructive Evaluation Workshop
Washington, D.C.
Contact: Anthony Armor (415) 855-2961

JANUARY

21–22
Seminar on Prevention of Failures in Condensers
Palo Alto, California
Contact: Barry Syrett (415) 855-2956

Kurt Yeager, Director

PRESSURIZED FLUIDIZED-BED COMBUSTION

EPRI has recently completed an evaluation of the results of the initial projects in its pressurized fluidized-bed combustion (PFBC) subprogram, as well as projects funded by others around the world. PFBC is one of several advanced options being considered by the utilities as a way to use coal more efficiently than in conventional power plants. In a PFBC system a gas turbine is turned by flue gas from a fluidized-bed combustor operating at temperatures as high as 1700°F (927°C) and pressures up to 16 atm (1.62 MPa). Although the problems of operating a baseload coal-fired gas turbine are formidable, results to date show promise for the development of a utility configuration with acceptable plant availability.

PFBC technology has been under development for the past decade. Among its advantages are SO_x and NO_x emissions well below projected standards without the use of scrubbers or NO_x removal systems, reduced water consumption, and potentially the simplest flowsheet of those coal-use options that increase overall plant efficiency. Until recently there was substantial uncertainty about this technology, primarily because of two interrelated factors—hot gas cleanup techniques have not been fully proved, and the ability of a gas turbine to withstand the expected level of particulates is uncertain. In 1978 EPRI initiated a PFBC subprogram as part of its fluidized-bed combustion effort. Five objectives were identified as prerequisites to any consideration of a major EPRI funding commitment to PFBC power plant development. The projects described below were undertaken to accomplish these initial objectives.

The first objective was to make a state-of-the-art assessment of PFBC technology for use in further planning. General Electric Co. undertook this task, reviewing past PFBC projects, past attempts to design coal-fired gas turbines, and the program plans of various organizations (TPS78-762). Its assessment summarizes the status of the technology and identifies key issues that must be resolved before commercialization.

The second objective was to estimate projected PFBC plant economics. The contractor, Burns and Roe, Inc., evaluated PFBC utility flowsheets provided by several PFBC developers. The procedures presented in EPRI's *Technical Assessment Guide* were used to facilitate comparisons with conventional technologies and other advanced technologies (RP1645-2). On the basis of preliminary capital cost estimates, it was concluded that PFBC options can potentially offer electricity at a cost at least 10% lower than that of electricity from a pulverized-coal plant with a flue gas desulfurization system.

For the third objective—to evaluate in-bed materials and cyclone dust collectors—EPRI joined DOE in funding a 1000-h test at the Coal Utilization Research Laboratory's 4-MW (th) PFBC pilot facility in Leatherhead, England (RP979-3). Also participating were American Electric Power Service Corp., Stal-Laval Turbine Ab, General Electric, and Babcock & Wilcox, Ltd. The test was completed in December 1979. An examination of the steam tubes that had been immersed in the fluidized bed indicated that erosion is not likely at the conditions of the test and that corrosion does not differ significantly from that in an atmospheric fluidized-bed combustor. In fact, very little damage was found. After gas cleanup by three cyclone collectors operating in series, particle loadings were between 100 and 225 ppm by weight; there was no corrosion or erosion reported on the turbine test specimens. The positive results of this test have supplied researchers with valuable data and have given momentum to PFBC programs worldwide.

Under RP1336 Westinghouse Electric Corp. is pursuing improvements in hot gas cleanup, which is the fourth objective. After a review of potential advanced cleaning methods, ceramic bag filtration was selected as the most promising for rapid development and scale-up. Two prototype baghouses—a 19-bag woven ceramic unit by the Buell Emissions Control Division of Envirotech Corp. (Figure 1) and a 5-bag felted ceramic unit by Acurex Corp.—were constructed for testing at the 12-lb/s (5.4 kg/s) PFBC simulator at Westinghouse's Waltz Mill facility. In initial tests of the Buell unit at 11 atm (1.1 MPa) and 1550°F (843°C), 99.7% of the particles above 1 μm were removed and the bags were successfully pulse-cleaned on-line. Although preliminary, these results are encouraging.

The fifth objective was to determine whether turbine reliability improvements could be achieved by using advanced materials. As part of this continuing effort, bench-scale evaluations of turbine materials

Figure 1 A 3M Co. alumina-borea-silica bag is lowered into the Buell fabric filter assembly at Westinghouse's Waltz Mill facility.

are being made in turbine test simulators. Under RP1337 General Electric is attempting to develop improved turbine materials and cladding. Under RP979-4 United Technologies Corp. (UTC) is studying the erosion of various metal samples by using mixtures of PFBC effluent dust and other compounds (catalytic-cracking effluent dust, and alumina and magnesia powders of well-characterized sizes). UTC has proved that when erosion and corrosion occur together, metal loss rates can be very high. This may happen because corrosion weakens the metal surface, making it more readily removed by the erodent, or because the erosion removes the protective oxide layer on the metal surface, resulting in more rapid corrosion by alkali salts.

On the basis of an evaluation of project results to date, a revised PFBC development plan is being prepared for industry review. It is projected that with a fairly modest R&D expenditure relative to those required by other high-efficiency coal options, EPRI can have a major impact on the development of an attractive peaking or baseload power plant that uses PFBC.

During 1980 the primary focus is on developing a test plant configuration that will resolve questions about hot gas cleanup and turbine reliability. The test plant must be on a utility scale (at least 20 MW [e]) and must be of reasonable cost to justify utility participation. Through a joint project (RP1645-3) with Brown Boveri Corp. and Babcock & Wilcox Co., EPRI is developing the requirements, preliminary design, and costs of such a plant (Figure 2). The first task is to select an optimal cycle configuration for a full-scale commercial unit. This is necessary because there are many ways to arrange the pressurized fluidized-bed combustor, gas cleanup train, heat transfer surfaces, and gas turbine to maximize plant performance. The test plant will then be designed to resolve the turbine reliability problems relevant to this selected configuration. *Project Manager: William Slaughter*

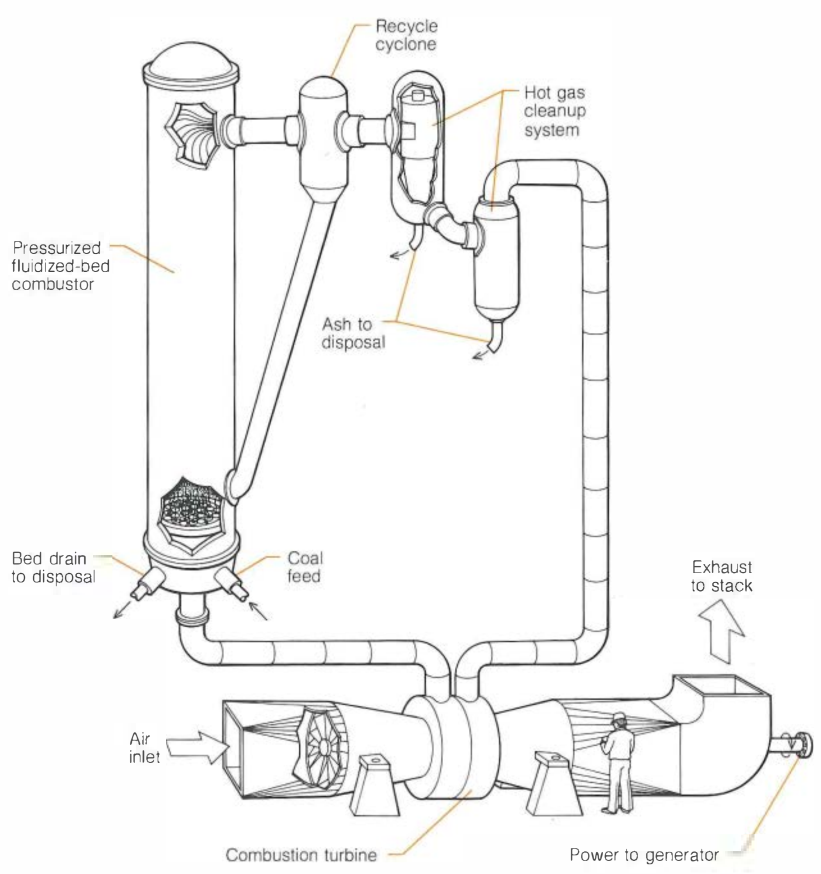


Figure 2 The conceptual EPRI turbine test plant will include a high-excess-air adiabatic PFB combustor, an advanced hot gas cleanup system, and a combustion turbine.

COOLING-TOWER BLOWDOWN DISPOSAL

Expanding environmental regulations and the dwindling supply of natural surface waters in many parts of the United States have become constraints on power plant siting, design, and operation. Consequently, utilities in water-scarce areas are turning to water conservation measures, wastewater reclamation and reuse, and plant effluent treatment. One area of concern is the handling of cooling-tower blowdown, a category of waste stream regulated by EPA. That agency is currently reviewing its 1974 limitations on the discharge of pollutants in effluents from steam electric power generating plants, and the proposed revised guidelines expected later this year may require more rigid control of cooling-water discharges. In response to utility concerns, EPRI's Water Quality Control and Heat Rejection Program has embarked on research to develop innovative technologies for reducing cooling-tower blowdown.

There are several approaches the utility industry can take in dealing with the problems of effluent restrictions and decreasing water supplies. One is to maximize the use of the water in a cooling system by recycling. Water is conserved and aqueous discharge is minimized. This is feasible up to a point (i.e., until dissolved solids begin to approach saturation). Typically, calcium carbonate, silica, and calcium sulfate present scaling problems. These precipitates may form insulating deposits on the condenser's heat exchange surfaces, degrading the overall performance of the power plant and forcing plant outage for condenser maintenance. Methods of achieving sustained operation at high dissolved-salt concentrations without detrimental fouling and scaling are being investigated in RP1261, which was described in an earlier report (*EPRI Journal*, July/August 1979, p. 38).

Blowdown reclamation and reuse

In specific situations cooling-tower blowdown can be reclaimed and reused within a power plant. This approach is gaining increased attention. Coupled with higher cycles of concentration in tower operations, it could enable a plant to reuse most or all of the aqueous effluent produced by the cooling towers. Much of this effluent could be recycled for use in ash handling and sluicing with little or no pretreatment; with treatment, it could be reused as scrubber or even boiler makeup.

Innovative methods have been developed in the last decade to reduce the volume of waste water rejected from cooling towers and to recover water of extremely high boiler condensate quality. (The concentrated brine fraction is stored on site in a lined pond.) Two significant areas of advancement involve membrane separation processes, such as reverse osmosis and electrodialysis, and evaporation-distillation technology. The costs of applying evaporation-distillation methods to cooling-tower blowdown are very high, but research to improve these methods continues to show progress.

The commercial evaporation equipment presently available for treating blowdown from recirculating cooling systems is not inexpensive. For example, the installed capital cost of a 400-gal/min (1.5-m^3/min) vapor compression–evaporation facility exceeds $8 million, or $20,000 for each gallon per minute of treatment capacity. Its energy consumption is also high (80–90 kWh/1000 gal of feed). The overall cost, including maintenance and operating expenses, is on the order of $6–$7/1000 gal of feed.

Waste heat evaporator

EPRI is currently evaluating a vertical-tube, foam-enhanced evaporation system capable of processing cooling-tower blowdown (RP1340). EPA and Envirotech Corp. are cosponsoring the project, which is being conducted by researchers at the University of California at Berkeley. The system consists of a 50,000-gal/d (189 m^3/d) steam-driven shell-and-tube evaporator with a 5000-gal/d (19 m^3/d) ancillary evaporator-crystallizer unit (Figure 3). Heat transfer performance is enhanced by the fluted-tube geometry of the heat transfer surface and by a foaming additive. Exhaust heat from the plant's steam turbine is the energy source. A tenfold concentration of the cooling-tower blowdown is achieved in the evaporator, with another fourfold concentration of the resultant brine in the evaporator-crystallizer. In all, the two-stage concentration system is expected to recover 98% of the blowdown as aqueous distillate for plant boiler makeup; the remaining 2% would be discharged as a crystalline salt slurry. Savings in both capital and operating costs are projected.

The specific objectives of RP1340 are (1) to demonstrate the use of an evaporator-crystallizer for cooling-tower blowdown disposal under actual plant operating conditions; (2) to demonstrate the feasibility of using waste heat from turbine exhaust steam (at temperatures greater than 49°C [120°F]) to drive the process; and (3) to develop realistic design and economic criteria for the engineering of commercial equipment.

Initial parametric testing to study the system's performance, hydrodynamics, and vapor-liquid disengagement characteristics was performed at the University of California's Seawater Conversion Laboratory in Richmond, California. Fresh potable water and San Francisco Bay salt water were used as feed. The tests, conducted over eight months, evaluated and compared upflow and downflow operating modes in the vertical-tube evaporator; for each mode, performance both with and without foam enhancement was investigated. Data were collected for the steamside temperature range representative of actual power plants (i.e., 40–60°C; 104–140°F).

The results have been encouraging. For example, when the saltwater feed, at 35,000 ppm total dissolved solids (TDS), was used and the vertical-tube evaporator was operated in the downflow mode at a steamside temperature of 50°C (122°F), a 30% increase in the overall heat transfer coefficient—from 1300 to 1700 Btu/(h·ft²·°F), or from 7381 to 9653 W/(m²·K)—was achieved with foam enhancement.

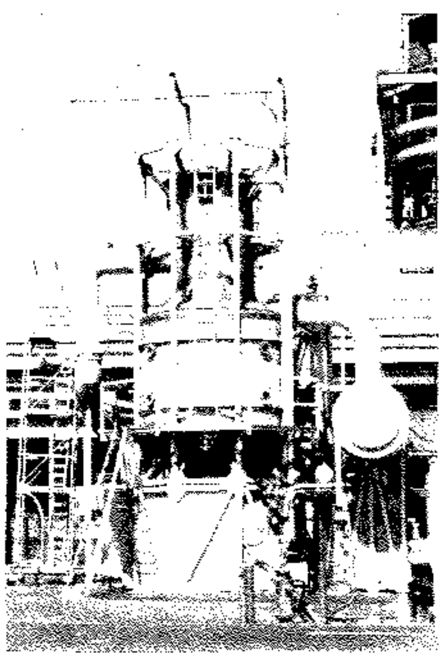


Figure 3 The 50,000-gal/d vertical-tube, foam-enhanced evaporator test facility at Southern California Edison Co.'s Etiwanda station near Ontario, California.

The prototype facility has been transported to Southern California Edison Co.'s Etiwanda station for four months of field demonstration tests. Before testing under steady-state operating conditions, it will be subjected to chemical scaling conditions to verify its tolerance to scale deposition and accumulation.

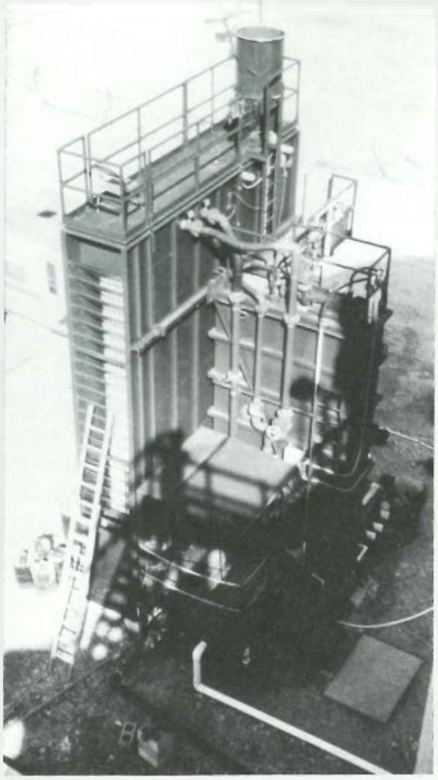
Results from this project should provide a sound basis for the feasibility and cost evaluations necessary to enable the design, manufacture, and supply of a commercial system. The technical participation of Envirotech's Goslin Division (a commercial evaporator manufacturer) and Bechtel National, Inc., will help ensure the results' usefulness.

MCT evaporation process

Another blowdown disposal approach is to simply evaporate the waste water without recovery for plant reuse. In 1979 the magma cooling tower (MCT) process, a novel evaporation procedure for use with recirculating cooling systems, was successfully demonstrated under the joint sponsorship of Nevada Power Co., Western Energy Supply and Transmission (WEST) Associates (a group representing 20 utilities in the western United States), and EPRI. (The process was renamed after this work began. It is now called the binary cooling tower [BCT] process.) Tower Systems, Inc., field-tested the process at Nevada Power's 85-MW (e) Sunrise station in Las Vegas (TPS79-740); CH2M-Hill, consulting engineers, monitored the testing and performed engineering and economic evaluations of the concept (RP1260-10). Figure 4 shows the pilot facility.

