Power From Industry

ELECTRIC POWER RESEARCH INSTITUTE

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