The process uses heat from the power plant cooling water to evaporate the cooling-tower blowdown. Figure 5 presents the arrangement of a typical heat transfer module. Based on evaporative-cooling principles, the process combines a mylar-surface, falling-film heat exchanger and conventional water treatment practices. Heat is transferred through the mylar panels from the plant's cooling-water loop to the concentrated-brine recirculation loop. Both latent heat of evaporation and sensible heat are rejected from the falling brine film to an ambient air stream, which is discharged to the atmosphere.

Figure 4 The 100-gal/min (nominal capacity) MCT process pilot facility at Nevada Power Co.'s Sunrise station in Las Vegas.



The testing was divided into two phases over a four-month period. Work initially focused on the performance of the process in a conventional water treatment operating mode. Plant cooling-tower blowdown averaging 5000 ppm TDS was mixed with recycled concentrated brine in a volumetric ratio of 19 to 1. The blend was chemically softened to reduce the calcium, magnesium, and silica concentrations before introduction into the tower, thereby avoiding scale deposition problems. By discharging only a small portion of the brine, it was possible to maintain a 10–12% concentration of dissolved solids in the brine recirculation loop.

Over 11 weeks of continuous operation, the first phase of testing successfully demonstrated the applicability and compatibility of the MCT process in a power plant. Chemical conditions in the brine loop at 20 cycles of concentration of the plant cooling water were stable, with no adverse scaling or biological fouling in any part of the system. Predicted operating parameters were verified. Treatment costs are estimated at $6/1000 gal, which is competitive with conventional wastewater reduction methods of similar sophistication and complexity (e.g., vapor compression–evaporation, reverse osmosis, and electrodialysis).

Testing was continued for two weeks to examine the process under more severe conditions. It was suggested that by altering the water treatment configuration and using the chemical softening makeup pretreatment unit as a brine loop crystallizer, savings of up to 15% of the total annual operating and maintenance costs might be achieved. In the course of testing, however, the crystallizer was unable to sufficiently remove supersaturated calcium sulfate from the brine recirculation loop. The result was precipitation and scale deposition throughout the unit. The brine concentration reached a maximum of 40,000 ppm, in comparison with the targeted design level of 100,000 ppm. Whether or not the crystallizer can be redesigned and successfully operated has not been determined.

Commercially available cooling-tower blowdown reduction techniques have rapidly expanded from the use of evaporation ponds to include vapor compression–evaporation, chemical softening in both makeup and sidestream treatment modes, reverse osmosis, and electrodialysis. The development of the vertical-tube, foam-enhanced evaporation system and the MCT process now offers the industry two more promising options for cooling-tower wastewater reduction. Their successful demonstration in the projects reported here will mark the first step toward commercialization. *Project Manager: Winston Chow*

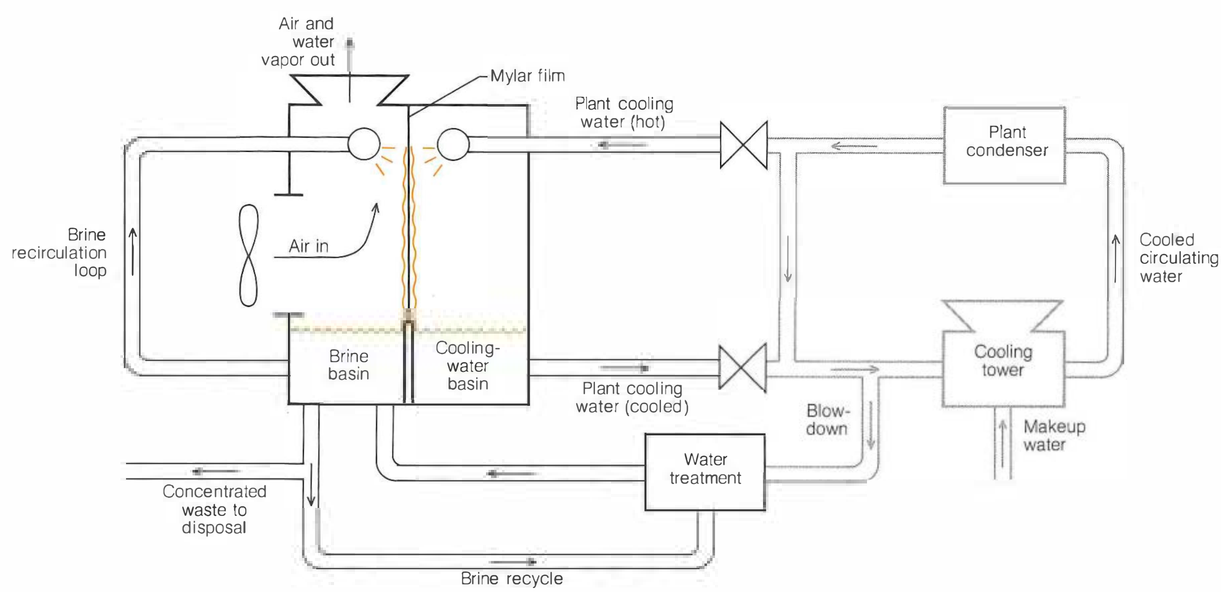


Figure 5 Schematic of the MCT process pilot facility. In this configuration, blowdown from the plant cooling system is blended with recycled brine from the MCT process. After being chemically treated to reduce total hardness and soluble silica, the blended solution is sprayed onto a mylar film. Heat from plant cooling water sprayed on the opposite side of the film evaporates water from the brine, leaving a higher concentration of dissolved solids in the brine. The water vapor is discharged to the atmosphere in a forced-air stream.

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

POWER SYSTEM PLANNING AND OPERATIONS

Array processor power flow

Many static and dynamic power system computations are based on power flow calculations. In recent years engineers in electric utilities have experienced increased difficulty in acquiring the number of power system simulations needed to solve today's complex problems; the difficulty arises from the large amount of computer time required for such a great number of simulations, the shortage of computer storage, and cost limitations. Further, if a utility's corporate computer is also used for planning studies, financial and other nonengineering tasks often take priority over engineering computations. Thus, engineers need access to other, improved computation facilities if they are to obtain solutions in a timely and cost-effective manner. Similar problems exist in real-time applications because many energy control center computers are fully utilized.

Fortunately, computer hardware has undergone many changes in the last several years, including new architectures, improved computation speeds, and reduced equipment costs. The array processor is a good example of recent improvement because of its low cost and the fact that it is a peripheral device that can be attached to a general-purpose (host) computer.

The main objective of RP1710 with BCS is to determine the applicability of array processors to power flow computations. In support of this objective, a production-grade power flow program and subroutines will be developed to perform the steady-state network solution used in power system computations. Subroutines useful in such applications as optimal power flow, transient stability, contingency evaluation, real-time applications, and operations control will also be developed.

The second objective is to determine what hardware and software features are desirable for a host computer–array processor combination without regard to present market availability. The third objective is to assess the impact of an array processor with power flow software on optimal power flow computations, both now and in the future. *Project Manager: John Lamont*

Numerical simulation methods

A nearly completed research project with Boeing Computer Services, Inc. (BCS) addressed both the efficiency and the reliability of present methods for simulating dynamic power system performance (RP670). The project also developed the capability to perform the more complex simulations anticipated for the future.

The project's initial effort produced a diagnostic transient stability computer program for testing individual solution algorithms. In addition to performing timings of the numerical computations, the diagnostic program provides performance timings on the numerical methods employed. A user's manual has been prepared, and the diagnostic program is currently available from EPRI's Electric Power Software Center.

BCS has also investigated numerical procedures involving high-performance processors, such as the array processor. Two procedures for solving sets of sparse linear equations have been developed and tested. The first procedure is for such arbitrary sparsity patterns as machine equations, and the second is for patterns that occur in the network equations. The resultant solution methods have been applied in conjunction with the procedures commonly used for large sets of sparse linear equations.

The basic building blocks of generator control equipment (including exciters and governors) were studied in a parallel effort, and a data structure was designed that allows the rapid evaluation of machine equations by means of array processors.

The final report on this project will be available for distribution in the fall. *Project Manager: John Lamont*

Modeling unit operating conditions

The reliability of a utility's generating units affects the operating costs of the utility. In the past, utilities have done well in rotating planned maintenance outages and providing sufficient reserve for forced outages in an effort to improve generating capacity reliability. However, today's intricate interconnected systems demand a more sophisticated evaluation of such factors as the spinning reserve policy and the effect of unit startup failures. Other factors that should be built into a model for assessing generating-capacity reliability are unit startup times and the benefit that might be derived from delaying planned outages.

It has already been determined that the Monte Carlo simulation approach for modeling unit operating conditions is expensive in terms of computation time and data requirements; hence, analytic models would be most desirable for this purpose. EPRI has contracted with Associated Power Analysts, Inc., to focus on such models (RP1534).

When the analytic models are complete, they will be validated by applying them to an operating utility's data. This should make it possible to evaluate trade-offs between installed reserve (capital cost) requirements and operating costs. These models will also be validated by comparison with Monte Carlo simulations of the same utility operating data.

When delivered in 1982, the analytic models will be useful to operating utilities for evaluating their generating capacity reliability. In using the model, the utility will be able to incorporate any or all of the unit operating factors mentioned above. *Project Manager: Neal Balu*

OVERHEAD TRANSMISSION

Line maintenance by remote-controlled device

Higher operating voltages, closer conductor spacing, and growing legal restrictions are making the maintenance of overhead power lines more difficult with each passing year. Bare-hand work is illegal in some states, and live-line maintenance on higher voltages requires so great a distance between worker and energized hardware that working with tools is very difficult, if not impossible. When problems occur on overhead lines during very adverse weather conditions, linemen may not be able to work because of heavy rain, high winds, or bitter cold. Advanced compact line designs, which are becoming increasingly popular, often do not permit live-line work without extensive preliminary work to spread the conductors apart. In summary, there is a need to remove the human limitations from overhead line maintenance.

Budgetary restrictions, inability to obtain additional rights-of-way, and environmental pressures have forced electric utilities to make maximum use of their facilities. In the case of overhead lines, the circuits are often loaded to maximum capability and other means for serving the load are nonexistent. In other situations, the loss of a circuit may force the purchase of expensive interchange power or the use of alternative high-cost generation.

A solution to many of the above problems is being sought in an EPRI-sponsored project with General Electric Co. and others to examine the feasibility of developing a remote-controlled device to perform overhead line maintenance work (RP1497). Robots are playing an ever-increasing role in today's automated world, and the application of a remote-controlled device to overhead line work suggests exciting new concepts for line maintenance.

As a prelude to this project, General Electric, A. B. Chance, and Philadelphia Electric Co. hosted a demonstration and workshop on December 13 and 14. Twenty-eight representatives from 19 electric utilities were present at King of Prussia, Pennsylvania, to watch a General Electric manipulator being used to remove and install a string of insulators on a Philadelphia Electric transmission tower (Figure 1).

Following the demonstration, all utility representatives had the opportunity to operate the device themselves. During the workshop, the utility representatives were asked for information on their present maintenance tasks, and their suggestions for using the device were requested. Feedback from the workshop will help determine which maintenance tasks the device will be designed to perform. EPRI and the project team plan to maintain close coordination with potential utility users.

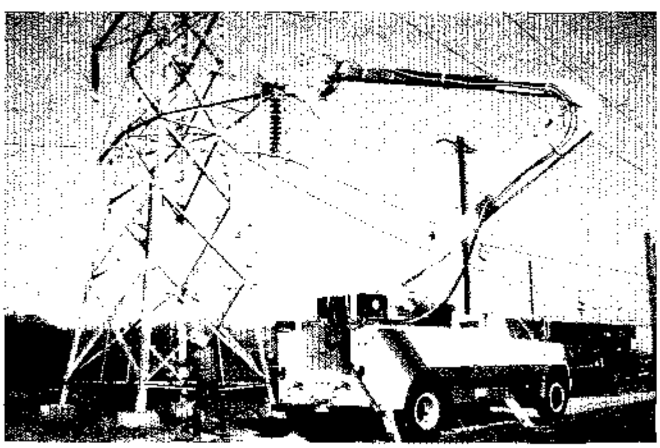
The proposed device is intended neither to replace the lineman nor to replace hot-stick or bare-hand maintenance methods. It is seen as an additional tool to increase efficiency or to enable a lineman to work under conditions that preclude the application of conventional techniques. The device may allow utilities to expand their maintenance capabilities significantly. *Project Manager: John Dunlap*

DC conductor development

Historically, dc transmission lines have been built with conductors designed for ac lines. The mechanical considerations are about the same for each case; however, the electrical characteristics are quite different. These differences offer the opportunity for development of a conductor for HVDC applications that will be significantly better than those currently in use. Alcoa Conductor Products Co., working with General Electric, is developing a conductor uniquely suited to HVDC overhead lines (RP1514).

In the first phase of the project the research team will examine the differences between the electric characteristics of ac and dc conductors and develop ways to take advantage of the characteristics of dc. For example, in dc conductors the current is distributed throughout the various layers of the conductor rather than concentrated in the top layers (skin effect). Also, ion currents between positive and negative poles, or from conductor to ground, have an important role in HVDC transmission line operation. Finally, there is no inductive or capacitive coupling between dc conductors and surrounding objects; however, converter-generated harmonics do couple to nearby communication circuits. Therefore, entirely new concepts of pole geometry, conductor resistivity, surface coating, and stranding are needed to optimize the design.

Successful conductor design often is a compromise between an optimal theoretical design and a practical solution that can be manufactured and installed with reasonable ease. The practical aspects necessary



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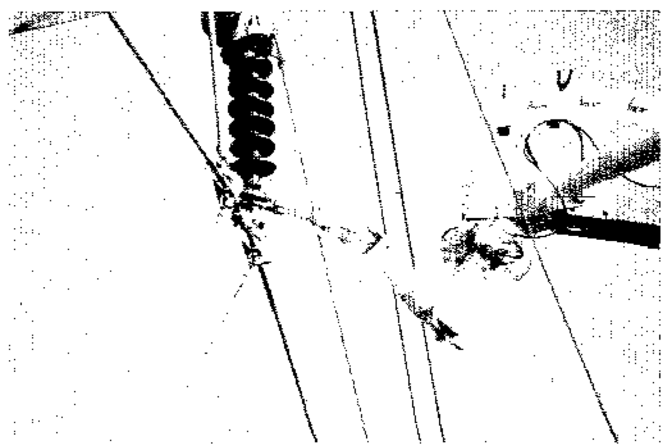

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Figure 1 Remote-controlled line maintenance device. **(a)** To demonstrate the concept of using such a device, the bucket on a Pitman boom truck was replaced with a General Electric manipulator. With this setup and a closed-circuit TV system, a string of insulators was replaced by operating controls mounted in the truck bed. **(b)** Close-up of the manipulator.

for a commercially successful product will be handled by members of the research team knowledgeable in conductor manufacture and field installation. On completion of a detailed analytic design, the contractors will fabricate suitable lengths of the newly developed conductor for mechanical and electrical tests.

The goals of this project include not only the reduction of line losses but also improvement in the area of environmental effects of HVDC line operation. If this project is successful, a dc conductor with significant improvements over conductors now in use could be made available for installation on the next generation of HVDC lines. *Project Manager: John Dunlap*

Project UHV

Set up to develop useful guidelines for ac transmission lines rated through 1200 kV, Project UHV (RP68) has served its intended purpose (*EPRI Journal,* May 1979, p. 52). The final task, now being completed, is publication of the revised *Transmission Line Reference Book—345 kV and Above*. The revised edition will contain Project UHV research results developed since 1974, as well as published results from other sources in the United States and abroad.

The data developed during the past five years is a significant extension of material developed prior to 1974 because the latter involved three-phase research rather than the single-phase testing of the earlier work. Thus the new data have prompted major revisions in all 12 chapters of the reference book; for example, the chapter on conductor configurations and circuits now covers the electric characteristics of delta circuits, toroidal corona shields, and thermal capacity of overhead UHV lines. The two chapters dealing with corona on transmission lines now contain data on the influence of corona currents on switching-surge overvoltages, a new section on the measurement and calculation of ozone concentration, and updated design charts for computation of corona loss. The chapter on radio and television interference and the one on audible noise include updated charts for estimating these effects for both horizontal and delta circuits.

One of the largest chapters addresses the field effects of overhead lines and transmission substations, and emphasis is placed on practical design concepts that can be used to reduce these effects. The 19 sections of this chapter contain the bulk of research results from a related research project on the electrostatic and electromagnetic effects of UHV lines (RP566).

The revision, published in a hardbound edition, should be available by the end of 1980. *Program Manager: Richard Kennon*

Geomagnetically induced currents

Magnetic storms, triggered by solar phenomena, can cause geomagnetically induced current (GIC) in electric power systems. Power systems in northern latitudes are more susceptible to these solar magnetic storms. The interconnected system of three utilities in particular is one such example (Manitoba Hydro, Minnesota Power & Light Co., and Northern States Power Co.). The higher GIC in this interconnected system is caused not only by its northern latitude but also by the high earth resistivities of the igneous rock in the area. As a result, the power system is the preferred path for GIC.

The GIC flow in the power system is caused by the difference in earth surface potential (ESP) between grounded neutrals. This could be a problem, for example, in a long transmission line with grounded-wye (high-voltage-side) transformer banks at each end. The ESP disturbances accompanying a solar magnetic storm are known to be cyclic over a 5–15 minute period. Because of this long cycle, the resultant induced GIC can be considered to be quasi dc. The flow of this GIC through the transformer windings can cause half-cycle saturation. A similar effect can occur if stray dc enters the ac power system during monopolar earth return of a nearby HVDC system.

Because a 500-kV intertie between the mentioned utilities is currently under construction in Minnesota, GIC is of immediate interest there, and a project was initiated in 1978 to study this phenomenon and quantify its effects (RP1205). This project has now been completed. With the increase in the number of other interconnections between utilities in the northern latitudes, this study may be of significance to many utilities in the United States and Canada. A comprehensive final report is expected to be published in the fall of 1980. The contractor was Minnesota Power & Light.

The load-flow studies of RP1205 also revealed the serious nature of the voltage drop and the real and reactive power flows that can occur on an interconnected system during magnetic storms. Switching studies have also revealed some potentially dangerous effects. As a result, a new research project has been initiated to focus on evaluation and field trials for mitigating the effects of both GIC and stray dc currents (RP1770). This work is expected to be completed by the end of 1981. *Project Manager: Joseph Porter*

UNDERGROUND TRANSMISSION

Waltz Mill cable test facility

The Waltz Mill Underground Cable Test Facility has been under lease to EPRI for three years. Installation and testing activity is now at an optimal level, with an ambitious schedule of construction and installation planned for 1980. At the facility, prototype samples of underground transmission systems and components being developed in separately funded projects are field-tested to assess suitability for long-term electric utility service. Because of EPRI's cooperative agreement with DOE, prototype samples from both EPRI and DOE projects are evaluated. Satisfactory performance under installation and test generally results in electric utility acceptance and incorporation into industry specifications, as applicable, by the appropriate standardization groups.

At the beginning of 1980 Waltz Mill had four samples or systems under active test, five in advanced stages of installation or construction, and six in planning (where at least a major portion of the installation is expected to be completed in 1980). A similar level of activity is planned for 1981. One notable addition to the facility this year will be dc test capabilities. An expandable ±1000-kV dc voltage supply and a dc current supply were ordered in 1979 for delivery in 1980.

Figure 2 is the Waltz Mill installation of a 1200-kV, SF_6-insulated bushing and bus section developed by Westinghouse Electric Corp. under contract to DOE. Late in 1980 a complete loop will be made, incorporating a gas-insulated current- and voltage-sensing element developed by General Electric Co. and a gas-insulated arrester developed by Ohio Brass Co. This prototype system installation involves evaluation of assembly and field-handling problems; voltage and current testing will follow to enhance overall design credibility and encourage eventual industry acceptance.

Figure 3 depicts the installation of one test bay for the Elastimold 138-kV, premolded joints for solid-dielectric cable, developed under RP7815. Twelve joints are under test, four each in three separate test bays. One bay is always filled with water; one bay is always dry; the third bay is

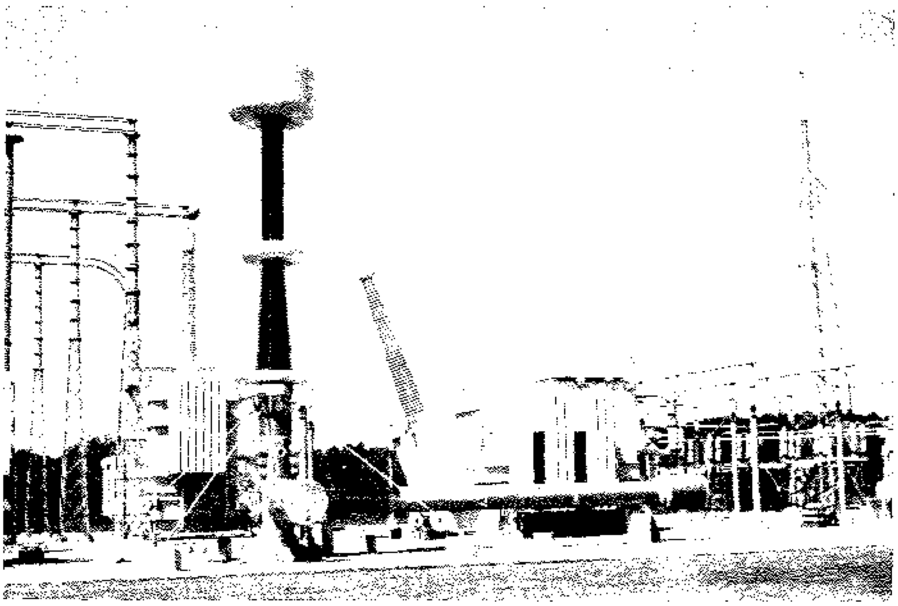


Figure 2 Prototype 1200-kV, gas-insulated bushing and bus system undergoing test at the Waltz Mill cable test facility. The SF_6-insulated bushing is 48 ft (14.6 m) tall, and the bus section has an inside diameter of 30 in (76 cm).

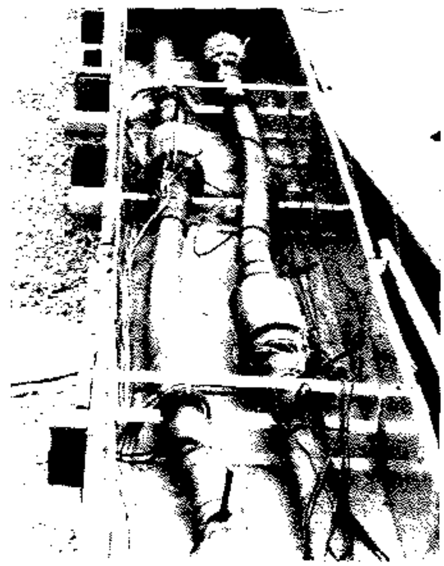


Figure 3 One of three bays used to test twelve 138-kV, premolded joints for solid dielectric cable. One bay will be wet, one dry, and one alternately wet and dry. Note the cable bending caused by load cycling.

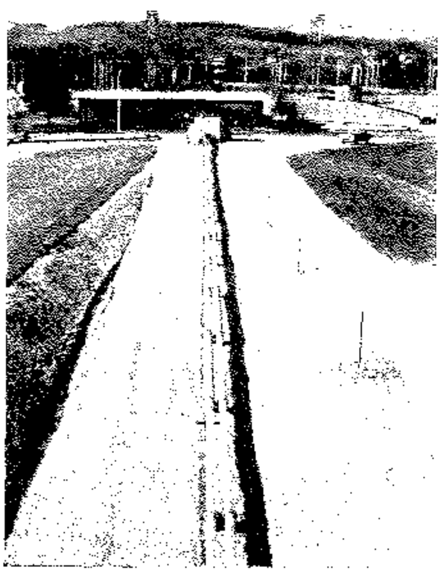


Figure 4 New extruded-dielectric test bay designed to simulate realistic cable field conditions. A manhole at the far end, which can be filled with water, is coupled with a direct-buried return loop on the right.

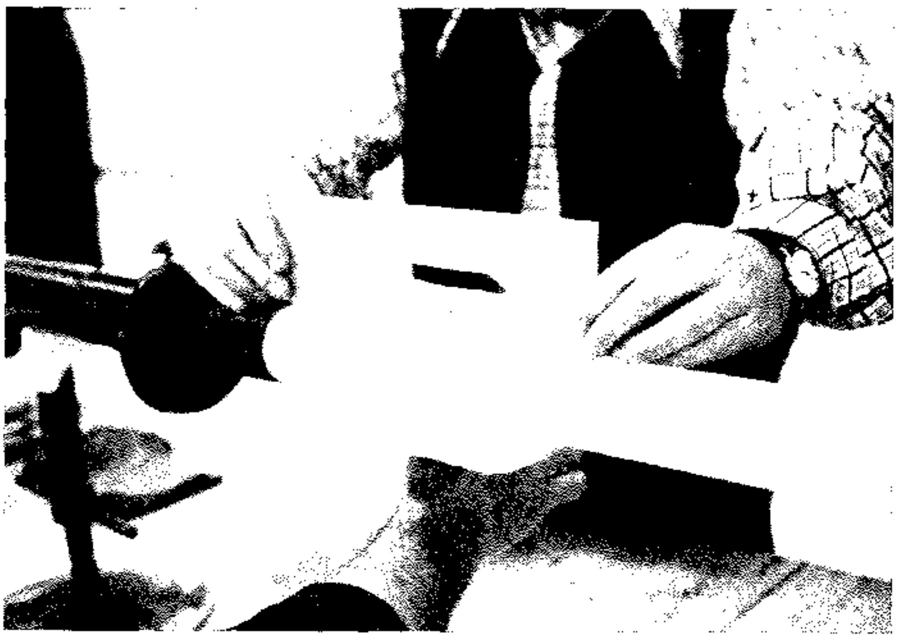


Figure 5 This high-stress, 138-kV, cross-linked polyethylene cable was the first prototype tested in Waltz Mill's wet-dry test bay. The hand-taped stress cone is completed just prior to the molding operation.

alternately wet and dry. These joints are a highly desirable alternative to hand-taped or field-molded joints.

Figure 4 shows a new test bay arrangement recently completed at Waltz Mill for solid-dielectric cable. A long conduit run and a manhole that can be filled with water are coupled with a direct-buried return loop, allowing closer simulation of actual field conditions. This testing arrangement will overcome the deficiencies of past tests, which were carried out only in a dry, air-filled pipe.

The first prototype sample installed in this bay at Waltz Mill is the high-stress, 138-kV, cross-linked polyethylene cable developed by General Cable Corp. under RP7829. This cable system has field-molded joints and terminations. Figure 5 shows a stage in construction of the stress cone prior to molding. This system offers cable that will operate at the same electric stress levels as paper cables, possible cost savings over competitive systems, and increased reliability in comparison with commercial solid-dielectric systems. *Project Manager: John Shimshock*

High-ampacity potheads

The introduction of forced-cooled cable systems has increased the ampacity requirements beyond the limits of the usual self-cooled cable termination (pothead) designs. The use of forced cooling directly in the terminations is risky because of the undesirable mechanical stresses developed at the internal surface of the porcelain insulator when the oil inside the termination is colder than the ambient temperature. Hence, EPRI has initiated a project to explore means by which cable terminations may be cooled without creating additional stress (RP7857).

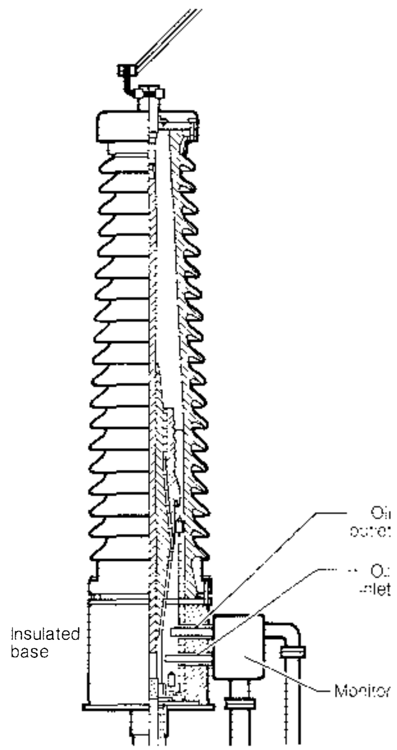
The ampacity of cable terminations may be increased by methods that take advantage of the low thermal resistance of the cable conductor. These cooling methods increase the axial heat flow out of the central part of the cable terminations by cooling either the top or the base without decreasing the oil temperature in the main part of the termination to dangerous subambient levels.

Use of a long, massive copper connector can increase the rate of heat removal at the top end of the cable conductor in the termination. However, the benefits of such a connector are substantially improved by internal forced cooling of the connector. Cooled oil can be supplied to the top connector by installing oil conduits of polymer tubing in the termination's internal oil space.

Cable terminations can also be cooled by forced cooling of the cable in the base of the design (Figure 6). Separate insulation coolers installed in this location were relatively successful, but the efficiency was increased substantially by using the entire base section of the termination to force-cool the cable where it enters the bottom of the termination. A barrier of open-pore, ethylene-propylene terpolymer sponge may be inserted between the base section and the center section of the termination design to prevent direct contact between the cooled oil and the internal surface of the porcelain insulator.

The performance of the top and base cooling methods depends on the type and size of the terminations and of the cables. In many cases it will be possible to obtain impressive increases in the ampacity by a combination of top and base cooling. In terminations for 138–161-kV cable, the increase in ampacity is now able to match

Figure 6 The ampacity of this cable termination is increased by cooling the oil in the base to 20°C below ambient. This increase in ampacity is equal to that of force-cooled cables that are designed with larger copper conductors.



the expected requirements of force-cooled cable installations designed with large copper conductors. Because of the large variety of designs for high-voltage cable terminations, it was impossible to cover all known constructions, but the investigation of the cooling methods was designed to be as universal as possible for application to the most typical designs. *Project Manager: John Shimshock*

TRANSMISSION SUBSTATIONS

Arc interruption

Use of the SF_6-gas, puffer-type circuit breaker is increasing all over the world. The puffer breaker takes advantage of the excellent interrupting and insulating properties of SF_6 without the need for many of the auxiliary devices required by breakers that use a two-pressure gas system. A piston that moves with the contacts compresses gas, which provides the pressure differential required for arc interruption. A gas compressor, with its drive motor and pressure control switches, is not required. The gas is not stored at high pressure, so the high-pressure reservoir, with its heaters and controls, is also eliminated. The auxiliary power requirements are greatly reduced and there are fewer breaker auxiliaries, so maintenance is reduced and breaker reliability is improved with the puffer-type breaker.

It is desirable that research on SF_6-gas interrupters be directed so that the knowledge gained can be applied to the puffer interrupter concept. EPRI has had a four-year project with General Electric that concerns a fundamental investigation of arc interruption in gas flows (RP246). So far the investigation has been confined to the thermal interruption process that occurs around the current zero regime—the most critical element in establishing the desired performance in an interrupter. The effort has investigated interrupter design parameters (which can be controlled by the switchgear designer) to determine their influence on interrupter performance. Results of the first phase of this four-year effort were published in 1977 (EL-284), and second-phase results are nearly ready for publication.

The third phase of this project is now under way: a three-year effort to apply the new fundamental knowledge gained in the previous phases to SF_6 puffer-type interrupters. This phase will also investigate how design parameters affect the early dielectric recovery during the first 100 μs following current zero, another factor that can affect interrupter performance.

Much of the work in the first two phases of this project was done on dual-pressure interrupters. Single-pressure puffer interrupters are different in that the gas flow and interrupter pressure generated are functions of the interrupter stroke. In puffer-type interrupters, the gas flow in the nozzle is commonly blocked by the arc plasma during a portion of the arcing, which helps to reduce the amount of gas to be compressed for arc interruption. A part of this investigation will now be directed to a study of the effects of blocking and unblocking on interrupter performance.

Both single-flow and double-flow nozzles will be investigated to optimize their designs and to determine comparative performance.

The results of this project should help the switchgear designer to better meet the utilities' power circuit breaker requirements. *Program Manager: Narain Hingorani*

Light-fired thyristors

Light-fired thyristors have several potential advantages over electrically fired thyristors in HVDC rectifier/converter valves and for the control of reactive power (*EPRI Journal*, May 1979, p. 56). Light-fired thyristors are triggered by a light pulse transmitted through self-insulated optical fibers, which eliminates the problems associated with isolation of thyristor gates above ground potential. This improves the reliability of thyristors by reducing the number of electronic components required. Light-fired thyristors are also unaffected by electromagnetic noise that normally occurs where thyristors are used.

Westinghouse recently installed a light-fired switch to replace one electrically fired phase of a static VAR generator at Minnesota Power & Light Co.'s Shannon substation (RP567). This VAR generator had completed over a year of field testing with electrically fired thyristors and has started its second test year with the light-fired module. Although there were some startup problems, the unit now appears to be operating properly.

General Electric has completed work on a commercially acceptable 2.6-kV, 53-mm light-triggered thyristor (RP669). Both Westinghouse and General Electric are working on second-generation light-fired devices, each with added built-in self-protection to further reduce external electronic components.

In other projects General Electric is working on a 5-kV light-triggered thyristor, an improved light source (RP1291-2), an improved thermal package (RP1291-1), and forced-vaporization cooling (RP1207). Of course, the ultimate goal of these projects is improved reliability and lower costs and losses in thyristor assemblies that are employed in power switching and conversion applications. *Project Manager: Gilbert Addis*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

UTILITY PLANNING METHODS

In the past, EPRI's Energy Analysis Department focused on developing a fact base for use in EPRI and utility planning. Methods and data were developed for forecasting fuel resource availability and costs, as well as national and regional patterns of electricity demand. The results of this research were made available to utilities for planning activities. However, the forecasting methods themselves were not designed for application by utilities. Now the department is also focusing on the definition and development of planning methods that will be useful to various groups within utilities. Thus its concern has shifted from the facts utility planners need to how they apply those facts (along with internal information) to arrive at business decisions.

One important reason utilities need better planning methods is that they must often replicate their analyses for external regulatory bodies. EPRI expects many of the methods being developed for utilities to be used extensively by state utility and energy commissions and federal agencies. This has already been the case with the over/under capacity planning model (RP1107), which has been used by nearly 100 utilities and regulatory commissions.

The development of utility planning tools requires input from three programs in the Energy Analysis Department: the Systems Program, the Demand and Conservation Program, and the Supply Program. A departmentwide committee oversees all research in this area. Current projects involve the development of detailed integrative planning models and broad corporate models, as well as the definition of long-term strategic issues and options.

Detailed integrative planning models

This effort draws on the previous modeling experience of utilities in generation expansion planning and production costing. Models developed for those purposes are now being expanded to include details of such demand-side options as time-of-day rates, direct load controls, customer conservation options, and cogeneration.

The Tennessee Valley Authority (TVA) has extensive experience in both generation expansion modeling (TARANTULA) and production cost modeling (POWRSYM). It has also acquired considerable data from field experimentation with direct load controls and customer conservation. EPRI is helping to integrate these new demand-side data into the TVA models and to facilitate data transfer to the rest of the industry (RP1808E). This effort is being coordinated with a similar model development project managed by EPRI's Electrical Systems Division (RP1529).

Detailed integrative planning models seek to optimize both supply-side options and demand-side options. This objective is the same as that embodied in the cost-benefit analysis requirements of the Public Utility Regulatory Policies Act (PURPA), which have been researched in EPRI's Rate Design Study. The examination of rate issues and load management issues by the Rate Design Study has stimulated the development of an integrative model that may help utilities and rate commissions sort out the complex issues involved in implementing PURPA (RP950).

Another project involves an integrative planning model for evaluating load management strategies (RP1485). The user selects combinations of load management options, which the model then scores in terms of quantifiable outcomes, such as customer cost, energy conservation, and utility revenue and costs. This model is intended to be integrated with a technology mix model—both models were developed by Decision Focus, Inc. It should be useful not only to utilities but also to EPRI's Energy Management and Utilization Division, which is studying load management technologies to determine which are most compatible with rate structures and other actual utility conditions.

Corporate planning models

Utility corporate planning departments need models that are small enough to be run quickly by a small staff; they do not need or want all the information incorporated in detailed integrative planning models. They want a tool that is flexible enough to take into account many judgments about future financial and regulatory conditions and that produces clear, defensible results.

A working group of the Utility Modeling Forum is surveying and comparing the corporate planning models now used by utilities (RP1303). Information from this study will help guide EPRI in developing a new model under RP1819E. The development effort will draw on corporate planning model techniques in use outside the electric utility sector and on the latest techniques available from university business schools. The objective is not to develop a definitive corporate planning model but rather to develop a generic corporate modeling system that can be easily adapted to the circumstances of individual utilities. The newly formed Corporate Planning Committee of the Edison Electric Institute (EEI) is providing advice and support for this project.

The corporate model development effort, like much of the other work in the Energy Analysis Department, places great emphasis on the role of capital constraints in utility decision making. This emphasis simply recognizes the severity of the financial pressures on the industry and the likelihood that conditions will get worse before they get better. The department does not intend to quantify the financial problems of the industry as a whole or to make prescriptions about solutions to these problems at the national or the utility level. What is intended is to provide each utility with better tools for analyzing the full implications of these financial problems for its decisions.

Definition of long-term strategic issues

In most corporations, strategic planning is deliberately separated from operations planning and capital planning (capital budgeting). Sometimes called business portfolio analysis or diversification analysis, strategic planning evaluates business opportunities that are expected to arise over a period of 5–10 years and determines which fields are attractive for a corporation to be involved in and which are not. Utilities must now pay more attention to this kind of planning because energy conservation is resulting in a deceleration of load growth, and load management, customer conservation, decentralized electricity generation, and cogeneration are presenting some unusual challenges and diversification opportunities.

The Energy Analysis Department is planning two series of workshops on strategic issue definition. One series, in cooperation with EEI, is for senior executives of investor-owned utilities. The other, in cooperation with the American Public Power Association, is for senior executives of publicly owned utilities. These workshops will provide an opportunity to examine current utility strategic planning practices and possible improvements and to identify the key strategic issues facing utilities. It is hoped that they will help EPRI define new research projects in the area of utility strategic planning. These projects may or may not involve further model development.

Model transfer

To ensure that the new planning tools being developed by EPRI will be used by small and medium utilities as well as by large companies, it is necessary to go beyond the traditional transfer mechanism of workshops and conferences to develop new, more direct mechanisms. User groups for individual software packages can serve as a vehicle for the exchange of information on bugs in a model and on individual refinements and extensions of the model. Often these groups grow out of the advisory groups that support the model development effort. Another experiment in technical transfer is the Energy Analysis Model Applications Center (RP1814), which will promote the use of selected software packages by utilities, assist these users, and provide feedback to EPRI about overcoming barriers to model application. The Utility Modeling Forum also serves as a mechanism for information exchange within the industry and helps keep EPRI up-to-date on model development needs.

Extended focus

EPRI's Energy Analysis Department has traditionally conducted research studies on the external supply and demand conditions facing electric utilities. These attempted to narrow the range of uncertainty in forecasts of the external environment. Now the department is also attempting to develop planning methods that utilities can use to make sound business decisions despite the existence of large and growing uncertainties. *Department Director: James Plummer*

ECOLOGICAL EFFECTS OF ACID DEPOSITION

A major international conference on the ecological effects of acid deposition was recently held in Norway. There appears to be general agreement that the acidity of surface waters in Norway, Sweden, Canada, and the United States has increased within the last 100 years and that acid precipitation has been a factor. However, questions still remain about the timing and magnitude of the acidification and about the relationship between acidification and a watershed's biogeochemical characteristics. Models are needed to quantitatively predict how surface waters react to different levels of deposition of atmospheric acids. In the case of terrestrial ecosystems, not enough data exist to permit general quantification of the effects of acid deposition. Because of the complexity of the phenomena involved in the interaction between acid deposition and aquatic and terrestrial ecosystems, it is advantageous for research organizations to develop cooperative international efforts.

This past March, one EPRI staff member and several EPRI contractors participated in the International Conference on the Ecological Impact of Acid Precipitation, held in Sandefjord, Norway. The conference was organized as part of a Norwegian research program on the effects of acid precipitation on forests and fish (the SNSF project). The meeting marked the conclusion of the $95 million project, which started in 1971 under the joint sponsorship of the Norwegian Council for Scientific and Industrial Research, the Agricultural Research Council of Norway, and the Norwegian Ministry of Environment. Approximately 300 researchers attended the conference. Countries most heavily represented were Norway, Sweden, the United States, the United Kingdom, and Canada, but participants also came from the Netherlands, Belgium, Denmark, Italy, Spain, the Philippines, Poland, Finland, the Federal Republic of Germany, and India. This wide range of participation reflects the growing international interest in acid precipitation.

EPRI had three objectives in participating in the conference: to learn the results and hypotheses of other researchers in this field and the directions they intend to follow; to inform other participants about EPRI's acid precipitation research; and to develop plans for cooperative research with other organizations.

Research by other organizations

Freshwater Ecosystems Data were presented to indicate that surface waters in regions of Norway, Sweden, Canada, and the United States have become more acid in the last several decades and fish populations have declined. A member of the SNSF project presented a method for predicting lake acidification based on an empirical relationship between a lake's calcium concentration and the average annual pH of precipitation (*1*). This method generated considerable discussion at the meeting, and participants showed strong interest in testing its validity. It should be noted that the relationship describes an equilibrium and not a dynamic situation (i.e., it is to be used to determine the final response of a lake to continual precipitation at a given average pH, but it does not incorporate a basis for predicting how long the lake will take to reach its final state).

Changes in land use have been claimed to be a major factor contributing to the acidification observed in Norwegian lakes. Another member of the SNSF project presented a correlation analysis of acidity in Norwegian lakes and land use in their watersheds (*2*). He reported no major significant correlations between acidification and land use.

Terrestrial Ecosystems Two excellent papers dealt with the effects of acid deposition on vegetation. One reviewed the literature on the effects on agricultural crops and discussed possible mechanisms by which effects could occur (*3*). The author noted that experiments in which agricultural plants had been treated with simulated acid rain have yielded a wide range of results, including positive, negative, and no effects. He stated that not enough data were available to quantify the effects on agricultural production and suggested the following hypotheses for testing:

- Rain with a pH above 4 presents a low risk to agricultural crops.
- Rain with a pH between 3 and 4 can have positive, negative, or no effects, depending on species, cultivar, environmental conditions, cultivation practices, and rainfall patterns.
- Rain with a pH below 3 presents a serious general risk if it occurs repeatedly during the growing season.

The other paper reviewed the state of knowledge about effects on forest vegetation (*4*). Experiments in which forest vegetation was treated with simulated acid rain show the same range of results as experiments on agricultural crops—positive, negative, and no effects, depending on experimental design and species. The author hypothesized that when increased growth was observed, it was primarily a result of increased nitrogen availability. He further suggested that in certain forest systems acid precipitation might have positive short-term effects as a result of increased nitrogen and sulfur availability but long-term negative effects as a result of increased leaching of calcium and magnesium from the soils. He stressed the need for long-term studies.

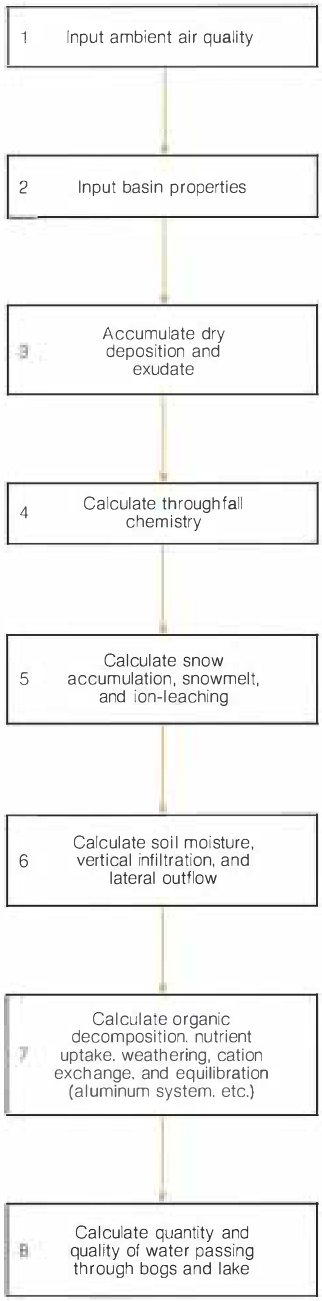
EPRI research

Freshwater Ecosystems Previous research by others has reported a link between acid deposition and surface water acidification. Now the quantitative nature of the link must be established. A theoretical framework is needed for predicting how the acidity of surface water will react over time to given levels of deposition of atmospheric acids; this framework must take into account the biogeochemical characteristics of drainage basins. To evaluate the effectiveness of various control and mitigation strategies, it is necessary to predict how lakes not now acidified will react if acid deposition continues at current levels, and how all lakes will respond to changed levels of acid deposition and various liming strategies.

EPRI is attempting to develop a mathematical model for making such predictions through its integrated lake-watershed acidification study (ILWAS), described in an earlier *EPRI Journal* (September 1979, p. 20). In this project, researchers are amassing data on three Adirondack lakes: Woods Lake, which shows considerable acidity; Sagamore Lake, which has a variable pH; and Panther Lake, which has an approximate average annual pH of 7. At the Sandefjord conference, representatives of EPRI and its contractors made one oral and seven poster presentations on ILWAS. Because the study had just reached the point where enough data had been collected to permit interpretation to begin, the results reported were preliminary and could be considered working hypotheses.

The objectives and scope of ILWAS were defined, as well as the role of its mathematical model. A schematic of the model was presented (Figure 1). It was reported that the hydrological, canopy chemistry, and snow chemistry modules of the model had been coded and were being tested, and that the soil biogeochemistry module was being programmed. Hydrograph comparisons of the observed outflow and the simulated outflow for one watershed (Panther Lake) showed good general agreement (Figure 2).

Figure 1 Schematic of the ILWAS mathematical model for determining the contribution of atmospheric acids to the acidification of surface waters. The model simulates ecological processes that consume and produce acids in a lake-watershed system, calculates the quantity and quality of water in each component of the system, and integrates the results. Steps 6 and 7 are repeated for litter, organic, and inorganic soil layers.



The annual inputs and outputs of major ions for the three ILWAS watersheds were presented. The annual input of hydrogen ions for all three watersheds exceeded the output, while the annual outputs of the magnesium, calcium, sodium, potassium, and aluminum cations exceeded the annual inputs. The net gain of hydrogen ions from the atmosphere could account for the net loss of basic cations from the acid watershed, Woods (average outlet pH about 4.7), but not for the loss from the neutral watershed, Panther (average outlet pH about 7).

Much of the data collected on lake acidification are derived from regional surveys, in which water quality for a particular location has been sampled only once. ILWAS data, based on year-round water quality sampling, indicate that lake alkalinity can fluctuate considerably with depth and time (Figure 3). Panther shows the greatest seasonal variation and Woods the least. During the spring thaws of 1979 and 1980, alkalinity measurements for the Panther outlet declined dramatically, but it has been shown that this increased acidity during snow thaws is a result of acidification in the surface water only, not at all depths. Why do the three lakes respond so differently to similar atmospheric inputs? ILWAS researchers have hypothesized that soil depth is a major factor determining the different behavior of Woods and Panther watersheds. Measurements indicate that the soils of the Panther watershed are considerably deeper.

A summary of the atmospheric input data for the ILWAS watersheds was presented at the conference. Major ions in the precipitation were H^+, NH^+, Ca^{++}, $SO_4^{=}$, and NO_3^-. Summer peaks of sulfate and hydrogen ions were observed. Sulfate and nitrate were nearly equal during the winter months.

Terrestrial Ecosystems Although no results were available for presentation at Sandefjord, three EPRI research projects are under way that address the need for data on the effects of acid deposition on agricultural and forest productivity: a microcosm evaluation of acid deposition on forest ecosystems (RP1632); a study of the effects of acid precipitation on agricultural crops in the Northeast (RP1812); and a study of the effects of acid precipitation on the nutrient status of forest ecosystems (RP1813). Several projects are planned to study crops in other sections of the country and to quantify dry deposition rates of acid substances.

Development of cooperative research efforts

Norway, Sweden, and the United Kingdom have major research programs on the eco-

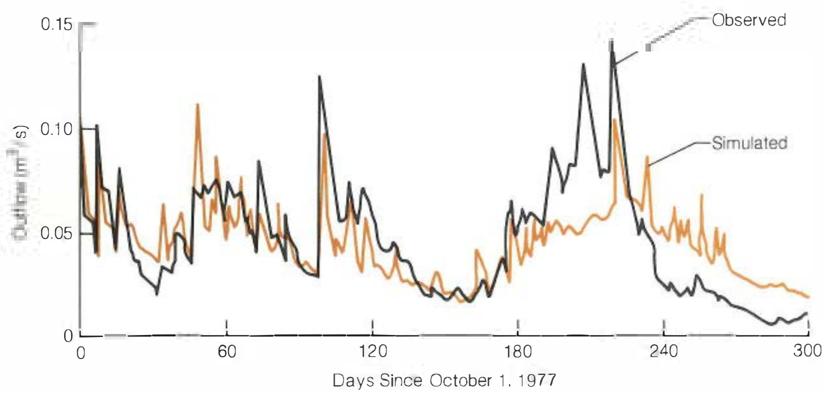


Figure 2 Simulated and observed outflows of water from the Panther Lake watershed. Over the period of simulation, the total simulated outflow and the total observed outflow are nearly identical, at approximately 1.15×10^6 m^3. During periods of high precipitation and snowmelt, water tends to move through the real system faster, possibly because of a subsurface layer that has a significantly lower hydraulic conductivity than the overlying soil.

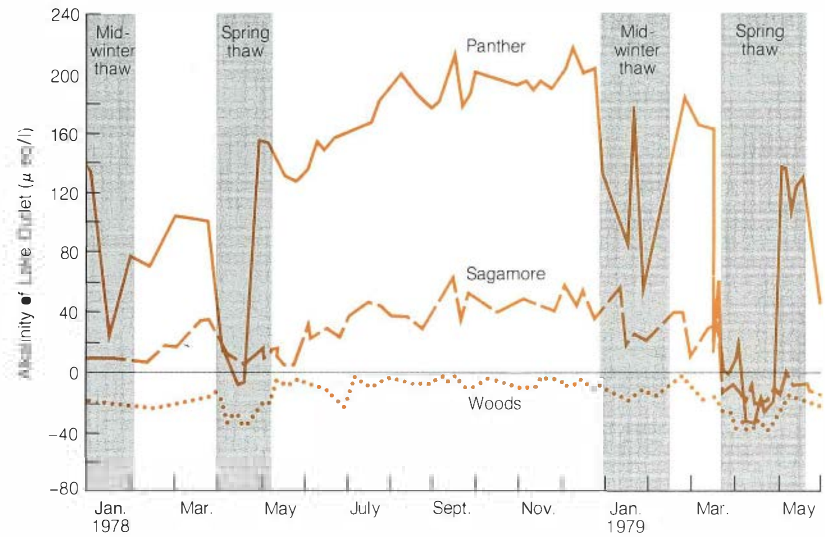


Figure 3 Alkalinity of outlets for the three ILWAS watersheds exhibit considerable temporal variation. Variation is greatest for the Panther Lake watershed, which has an average annual pH of approximately 7. Decline in alkalinity is greatest during snowmelt periods. Alkalinity of outlets tends to reflect the alkalinity of a lake's surface water and is not necessarily indicative of all depths.

logical effects of acid precipitation. To put research monies to the most effective use, EPRI and organizations in other countries will cooperate in analyzing and synthesizing existing data and plan future research efforts that will be mutually supporting. EPRI has actively pursued these goals since it became interested in acid deposition in 1976. Discussions of possible cooperation first took place in May 1977 at a meeting of research managers hosted by the Swedish Environmental Protection Board. At this meeting EPRI proposed to organize an international workshop with the UK Central Electricity Research Laboratories (CERL) to define the current state of knowledge about the ecological effects of acid deposition. This workshop was held in September 1978 and resulted in two EPRI publications: the workshop proceedings (EA-79-6-LD) and and international inventory of ongoing and planned acid deposition research.

At the Sandefjord conference several new cooperative activities were discussed: a joint planning-review exercise this summer with Swedish scientists to study the applicability of the ILWAS mathematical model to Swedish data and research; a workshop next winter with SNSF modelers to review ILWAS and SNSF modeling approaches and data; and the participation of CERL scientists in ILWAS. CERL proposed to support a series of experiments on the neutralizing capacity of soils. These experiments would involve exposing various soils, including those from the ILWAS watersheds, to different acid treatments.

The Sandefjord conference presented a valuable opportunity to exchange research results and ideas and to develop plans for cooperative efforts. The proceedings of the conference will be published by the SNSF project later this year. Questions about their availability should be addressed to the project at P.O. Box 61, 1432-Ås-NLH, Norway. *Project Manager: Robert Goldstein*

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Presented at the International Conference on the Ecological Impact of Acid Precipitation, Sandefjord, Norway, March 11–14, 1980.

1. A. Henriksen. "Acidification of Fresh Waters: A Large-Scale Titration Process."

2. D. Drabløs and I. Sevaldrud. "Lake Acidification, Fish Damage, and Utilization of Outfields: A Comparative Survey of Six Highland Areas in Hedmark County, Eastern Norway."

3. J. S. Jacobson. "The Influence of Rainfall Composition on the Yield and Quality of Agricultural Crops."

4. G. Abrahamsen. "Acid Precipitation, Soil Structure, and Soil Chemistry."

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Director

ADVANCED FUEL CELL TECHNOLOGY

Currently, two types of fuel cells are being examined in EPRI's advanced fuel cell technology subprogram: acid fuel cells (with an operating temperature of about 200°C) and molten carbonate cells (about 650°C). The objective of this work is to achieve power plant heat rates of 7500 Btu/kWh with cell materials and components that are capable of operating for at least 40,000 h. The major goals are to improve the performance and materials of the acid fuel cell cathode and to redesign the molten carbonate fuel cell to allow manufacture of practical units. Program and project background has been discussed in previous EPRI Journal *articles (June 1978, p. 34; November 1978, p. 6; November 1979, p. 40).*

Acid fuel cells

According to EPRI's assessment of the acid fuel cell, progress can be made in the areas of performance, cost, and endurance. The major opportunities lie with the oxygen electrode; hence a group of projects focus on its materials and construction (RP1200). When this work started in 1978, it was evident that state-of-the-art, nonproprietary air (oxygen) electrodes were only marginally suitable for utility applications. As a means of reducing stack and power plant costs, increased operating temperature and pressure conditions were considered. These conditions exacerbate corrosion of the catalyst support, however, as well as recrystallization and dissolution of the high-surface-area platinum catalyst. Materials able to tolerate these conditions were investigated under RP1200, and those developed are being tested at Energy Research Corp. (RP1200-1). The specific areas of study are described below.

Catalyst Supports A catalyst support must be electronically conductive and stable. Also, it must have a high surface area to allow the catalyst crystallites to be dispersed at a considerable distance from each other; this is necessary to maintain a high catalyst surface area and to avoid losses in the electrode from diffusion limitations. There is evidence that catalyst surface area increases with increasing support area but reaches a limiting value for support areas in the 200–250-m^2/g range (RP1200-2).

Until 1978 the material most commonly used as a catalyst support was Vulcan XC-72 (Cabot Corp.), a conducting furnace black with a surface area of about 250 m^2/g. This material has corrosion properties that make it unsuitable for operation in a utility environment for long periods. Work by Stonehart Associates, Inc., has been aimed at finding a substitute for Vulcan with a higher corrosion resistance (RP1200-2).

Various classes of carbons that have received different chemical treatments have been examined. It was concluded that graphitic supports tend to have rather low surface areas (100 m^2/g or less), and they are difficult to catalyze satisfactorily and make into electrodes. Kocite supports (prepared by depositing cracked hydrocarbons on alumina and then leaching the alumina) have fairly satisfactory corrosion rates but are not easily fabricated into good electrodes (UOP, Inc.; RP1200-3). Acetylene blacks have low corrosion rates, with a steam-treated version (925°C) giving the lowest values yet discovered—about two orders of magnitude lower than that of Vulcan XC-72 at fuel cell operating conditions (RP1200-2). This support is easily catalyzed, has a surface area of over 200 m^2/g, and can be made into satisfactory electrodes. Another interesting development is the production of a fluorinated, phosphonated Vulcan by ECO, Incorporated (RP1200-6). The phosphonic acid groups promote wetting and appear to act as anchor sites for platinum crystallites, as suggested in previous work by Exxon Research and Engineering Co. (RP1200-4). Final reports on RP1200-3, RP1200-4, and RP1200-6 will soon be available.

While the supports described above are relatively satisfactory, alternatives to carbon may be required under more extreme operating conditions, for example, if new electrolytes result in improved oxygen electrode activity. Future research will examine this possibility.

Catalysts Work under RP1200-2 has shown that adequate catalyst surface area can be maintained for 40,000 h; thus platinum corrosion and recrystallization appear to be less of a problem than first suspected. Another encouraging finding (by Lawrence Berkeley Laboratory, RP1200-5) is that platinum crystallites on carbon can be converted by simple chemical treatment into high-surface-area intermetallic compounds of the Engel-Brewer type (Pt-V, Pt-Zr, Pt-Ta). These have about twice the specific activity of pure platinum and are considerably more stable with respect to recrystallization. This finding could lead to significantly improved heat rates and longer lifetimes.

Electrolytes Work by Case Western Reserve University under RP1200-7 has demonstrated the instability of concentrated phosphoric acid under hydrogen electrode conditions at high temperature (200°C). Thus cell operation requires a more dilute acid. An advantage of this is the lower evaporation rate of the acid; a disadvantage is the higher corrosion rate of the carbon supports at high water-vapor partial pressures (RP1200-2). Clearly, compromise conditions are necessary. Further work is planned in this area.

Molten carbonate fuel cells

Cell Structures In contrast to work with acid fuel cells, where the focus is on improving the performance of one component (the air electrode) of a definitive structure, work on the molten carbonate cell involves a complete structural rethinking. Before 1979 all molten carbonate cells were constructed by a method dating from about 1960. This uses an electrolyte consisting of a hot-pressed tile that contains the carbonate electrolyte (approximating $LiKCO_3$ in composition) and an inert binder (now $LiAlO_2$ powder). Despite the fact that this tile becomes a thixotropic paste at working temperatures (about 650°C), it is the cell's basic building block.

Since the ionic resistance (IR) of the tile represents a large percentage of the resistance of the whole cell, large cells require relatively thick (0.03 in) tiles and consequently show high internal losses in comparison with phosphoric acid cells. Classical laboratory cells use electrodes smaller in diameter than the tile, whose edge is sandwiched between two metallic current collectors and is protected from gas leakage by a thin molten carbonate film (wet seal). This structure is impractical because the thermal expansion of the tile (below its melting point) and the expansion of the metal hardware are not matched; hence the thick tiles develop cracks. These cracks do not heal on heating up and lead to cell failure. Thus the structure is not thermally cyclable. Also, the hot-pressing technique cannot easily be scaled up to an economical process for manufacturing practical-sized cells.

A primary objective of EPRI's molten carbonate fuel cell research is to design cell structures that have a lower IR loss, are simpler in construction, and are able to maintain pressure integrity even on thermal cycling. United Technologies Corp. (UTC) successfully addressed some of the problems involved, as well as problems of stack design (Figure 1), in a project that served to define approaches for DOE's molten carbonate fuel cell development program (RP114). Further work on new types of low-cost, thermally cyclable cell structures is being pursued at UTC (RP1085-4), and related efforts are under way at General Electric Co. (RP1085-1) and Energy Research Corp. (RP1085-3). As new structural concepts are proved, they will be incorporated into EPRI's fuel cell systems subprogram for scale-up and testing in stacks; they will also be incorporated into DOE's program if the time scale allows.

Systems A second major area of molten carbonate cell research involves the problems inherent in fuel cell systems. As part of RP1085-1, General Electric is assessing conceptual combined-cycle power plant systems that use either coal or oil fuels. Oil-fired plants appear to have some promise for cogeneration applications, while coal-fired plants in a suitable combined cycle should be capable of yielding heat rates of 6800 Btu/kWh (coal to ac power). In another project the Institute of Gas Technology (IGT) is measuring carbonate evaporation rates at high pressures to enable accurate inventory estimates that will make long cell lifetimes possible (RP1085-2). Previous work under RP1085-1 and -2 determined that the sulfur tolerance of molten carbonate fuel cells is low; however, complete sulfur removal upstream of the fuel cell represents only a small ($40/kW) cost penalty. Physical Sciences, Inc., is modeling carbonate loss with time and examining the possibility of carbonate makeup by vapor phase addition (RP1085-5). Finally, UTC is studying the kinetics of other possible gas-phase chemical reactions (carbon formation and methanation) so that operating limits for the system as a whole can be defined (RP1085-4).

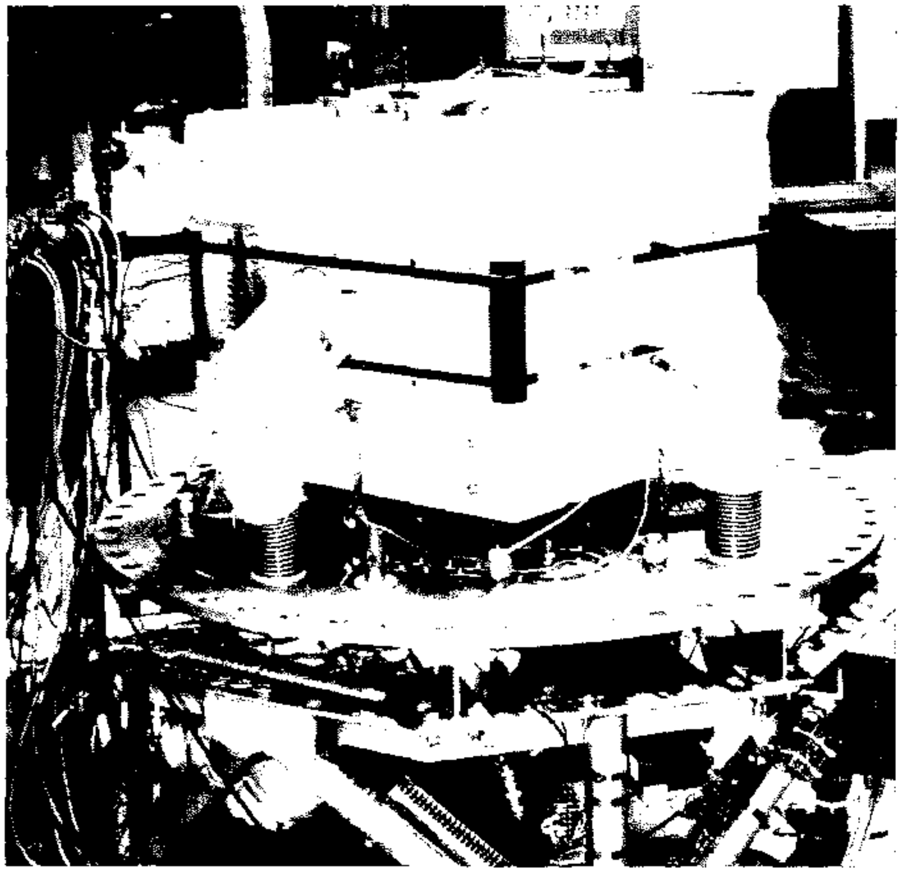


Figure 1 Molten carbonate fuel cell proof-of-principle stack. This stack was successfully tested over 2000 h by United Technologies Corp. and was subjected to five thermal cycles.

Performance Improvement IR losses have been improved by the use of thinner electrolyte layers in practical cell configurations as discussed above. IGT is examining the effect of electrolyte composition on cell performance, particularly that of the cell cathode (RP1085-2). While polarization problems in the molten carbonate cell cathode are not serious compared with those in the acid cell, there is enough potential improvement to warrant attention. UTC is also working in this area as part of RP1085-4.

Outlook

The acid fuel cell is currently capable of heat rates of 8300 Btu/kWh, and its performance should improve as a result of the advanced components being developed in this subprogram. In particular, the use of alternative synthetic acids could yield significant improvements in the longer term. The molten carbonate fuel cell is still in an early state of development, but results on practical, real-world structures are promising, and performance and lifetime are close to expectations. Future work on molten carbonate cells will concentrate on performance improvement and on new materials, particularly those contributing to higher stability (e.g., new cathode materials to replace nickel oxide) and lower costs (e.g., copper alloys for anode materials). *Project Manager: John Appleby*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

HUMAN FACTORS ENGINEERING

The effectiveness of nuclear power plants depends on the performance of individual components. One of the most critical of these components is man. Human factors engineering (HFE) is the science of applying behavioral principles to systems by integrating the human element with system hardware, software, environment, and information. The major objectives of HFE are to prevent human error and achieve more efficient operations. Particular emphasis is placed on the capabilities and limitations of the people who operate and maintain the system, the tasks they must perform, and what they need to accomplish those tasks. HFE research in EPRI's Nuclear Power Division addresses man-machine interface problems specific to the nuclear power industry.

Two related phrases that have been used more and more frequently since the Three Mile Island accident are *man-machine interface* and *human factors engineering.* They are not always used precisely, however. The confusion extends to *human engineering,* which often appears as a synonym for human factors engineering but is actually only one element of an integrated HFE program.

HFE was pioneered by the armed forces during World War II, and the criteria formulated by the U.S. Air Force (with emphasis on a systems approach) serve well as working definitions for the application of HFE to the nuclear power industry. According to Air Force Regulation (AFR) 800-15, HFE is concerned with engineering and management tasks that promote effective human performance in a system. As a part of the mainstream engineering effort throughout the system life cycle, HFE seeks to improve the system by optimizing the performance of those who operate, maintain, support, and control it. AFR 800-15 specifies five major elements.

□ Human engineering: the application of knowledge about human capabilities and limitations to system and equipment design in order to meet desired system performance requirements through the most effective use of these capabilities

□ Biomedical aspects: the development of provisions for the health and safety of personnel throughout the system and for their protection, survival, escape, and recovery in the event of an accident

□ Manpower and personnel requirements: the identification of manpower and personnel requirements to ensure that enough trained people are available to operate, maintain, and support the system or equipment

□ Training: the development of training requirements, plans, equipment, support data, and facilities

□ Human factors test and evaluation: the determination of whether personnel can in fact operate, maintain, and support the system in its intended operational environment

The HFE program in EPRI's Nuclear Power Division has projects in all areas except the last, but its major focus is human engineering.

Plant design and man-machine interface

Under RP501-1 the human factors aspects of five operational nuclear plant control rooms were studied, and several minor and major deficiencies were identified (NP-309). A follow-on project addressed the feasibility of correcting deficiencies on a retrofit basis, with particular emphasis on corrections that could be made while the plant remained operational (RP501-3). It was concluded that several changes were possible that would improve the man-machine interface and reduce the likelihood of operator errors.

□ The use of taped lines to demarcate and highlight functionally related subgroups of panel elements

□ The replacement of atomistic, repetitive labeling of each panel element with a hierarchical labeling system to reduce operator search time

□ The use of distinctive shapes or color coding in large arrays of identical controls to minimize chances of accidental activation of the wrong control

□ The use of raised barriers or covers to protect key controls against accidental disturbance

□ The coding of meter faces to allow readings that indicate normal operation to be easily distinguished from readings for out-of-tolerance or dangerous conditions. This work is described in detail in a four-volume report (NP-1118); a summary report is also available (NP-1118-SY).

Research was initiated in July 1980 to develop a human engineering design guide tailored to the needs of the nuclear power industry (RP1637). The guide will present human engineering criteria and principles (derived from empirical research) that will be helpful to design engineers in making design trade-off decisions. It will be extensively indexed for ease and efficiency of use. The project is expected to be a two-year effort.

Plant operations and maintenance

A project nearing completion has reviewed the HFE aspects of maintenance activities at five nuclear plants and four fossil fuel plants (RP1126). These areas were investigated: equipment design; accessibility for maintenance; environmental factors; coding and labeling practices; adequacy of spares, tools, and fixtures; malfunction monitoring and diagnostic aids and procedures; and provisions for scheduling and tracking maintenance activities.

A number of problem areas were identified and substantiated—many with photographs. Manning levels consistently have been underestimated for maintenance activities at all five nuclear plants and, to a lesser extent, at the fossil plants. Standard coding and labeling practices generally have not been followed. High-noise, high-radiation, and high-temperature environments pose problems. Designs frequently violate anthropometric standards; in fact, the most common complaint of maintenance personnel is that it is difficult to gain access to the equipment to be serviced. Other problems include crowded working conditions, inadequate tools and spares, and the lack of a well-planned, well-run training program. A final report on this project is due shortly.

A project is under way to develop and evaluate job performance aids (JPAs)—detailed, step-by-step task instructions—for power plant applications (RP1396). The usefulness of such technical instructions has been demonstrated in the military. They are based on a comprehensive task analysis of the job to be performed and are presented as an easy-to-read text with many illustrations.

In the military, JPAs have been used primarily in connection with maintenance tasks; EPRI is testing them in a number of other functional areas. Nine JPAs are in various stages of the development and validation process. Utilities participating in this program are Philadelphia Electric Co., Public Service Electric and Gas Co. (New Jersey), the Tennessee Valley Authority (TVA), Toledo Edison Co., and Detroit Edison Co. Results will be available in December 1980.

Other HFE activities

A project is being conducted (1) to provide an empirical data base for statistical analysis of operator reliability; (2) to develop a method for evaluating the effectiveness of control room designs and operating procedures; (3) to develop a system of rating operator performance for use in training evaluations; and (4) to support research on operator selection (RP769-2).

To meet these objectives, a performance measurement system has been developed that is capable of automatically recording statistical information on operator actions and plant response. Exercises involving both normal and emergency procedures for PWR and BWR plants are being run on TVA's simulators at Browns Ferry and on Duke Power Co.'s McGuire simulator. The project is scheduled for completion in December 1980. Preliminary results are very encouraging, and both trainees and instructors have commented favorably on the completeness and fairness of the performance measurement system.

Protective garments currently used by maintenance personnel in nuclear plants do not have the cooling capability required for unfavorable temperature and humidity environments and, in addition, are bulky and cumbersome. It is not uncommon for a worker to be limited to 20–30-min periods of productive activity. In response to this problem, EPRI is sponsoring a project to develop a cooling garment that will increase a worker's exposure tolerance to 2–2½ h (RP1705). Three prototype garments are under development for testing in a controlled laboratory environment. If results are positive, the garments will be tested in an operational environment. Results will be available in late 1980 or early 1981.

Other HFE projects in the planning or the initiation stage include a communications study, a study of normal operating procedures, and a compilation of an anthropometric data base specific to the nuclear power industry. HFE personnel are also supporting work within EPRI on disturbance analysis and surveillance systems (RP891), assisting the Institute of Nuclear Power Operations in the development of HFE benchmarks of excellence, and cooperating in human factors efforts by NRC, DOE, EEI, and IEEE. *Program Manager: Howard L. Parris*

TURBINE MISSILE CONCRETE IMPACT TESTS

Full-scale rocket-sled tests are proving that reinforced-concrete reactor containment buildings are highly resistant to postulated impacts by high-energy turbine fragments. Such missiles could conceivably be produced by the highly unlikely failure of the shrunk-on steel disks that retain the rotating blades of large steam turbines. The test results demonstrate that current design practices regarding turbine missile effects are conservative. Full-scale testing at the rocket-sled facility of Sandia Laboratories in Albuquerque, New Mexico, is a key component of EPRI's research in this area. Supplemented by analyses and scale-model tests, the full-scale tests are providing valuable information to support plant licensing.

Turbine rotors in nuclear and nonnuclear power plants are highly reliable components. Major failures have occurred only once per few thousand turbine-years of operation worldwide, and this record is expected to improve as a result of advanced technology being applied in modern steam turbines. Nevertheless, the safety implications of possible rotor failure continue to be considered in design and licensing of nuclear plants.

The potential failure of main interest in nuclear plant design is the rupture of a steel disk that holds one of the rows of rotating blades in the low-pressure section of an 1800-rpm steam turbine. In the event of a disk rupture, fragments weighing as much as several tons could leave the rotating shaft at high speeds. In some cases the fragments would be contained within the heavy steel turbine casing. This is what happened in the 1974 Shippingport failure and in the Yankee Rowe failure earlier this year; no missiles were produced by these failures. However, in other failures, it is possible that fragments could break through the casing. This has happened in a few U.S. and foreign fossil fuel plants and in one foreign nuclear plant, but turbine missiles have not been produced by U.S. nuclear plants in approximately 400 operating-years of experience.

If missiles were produced by disk failure, most of the possible trajectories would not intersect the plant at all, although some could intersect the containment or auxiliary buildings. These buildings have reinforced-concrete walls that are 0.6–1.8 m (2–6 ft) thick to protect the safety-related equipment. In the current phase of its missile impact research, EPRI is examining the resistance of reinforced-concrete structures to turbine missile impact. Earlier phases of the program provided valuable data on how steel casings slow or stop turbine fragments and how concrete walls protect plants from tornado-driven debris, such as pipes and poles. (Documentary films of earlier tests are available for loan or purchase on written request to the EPRI project manager.)

A turbine missile striking a containment building would be tumbling, and the angle of impact would be random. Such a blow would not be as severe as the kind being simulated in the full-scale tests at Sandia—a head-on impact of a nontumbling turbine fragment. The target structure (Figure 1) represents a section of the reinforced-concrete wall of a PWR containment building. It is typical of actual nuclear plants—1.4 m (4.5 ft) thick, with eight layers of reinforcing bars 5.7 cm (2.3 in) in diameter arranged in three mats. The wall is 6 m (20 ft) square and weighs 154,000 kg (338,000 lb). The wall is cast horizontally; after curing, it is moved on rollers in front of the massive concrete backup structure and lifted into place.

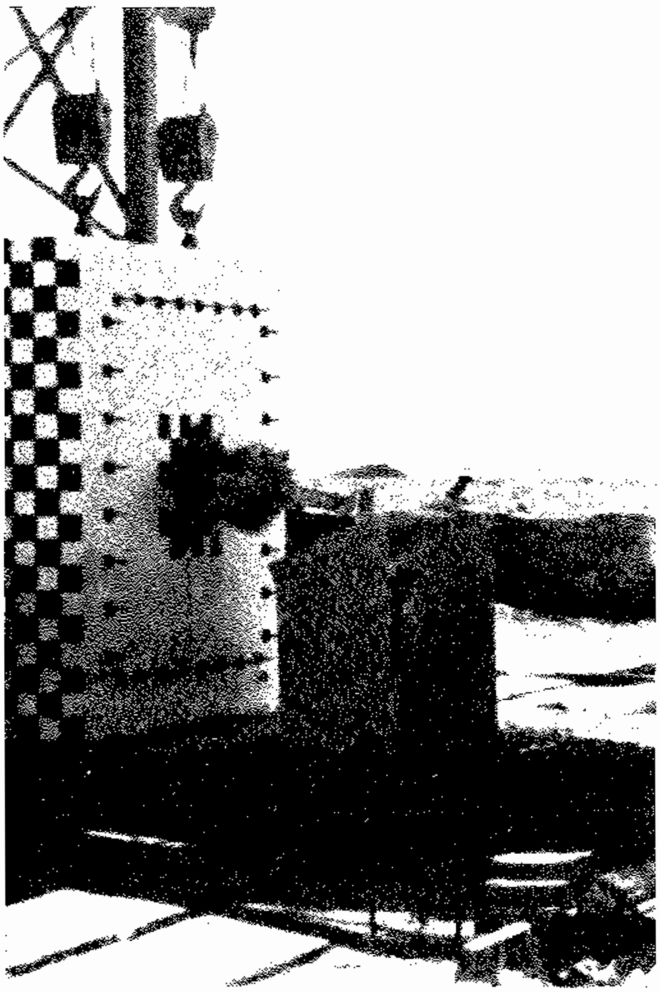
Three tests were performed with a 120° segment of a shrunk-on disk provided by Westinghouse Electric Corp. The 1500-kg (3250-lb) missile had no blades—it was assumed that the blades would be broken off or crushed during the disk's exit through the turbine casing.

The impact velocity in the first two tests was 90 m/s (200 mi/h), which equaled the greatest exit velocity measured in the earlier full-scale casing impact tests at Sandia. This represents the failure of a turbine disk spinning 20% faster than normal operating speed and accounts for the substantial energy dissipation caused by impact with the casing. Since the impact orientation of a tumbling missile would be random, two extreme orientations were used in the tests—a piercing orientation (with sharp-corner impact) and a blunt orientation (with curved-edge impact).

In the test with piercing orientation (Figure 1), the missile penetrated 0.5 m (19 in), or one-third the thickness of the wall. In the test with blunt orientation, the penetration depth was only about half that much. An important result of these tests is that the rear surface of each wall was only slightly cracked; formulas currently used in plant design predicted much more damage (pieces of concrete thrown from the back of the wall).

In the third test the piercing orientation was again used, and the impact velocity of the missile was increased to 130 m/s (295 mi/h), which corresponds to a failure at about 50% above normal operating speed. The target wall was identical to those in the previous tests, except that a steel plate 1 cm (3/8 in) thick was anchored to its rear surface during construction. This represented the leakproof liner plate installed in all conventional PWR containment buildings. The missile penetrated 0.6 m (25 in) into the wall and produced a slight bulge (4 cm; 1.6 in) in the liner plate. The results contrast sharply with those of current design formulas, which predict almost total perforation of the wall by the missile.

The fourth and final test of this series was performed with a heavier missile (2060 kg; 4540 lb) in the piercing orientation. The missile was a 137° disk segment provided by General Electric Co. The test velocity was specified to be the same as in the third test (130 m/s; 295 mi/h), giving a 40% in-



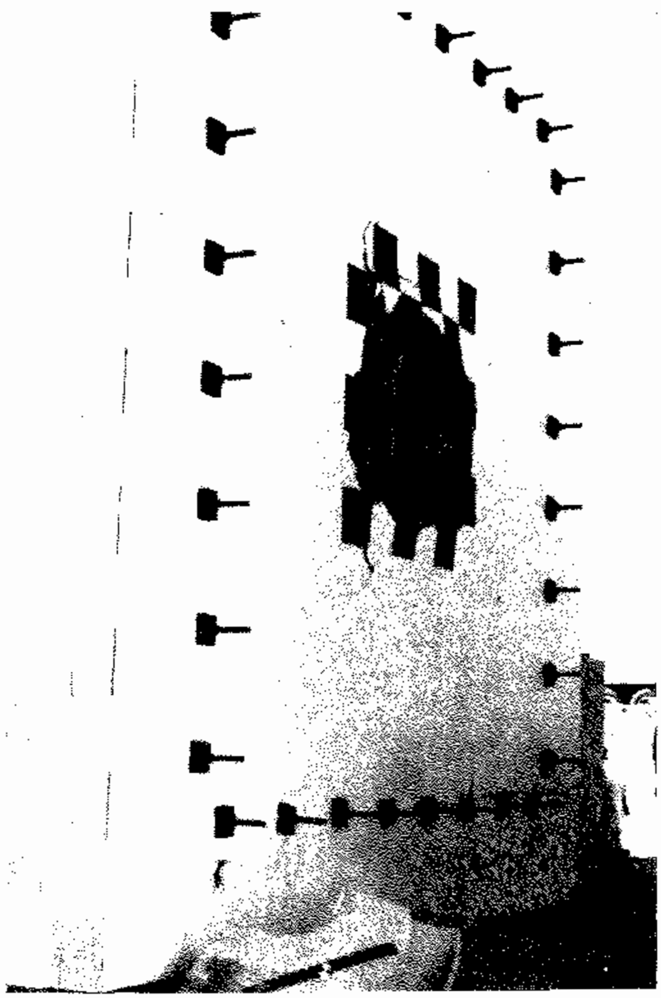


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Figure 1 Full-scale turbine missile test at the Sandia rocket-sled facility: **(a)** impact of the turbine disk fragment on the 1.4-m (4.5-ft) thick reinforced-concrete wall section; **(b)** minor damage produced by the missile in a worst-case (piercing) orientation.

crease in missile kinetic energy. However, because 2 of the 16 rockets misfired, the actual impact velocity in the fourth test was only 115 m/s (257 mi/h), giving an 8% increase over the third test in missile kinetic energy.

The slightly greater missile energy produced slightly greater target response. The missile penetrated 0.67 m (26 in) into the wall and produced about a 5-cm (2-in) bulge in the liner plate. Although the desired increase in impact energy was not achieved, this test result contributed significantly to the understanding of turbine missile impact on reinforced concrete.

Because of the high cost of these tests, no further full-scale testing is planned at present. Instead, low-cost scale-model tests are being designed to study a wide range of missile, target, and impact parameters. Scoping tests using $\frac{1}{11}$-scale models have already been performed in the gas-gun laboratory of SRI International (RP393). Results from SRI model tests in which a 1.1-kg (2.5-lb) missile impacted a target 12.5 cm (5 in) thick were remarkably similar to those of full-scale tests with piercing orientation.

Information from full-scale and scale-model tests of steel casings and concrete protective structures is being used in a separate study to assess the overall risk from turbine missiles (RP1549). As part of this work Battelle, Pacific Northwest Laboratories is reexamining current estimates of the probability of missile generation and is developing a method to determine the characteristics of missiles that may exit from a turbine casing. Another contractor, Research Triangle Institute, Inc., is reviewing existing methods of evaluating turbine missile risks; it will also develop improved calculations of missile trajectories and impact damage and will apply an improved methodology to typical case studies.

Results of the current series of full-scale concrete tests will be available in the last quarter of 1980. Scale-model tests examining various impact conditions will continue into 1981. The entire program, including the risk analysis, is scheduled to be completed by the end of 1981. *Project Manager: George Sliter*

ALTERNATIVE ALLOYS FOR BWR PIPING

Over the past decade, there have been a number of occurrences of intergranular stress corrosion cracking (IGSCC) in the weld-heat-affected zones of type-304 stainless steel piping in certain lines of BWRs. While these incidents have not presented undue risk to public health and safety, they have resulted in costly reductions in plant availability. A research effort is in progress to select and qualify alternative BWR piping alloys and to introduce them into service, both in new plants and as a replacement for type-304 stainless steel pipes in operating plants (RP968). Statistical testing of full-size welded pipes is being used to qualify alloys as immune to IGSCC for the plant design lifetime. On the basis of successful test results and other criteria, two alloys have been selected for further testing: nuclear-grade type-316 and nuclear-grade type-304 austenitic stainless steels. The former is being installed in 18 plants under construction, and the latter is being considered as a replacement material in one operating plant.

A fundamental understanding of the phenomenon of IGSCC in welded 304 stainless steel pipe was developed in earlier EPRI research, and the key contributing factors were identified (NP-944). Three factors are necessary for IGSCC to occur—weld sensitization, tensile stresses, and facilitating environmental conditions. The effect that any one of these factors will have depends on the level of intensity of the other factors; to prevent IGSCC in welded 304 stainless steel, the coincidence of the three factors must be avoided.

On the basis of this model for IGSCC, a number of engineering solutions to the problem were identified. Three potential solutions, or pipe countermeasures, were developed and evaluated: solution heat treatment of pipe welds, corrosion-resistant cladding, and heat sink welding (NP-1222). These countermeasures were developed primarily for plants that are committed to 304 stainless steel piping. Solution heat treatment and corrosion-resistant cladding have been implemented in a number of plants.

Another engineering solution to the problem is to qualify a commercially available alternative piping alloy that is immune to cracking over the 40-year plant lifetime. In this solution a sensitized microstructure is avoided because of the alloy's chemical composition, in particular its carbon content. On the basis of this criterion (chemical composition), five commercial stainless steel pipe alloys were selected for evaluation in the program: nuclear-grade type-316, nuclear-grade type-304, type-347, type-316, and type-CF-3.

A nuclear-grade material, as defined by General Electric, is a material that is used primarily in critical nuclear steam supply system components and thus must meet extraordinary requirements. This material can be procured only from sources technically approved by General Electric. Nuclear-grade specifications are more rigorous than standard industry specifications in the areas of chemistry, cleanliness, heat treatment, melting process, hot working, microstructure, mechanical properties, surface finish, change control in the process, and approval of the sources of the material. Draft specifications for nuclear-grade 304 and 316 stainless steel pipes have been prepared. These limit the carbon content to 0.02 wt% and nitrogen to 0.06–0.10 wt%.

To determine which alloys are the most resistant to IGSCC and to demonstrate long-term performance capabilities, a statistical test program was formulated. This program involved the testing of full-size welded pipes to provide results that could be scaled to reactor service. In addition to the alternative alloys, 304 stainless steel was tested as a reference material. High stresses, cyclic loading, postweld grinding, and high levels of dissolved oxygen in the 288°C (550°F) high-purity water were used to accelerate the time to failure. The key criterion for qualification of an alloy was improvement over 304 stainless steel by a factor of 20 in the time to first failure. The factor of 20 is based on field experience and translates into an improvement that is conservatively equivalent to the plant design lifetime.

To meet the needs of the statistical qualification test program, General Electric constructed a special laboratory capable of testing 72 pipe specimens 10.16 cm (4 in) in diameter and two pipe specimens 25.4–40.6 cm (10–16 in) in diameter. Screening tests of the alloys and the 304 stainless steel reference material were made. Four of the five alternative alloys—nuclear-grade 316 stainless steel, nuclear-grade 304 stainless steel, 347 stainless steel, and CF-3 cast stainless steel—achieved the test goal of improvement by a factor of at least 20.

After the screening tests, a decision methodology based on the Kepner-Tregoe technique was used to select two alloys for final qualification testing and introduction into BWR service. In addition to the demonstrated improvement over 304 stainless steel in terms of susceptibility to IGSCC, these factors were considered: design strength properties, ASME coded material, availability, industry and NRC acceptability, fabrication properties, and economics. On the basis of this analysis, nuclear-grade 304 and nuclear-grade 316 stainless steels were selected.

Statistical pipe qualification testing of the nuclear-grade 304 and 316 austenitic stainless steels is continuing. Additional heats of the alloys and some large-diameter pipes have been procured for evaluation. A 40.6-cm (16-in) diameter pipe specimen of the nuclear-grade 316 alloy is shown in Figure 2. A limited number of tests are planned to verify the statistical results on the 10.16-cm (4-in) pipes.

Although this program is not completed, the capability of nuclear-grade 304 and 316 alloys to operate over the plant lifetime without IGSCC has been demonstrated by statistical testing of 10.16-cm (4-in) welded pipes. These results have played a key role in the decision of 18 utilities to install nuclear-grade stainless steel piping in plants under construction. In several of these plants, type-304 stainless steel piping already in place was completely scrapped and replaced. *Project Manager: Joseph C. Danko*

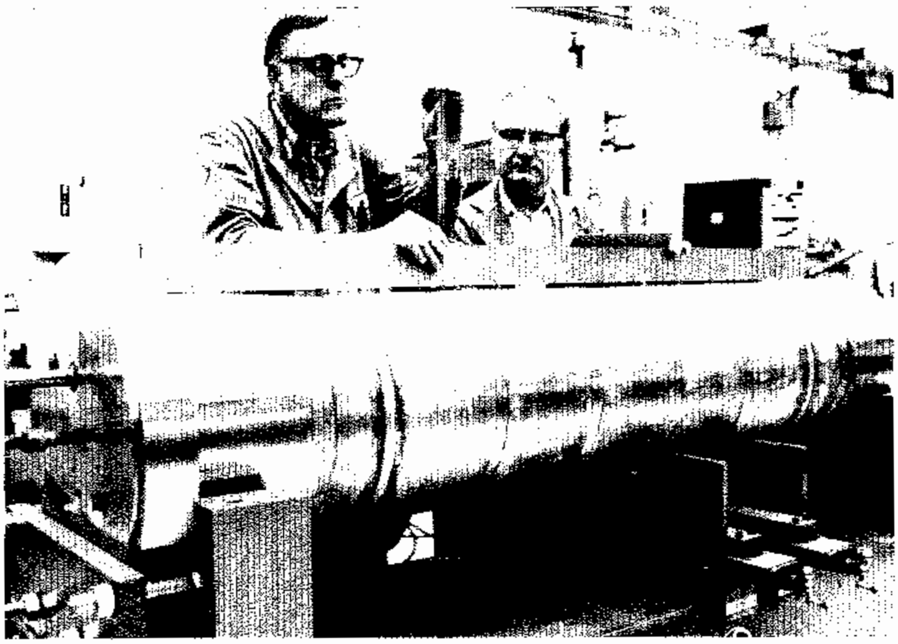

Figure 2 A 40.6-cm (16-in) diameter pipe test specimen of nuclear-grade type-316 stainless steel. This alloy is being used by 18 utilities for piping in plants under construction.

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP68-6	Project UHV: Modeling	6 months	29.1	Ohio State University *R. Kennon*
RP422-7	DCE–ACT Construction Management Services	15 months	2606.1	C F Braun & Co. *J. Bartz*
RP501-5	Survey and Analysis of Communications Problems in Nuclear Power Plants	6 months	55.8	General Physics Corp. *H. Parris*
RP606-7	Investigation of Advanced Acoustic and Optical NDE Techniques	33 months	167.5	Spectron Development Laboratories, Inc. *J. Quinn*
RP642-4	Development of Power Consolidation Circuits for MHD Applications	2 years	337.6	General Electric Co. *R. Schainker*
RP810-9	Approaches to Nonlinear Soil-Structure Interaction Design	6 months	19.6	Science Applications, Inc. *C. Chan*
RP875-4	Load Forecasting Method	27 months	8.3	Elrick and Lavidge, Inc. *S. Peck*
RP910-2	Trace Element Removal by Adsorption/ Coprecipitation on Iron Hydroxide (Engineering Evaluation)	2 years	205.4	Brown & Caldwell *W. Chow*
RP982-23	Lime Data Book Update	1 year	76.2	Black & Veatch Consulting Engineers *C. Dene*
RP986-8	Cost Estimate: Power Plants Using Gas From Coal	9 months	200.0	The Ralph M. Parsons Co. *B. Louks*
RP1008-2	Regional Load Curve Models: Sensitivity and Validation	6 months	50.0	Quantitative Economic Research, Inc. *A. Faruqui*
RP1021-6	Fracture Irradiation Embrittlement Investigation	2 years	89.2	Fracture Control Corp. *T. Marston*
RP1031-3	Calcium Sulfite Crystallization	28 months	83.3	University of Arizona *D. Stewart*
RP1085-4	Development of Improved Molten Carbonate Fuel Cell Technology	15 months	636.9	United Technologies Corp. *A. Appleby*
RP1085-5	Modeling of Long-Term Decay in the Molten Carbonate Fuel Cell	18 months	102.1	Physical Sciences Inc. *A. Appleby*
RP1179-9	Design and Testing Concepts for TVA–EPRI Pilot Plant Test Program	5 months	44.8	Pope, Evans & Robbins, Inc. *W. Howe*
RP1201-13	Evaluation and Comparison of the State-of-the-Art Techniques for Energy Conservation by Reduced Losses in AC Motors	8 months	50.0	University of Minnesota *R. Ferraro*
RP1216-4	Energy Forecasting for the Commercial Sector	4 months	18.9	ADM Associates, Inc. *E. Beardsworth*
RP1237-2	Validation and Implementation of the Two-Criteria Failure Assessment Procedure	13 months	99.6	Babcock & Wilcox Co. *D. Norris*
RP1260-19	An Assessment of Municipal and Industrial Wastewater Reuse as Makeup for Steam Electric Generating Stations	9 months	38.2	Water Purification Associates *W. Chow*
RP1276-6	Evaluation of Dual Energy Use Systems (DEUS) Cogeneration Systems Design: Paper Industry	15 months	310.8	KPFF Consulting Engineers *B. Mauro*
RP1316-6	Evaluation of Statistical Methods and Data Base for Relating Air Pollution to Human Health	8 months	32.3	Sigma Research, Inc. *R. Wyzga*
RP1318-2	Validation and Calibration of the EPA Integrated Assessment Model	10 months	55.0	Massachusetts Institute of Technology *P. Ricci*
RP1321-6	Frey Computer Code Portability Study	4 months	12.0	Science Applications, Inc. *R. Oehlberg*
RP1339-2	Economic and Engineering Analysis of Arc-Fired Furnaces	7 months	114.5	Foster Wheeler Energy Corp. *E. Cichanowicz*
RP1340-2	Demonstration of Cooling Tower Blowdown Treatment	13 months	20.0	Southern California Edison Co. *W. Chow*
RP1443-1	Alternative Containment: State-of-the-Art Review	4 months	84.3	Anco Engineers, Inc. *W. Bilanin*
RP1444-2	Response of Foundations in Soft and Improved Ground	19 months	52.0	Weidlinger Associates *C. Chan*
RP1455-6	Structural Studies of Coal-Oil and Coal-Water Fluids	3 months	10.5	University of Massachusetts *R. Manfred*
RP1493-1	Uplift/Compression: Transmission Line Structure Foundation	13 months	190.8	Cornell University *P. Landers*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1514-1	DC Conductor Development	23 months	556.2	Alcoa Conductor Products Co. *J. Dunlap*
RP1579-4	Nuclear Waste Disposal: Criteria Development and Safety Assessment	9 months	219.9	Analytical Sciences Corp. *B. Williams*
RP1604-2	Characterization of Wyoming Subbituminous Coals and Liquefaction Products by Fourier Transform Infrared Spectrometry	3 months	9.8	Advanced Fuel Research, Inc. *L. Atherton*
RP1625-2	Chemical Composition of Atmospheric Particles by Transmission Electron Microscopy	3 months	9.0	University of Tennessee *J. Guertin*
RP1636-1	Investigation of Bird Flight Interaction With Overhead Transmission Lines	13 months	111.8	Clemson University *J. Huckabee*
RP1644-1	Epidemiology Study of Utility Employees Exposed to High-Voltage Electric Fields	14 months	139.9	Tabershaw Occupational Medicine Association *L. Sagan*
RP1646-3	Fugitive Emissions From Coal-Fired Power Plants	9 months	12.0	Bechtel National, Inc. *D. Giovanni*
RP1648-3	Wear of Steam Turbine Journal Bearings at Low Operating Speeds	11 months	97.4	Battelle, Columbus Laboratories *J. Parkes*
RP1672-1	Geothermal Fluid Process Technology	23 months	380.0	Bechtel National, Inc. *V. Roberts*
RP1690-1	IBM/PDQ-7 Predictor-Corrector Installation	5 months	9.9	G.R.P. Consulting, Inc. *W. Eich*
RP1691-2	Evaluation of Shale Oil as a Utility Gas Turbine Fuel	1 year	284.0	United Technologies Corp. *H. Schreiber*
RP1707-4	Correlation Between Aging and Seismic Qualification for Nuclear Plant Electric Components	22 months	126.3	Wyle Laboratories *G. Sliter*
RP1714-1	Software Development and Maintenance Guidelines	15 months	139.4	Science Applications, Inc. *J. Lamont*
RP1716-1	High-Voltage Stator Winding Development	22 months	503.3	General Electric Co. *J. Edmonds*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1735-1	Electric Utility Use of Coal-Derived Fuels: Health, Personnel Protection, and Regulatory Considerations	1 year	139.8	Gulf Mineral Resources Co. *W. Weyzen*
RP1741-1	Study of Efficient Numeric and Physics Modeling Methods for the Analysis of LWR Transients	7 months	100.0	Argonne National Laboratory *G. Srikantiah*
RP1742-1	Cost-Benefit Analysis of Visibility Reduction	15 months	232.1	Charles River Associates, Inc. *R. Wyzga*
RP1757-1	Transfer of EPRI-Developed Technology to Standards and Codes Pertinent to Nuclear Pressure Vessel Integrity	1 year	34.5	Fracture Control Corp. *T. Marston*
RP1764-1	Parallel Multilevel State Estimation	13 months	49.8	Washington University *C. Frank*
RP1775-1	Evaluation of Existing Programs for Simulation of Building Energy Use	16 months	149.3	Arthur D. Little, Inc. *E. Beardsworth*
RP1822-1	Toxic Substances Subprogram Development Assistance	9 months	58.2	International Research and Technology Corp. *R. Brocksen*
RP1833-1	Impact of Load Management on Utility Load Shapes	8 months	77.3	Systems Control, Inc. *T. Yau*
RP1839-1	Action of Fuel Oil Additives Containing Magnesium and Manganese on Superheater and Reheater Surfaces	15 months	170.3	Battelle, Columbus Laboratories *J. Dimmer*
RP1845-2	Three-Dimensional Steam Generator Code, URSULA: Applications and Development	4 months	22.2	Cham of North America, Inc. *S. Kalra*
RP7876-10	Development of a Sensitive Technique for Detecting Water Molecules on the Surface and in the Bulk of Polyethylene	7 months	25.0	Western Kentucky University *M. Rabinowitz*
RP7884-1	Economic Evaluation of Pipe-Type Cable Systems	7 months	70.0	Systems Control, Inc. *S. Kozak*
RP7885-1	Emergency Ratings of Cable Terminations	18 months	119.9	G&W Electric Specialty Co. *J. Shimshock*

New Technical Reports

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

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ADVANCED POWER SYSTEMS

Large Wind Turbine–Generator Performance Assessment: Technology Status Report No. 1

AP-1317 Technical Report (RP1348-1); $4.50

This report assesses large wind turbine–generator development programs and test activities, and it develops an approach for gathering, distilling, and assessing test data. It summarizes DOE's large wind turbine development program and key private programs; describes the basic features of the DOE first- and second-generation wind turbines; and presents cost projections for electricity generated by clusters of second-generation turbines. The contractor is Arthur D. Little, Inc. *EPRI Project Manager: E. A. DeMeo*

Open-Cycle MHD Power-Conditioning and Control Requirements Definition

AP-1345 Final Report (RP642-1); $4.50

Line-commutated and forced-commutated inverters were compared and evaluated in terms of their suitability for MHD power applications. MHD-inverter-utility interface requirements were defined, and a forced-commutated inverter meeting these requirements was tested. Recommendations for future work were also developed. The contractor is Avco Everett Research Laboratory, Inc. *EPRI Project Managers: Andrew Lowenstein and Paul Zygielbaum*

Fusion Experimental Power Reactor (EPR) Design Tasks: Phase 1

AP-1347 Final Report (RP323-2); $16.50

This report describes research into several key physics and technology problem areas identified in an earlier experimental reactor study (ER-289). The areas investigated were plasma confinement, plasma heating, reactor refueling, and reactor first-wall regeneration. Two reactor refueling schemes were analyzed (convective transport and the use of high-speed frozen pellets), and tests of in situ wall replacement, using atomic coating processes, were conducted. The contractor is General Atomic Co. *EPRI Project Manager: D. J. Paul*

Conceptual Design of RST: An RF-Driven, Steady-State Tokamak

AP-1351 Final Report (RP323-3); $9.50

A project to develop the physics and engineering bases for a true steady-state tokamak reactor is described. The physics of a radio-frequency current drive that uses a variety of electromagnetic waves is discussed, and the device's novel superconducting toroidal magnetic field coil system is described, as well as techniques for impurity control and fueling. The contractor is General Atomic Co. *EPRI Project Manager: D. J. Paul*

Logistics Management of Paraho Residual Shale Oil

AP-1361 Final Report (RP1412-3); $4.50

This report describes the special considerations involved in producing, handling, and storing 4300 barrels of hydrotreated residual shale oil test material purchased by EPRI from the Paraho Development Corp. and the U.S. Navy in 1978. Loading and unloading operations, transportation, and storage are discussed, as well as recommendations for future handling techniques. The report includes the results of tests made on oil samples at various points in the logistics operation. The contractor is Radian Corp. *EPRI Project Manager: Leonard Angello*

Parameter Monitoring for Corrosion Control of Utility Gas Turbines

AP-1369 Annual Report (RP643-1); $5.25

Field data from 600 industrial gas turbine engines were analyzed to determine how fuel type, engine washing, air filtration, and site proximity to an ocean affect hot corrosion. The effects of sodium sulfate (with and without impurities), temperature cycling, and sodium in the fuel were determined by laboratory tests. An engine control system to monitor atmospheric and fuel-borne salt concentrations and to signal the need for an engine water-wash cycle was designed, built, installed, and tested. The contractor is United Technologies Corp. *EPRI Project Manager: R. L. Duncan*

Assessment of Drivers and Reactors for Inertial Confinement Fusion

AP-1371 Final Report (RP1346-1); $6.50

This assessment of particle beam drivers and reactors for inertial confinement fusion was prepared by a working group of fusion experts after a review of all available research in the field (and a classified briefing by DOE). Key technical, engineering, and economic issues were identified. The contractor is La Jolla Institute. *EPRI Project Manager: K. W. Billman*

COAL COMBUSTION SYSTEMS

Modeling the Fixed FGD Sludge Landfill, Conesville, Ohio: Phase 1

CS-1355 Final Report (RP1406-1); $5.75

This is the second in a series of reports evaluating the first full-scale flue gas desulfurization (FGD) sludge disposal system to use the IU Conversion Systems, Inc., sludge fixation process. (This system is in operation at the Conesville station of Columbus and Southern Ohio Electric Co.) The report describes Phase 1 of a groundwater modeling program and presents the data base and laboratory results used to develop, calibrate, and verify a two-dimensional, finite-difference hydrologic flow model for the study area. Phase 2 of the project will include extensive field monitoring for model verification and application. The contractor is Battelle, Pacific Northwest Laboratories. *EPRI Project Manager: D. M. Golden*

Development and Verification of Laboratory Model Techniques for Prediction of Near-Field Behavior of Cooling-Tower Plumes

CS-1370 Final Report (RP732-1); $6.50

Small-scale models of two existing mechanical draft cooling towers were developed, with water as the working fluid. The report summarizes modeling requirements and limitations and compares model test results with prototype data. It also discusses how plume buoyancy, ambient wind velocity, and plant location affect plume trajectories, tower recirculation, plume downwash, and plume merger. The contractor is the University of Iowa, Institute of Hydraulic Research. *EPRI Project Manager: John Bartz*

Feasibility of Retrofitting Catalytic Postcombustion NO_x Controls on an 80-MW Coal-Fired Utility Boiler

CS-1372 Final Report (RP982-12); $8.75

This report describes two catalytic postcombustion NO_x removal processes (the Chemico–Hitachi-Zosen process and the Kawasaki Heavy Industries–Electric Power Development Corp. process) and considers the technical feasibility and economic implications of retrofitting them on an 80-MW coal-fired utility boiler. A specification prepared for a typical 80-MW plant is included. The contractor is Stearns-Roger, Inc. *EPRI Project Manager: D. V. Giovanni*

Comparative Economics of Advanced Regenerable Flue Gas Desulfurization Processes

CS-1381 Final Report (RP784); $5.75

Eight flue gas desulfurization (FGD) processes, including advanced regenerable processes still in the development stage and selected commercial and semicommercial processes, are described and compared on an economic basis. Cost estimates were developed for a hypothetical FGD installation for a 500-MW utility boiler burning coal with a sulfur content of 3.5%. The contractor is Milton R. Beychok. *EPRI Project Manager: S. M. Dalton*

ENERGY ANALYSIS AND ENVIRONMENT

U_3O_8 Production Analysis for Nonsandstone Uranium Deposits
EA-733 Final Report (RP803-4); $9.50

The potential of producing U_3O_8 from these seven nonsandstone sources was investigated: vein-type deposits, wet-process phosphoric acid, copper leach solutions, uraniferous coal, black shales, extrusive rocks, and intrusive igneous rocks. No source showed outstanding promise. The contractor is NUS Corporation. *EPRI Project Manager: J. B. Platt*

Econometric Analysis of the Behavior of Natural Resource Prices
EA-1356 Final Report (RP1217-1); $7.25

The relationship between the rate of interest and the rate of change in natural resource prices was analyzed for 12 minerals, both metals and fuels. Simple econometric models for this relationship were defined and tested for substance and forecasting ability against 1900–1973 data. The contractor is Resources for the Future, Inc. *EPRI Project Manager: A. N. Halter*

Supply Models With Feedback Features
EA-1357 Final Report (RP1103); Vol. 1, $2.75; Vol. 2, $8.75; Vol. 3, $5.75; Vol. 4, $8.75

Volume 1 is an executive summary of this project, whose objective was to develop methods of incorporating adaptive (learning and feedback) behavior into energy supply models. Volume 2 reviews adaptive economics and recursive programming theories and methodologies; Volume 3 considers the feasibility of using adaptive economics in modeling coal supply; and Volume 4 reviews the system dynamics methodology and describes models that use it. The contractor is Economic Dynamics, Inc. *EPRI Project Manager: A. N. Halter*

Prototype Analysis of EPRI R&D Funding
EA-1366 Final Report (TPS79-701); $4.50

As a first step toward a quantitative framework to assist EPRI planners, a methodology based on decision analysis concepts was developed to evaluate net benefits of different total annual funding levels. The report evaluates various measures of R&D benefits and techniques for analyzing uncertainties. It also presents an application of the methodology and discusses problems to be addressed in future development work. The contractor is Applied Decision Analysis, Inc. *EPRI Project Manager: S. S. Sussman*

Modeling Plant Location Patterns: Applications
EA-1375 Final Report (RP953-1-2); $6.50

A computer model developed to predict probable locations of future (i.e., beyond 10 years) energy facilities is described. The model covers very large geographic areas and locates facilities with a county-level degree of accuracy. It is currently limited to baseload nuclear and coal-fired plants. Cases embodying capacity growth rates of 3–7% between 1978 and 2000 were run for the mid-Atlantic region and the Pacific Northwest, and the results were compared with projections by utilities and state agencies. The contractor is Johns Hopkins University. *EPRI Project Manager: S. S. Sussman*

Inventory of Organic Emissions From Fossil Fuel Combustion for Power Generation
EA-1394 Final Report (TPS78-820); $3.50

This report summarizes and evaluates published organic emissions data and bioassay results from fossil-fired electric power generation facilities. It also evaluates the sampling, sample preparation, and analytic methods used in developing these data. The contractor is GCA Corp. *EPRI Project Manager: P. W. Jones*

ENERGY MANAGEMENT AND UTILIZATION

Selected Delicacies in Experimental Design: Some Thoughts for the Battery Engineer Who Wishes to Avoid Statistically Flat Experiments
EM-1346 Technical Report (RP370-17); $5.25

This report presents an introductory essay on the use of statistical methods in designing advanced-battery experiments. Difficulties encountered in selected laboratories and in attempts to establish effective communication channels between statisticians and battery engineers are analyzed. Relevant reprints from *Chemical Engineering* and *Industrial Quality Control* are included. The contractor is Science Applications, Inc. *EPRI Project Manager: W. C. Spindler*

Assessment of the Potential for Heat Recovery and Load Leveling on Refrigeration Systems
EM-1348 Final Report (RP1087-1); Vol. 1, $3.50; Vol. 2, $12.00

This project investigated potential residential, commercial, and industrial applications of heat recovery from refrigeration units and evaluated their effects on electric utilities. It assessed potential energy and cost savings, the state of the art of the technology, various applications of heat recovery, and alternatives to heat recovery. Barriers to implementing heat recovery systems were also examined, along with approaches for removing them. Volume 1 summarizes the project, and Volume 2 presents detailed findings. The contractors are Arthur D. Little, Inc.; Planning Research Corp.; and Applied Energy Systems. *EPRI Project Manager: Quentin Looney*

Master Metering of 20 Solar and 20 Nonsolar Homes
EM-1362 Interim Report (RP1191-2); $2.75

This is a brief history of a project that is gathering diversity-of-demand information from comparable solar and nonsolar homes. Solar and nonsolar systems, monitoring and metering equipment, and system performance to date are described. A final report will analyze and compare demand data from the two groups of houses. It is hoped that eventually such data will enable predictions about the effect of a large number of solar homes on the participating utility's system. The contractor is Public Service Co. of New Mexico. *EPRI Project Manager: G. G. Purcell*

Individual Load Center–Solar Heating and Cooling Commercial Project: Detailed Design Activities, Phase 2
EM-1363 Final Report (RP844-2); $4.50

Detailed designs were developed for combined load management–solar heating and cooling systems for use in six commercial buildings. These designs are based in large part on parametric studies of system performance, using simplified models of the buildings and their heating and cooling equipment. The next phase of the project will entail system construction, experimentation, and data analysis. The contractor is Arthur D. Little, Inc. *EPRI Project Manager: G. G. Purcell*

Evaluation of Digas Cooling for Utility Fuel Cell Power Plants
EM-1365 Final Report (TPS79-725); $3.50

This report presents an assessment of the technical and economic feasibility of pressurized, gas-cooled fuel cell stacks for dispersed power plants. It includes conceptual design parameters for the fuel cell, fuel processor, and recirculating fan, as well as a detailed technical analysis of heat exchangers. The conceptual design of a 5-MW power plant is described, its performance analyzed, and costs of the recirculating-gas-loop components estimated. The conceptual design of a proof-of-concept demonstration unit is also presented. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: E. A. Gillis*

NUCLEAR POWER

Human Factors Methods for Nuclear Control Room Design: Human Factors Methods for Conventional Control Board Design
NP-1118 Final Report, Vol. 3 (RP501-3); $6.50

This volume, the third of four making up the final report, describes the application of human factors concepts to the design of conventional hardwired control boards and warning systems. Three control room subsystems were evaluated: reactor control, steam generator feedwater control, and turbine-generator control. Human factors checklists based on aerospace standards were applied to man-machine interfaces in five control rooms. Work included systems analyses, function and task analyses, preliminary board design efforts, and design verification. The contractor is Lockheed Missiles & Space Co., Inc. *EPRI Project Managers: R. W. Pack and H. L. Parris*

The URSULA2 Computer Program User's Manual
NP-1315 Final Report, Vol. 3 (RP1066-1); $6.50

URSULA2 is a computer code for analyzing steam generator thermal hydraulics. This volume presents information on code structure, flow charts, grid notations, coding style, and use of secondary storage. Subroutines and subprograms are divided into four functional groups and explained; emphasis is placed on the control and data input subroutines. Guides for the preparation of input data and for the interpretation of program output are provided, along with a program listing and a glossary of FORTRAN variables. The contractor is Cham of North America, Inc. *EPRI Project Manager: J. P. Sursock*

Review of Analytic Methods for Improvement of Nuclear Power Plant Availability
NP-1334 Final Report (SOA78-412); $4.50

This report presents a state-of-the-art review of methods for analyzing possible ways to improve nuclear plant availability. It covers mathematical programming, comparative trade-off analysis, allocation of availability goals, development of optimal preventive maintenance policies, and analytic tools for implementing on-line monitoring, job scheduling, and optimal plant layout. The feasibility of computerizing plant availability analysis is also discussed. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Boyer Chu*

Light Water Reactor Study Using RETRAN Models

NP-1342 Final Report (RP1320-1); $8.25

The RETRAN code was used to perform transient analyses for a BWR (Peach Bottom, Unit 2) and a PWR (Arkansas, Unit 2). Transients considered for the BWR, all at 100% power, were turbine trip without bypass, main steam isolation valve closure, and feedwater controller failure. Transients considered for the PWR were turbine trip at 100% power, complete loss of flow at 80% power, full-length rod drop at 50% power, and part-length rod drop at 50% power. The contractor is Nuclear Associates International, Inc. *EPRI Project Manager: J. A. Naser*

A Prediction of LOFT L1-4 (NRC Standard Problem 7)

NP-1350 Key Phase Report (RP695-2); $10.50

This report presents a prediction of LOFT (loss-of-fluid test) L1-4. The RETRAN computer code was used to analyze the test, an isothermal 200% cold leg break blowdown. The report also documents extensive post-data-release analyses, including several significant model changes and a revised calculation of the first 22 seconds of the 70-second transient. The contractor is Energy Incorporated. *EPRI Project Manager: L. J. Agee*

Comparison of Experimental Results With RETRAN Prediction for LOFT L2-3 (NRC Standard Problem 10)

NP-1352 Interim Report (RP496-1); $6.50

This report presents a prediction of LOFT (loss-of-fluid test) L2-3. The RETRAN computer code and state-of-the-art models were used to analyze the first 20 seconds of the test, which was a 200% cold leg break blowdown of a heated nuclear core at a nominal power of 36.7 MW. Experimental data are compared in overlay plots with the RETRAN prediction parameters. The contractor is Intermountain Technologies Inc. *EPRI Project Manager: L. J. Agee*

A Study of Pool-Swell Dynamics in a Mark II Single-Cell Model

NP-1353 Final Report (RP693-1); $5.75

The dynamics response of a Mark II pressure-suppression system during the early air-discharging phase of a postulated loss-of-coolant accident was studied in scale-model experiments. Tests using a single-downcomer scale model yielded quantitative information on the vent-clearing process, pool swell, the diaphragm floor differential pressure, and many other dynamic responses of interest. The report describes in detail the scaling considerations, the model, the instrumentation, and the test results. The contractor is SRI International. *EPRI Project Manager: C. W. Sullivan*

Optimization of Metallurgical Variables to Improve the Stress Corrosion Resistance of Inconel 600

NP-1354 Final Report (RP621-1); $8.75

Tests were conducted to define a heat treatment for PWR steam generator tubing that would improve its resistance to stress corrosion cracking (SCC). The grain boundary microstructure in Inconel 600 steam generator tubing was modified either by a thermal treatment in the carbide precipitation regime or by a high-temperature purification anneal. The tubing's SCC resistance was evaluated in caustic, pure-water, and lead-doped-water environments. The results of each test on the two treated pipes are described and compared. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. E. Smith*

The Prediction of Two-Phase Mixture Level and Hydrodynamically Controlled Dryout Under Low Flow Conditions

NP-1359-SR Special Report; $2.75

This report presents a theory for the thermal-hydraulic phenomena that occur during the uncovering of a flow channel. A model is described that defines a distinct equivalent collapsed-liquid level and a two-phase-mixture level. The constitutive relationship of these levels is defined, and analytic solutions are presented for the transient variation of both levels. These analyses are then compared with existing single-tube, rod bundle, and system data. *EPRI Project Manager: R. B. Duffey*

Loss-of-Feedwater Transients in PWR U-Tube Steam Generators: Simulation Experiments and Analysis

NP-1367-SR Special Report; $3.50

Thermal-hydraulic phenomena during simulation of transients involving a loss of secondary feed were studied by using a scale model of a PWR U-tube steam generator. Tests of both partial and total loss of feed were conducted, and secondary and primary flow conditions were observed. On the secondary side, vapor flow rate, dome pressure, bundle pressure losses, and two-phase density were measured; on the primary side, inlet temperature and temperature drop were recorded. The contractor is Acurex Corp. *EPRI Project Managers: S. P. Kalra and R. B. Duffey*

RETRAN Analysis of Semiscale Tests S-02-8 and S-06-4

NP-1373 Interim Report (RP695-1-3); Vol. 1, $5.25; Vol. 2, $5.25

Volume 1 describes a RETRAN analysis of Semiscale Tests S-02-8 and S-06-4 and compares the results with experimental data. Both tests involved a 200% double-ended cold leg break blowdown; S-06-4 also included emergency core cooling injections. The results for S-02-8 are compared with the previous RELAP4 analysis submitted to NRC for Standard Problem 5, and RETRAN's ability to predict large-break blowdowns is demonstrated. Recommendations for code and model development are made. Volume 2 contains appendixes presenting detailed results. The contractor is Energy Incorporated. *EPRI Project Manager: L. J. Agee*

SPEAR Fuel Reliability Code System: General Description

NP-1378 Interim Report (RP971-1, RP971-2, RP700-3); $6.50

This report describes the SPEAR fuel reliability code system (version ALPHA) and the methodology used in developing it. It discusses the code system's structure and major components: the data preparation routines, the mechanistic fuel performance model, the mechanistic cladding failure model, the statistical failure model, and sensitivity analyses. The contractor is Entropy Limited. *EPRI Project Manager: S. T. Oldberg*

New Endochronic Plasticity Model for Soils

NP-1388 Interim Report (RP810-5); $5.25

A new three-dimensional endochronic theory of plasticity is described that can predict the important features of soil response to seismic loading. It predicts elastic response at points where loading, unloading, or reloading begins and produces hysteresis loops that close for one-dimensional unload-reload processes. Models are developed for several simple types of deformation, including simple shear, hydrostatic compression, and densification under cyclic shear. The models are applied to appropriate existing soil data. The contractor is Systems, Science & Software. *EPRI Project Manager: H. T. Tang*

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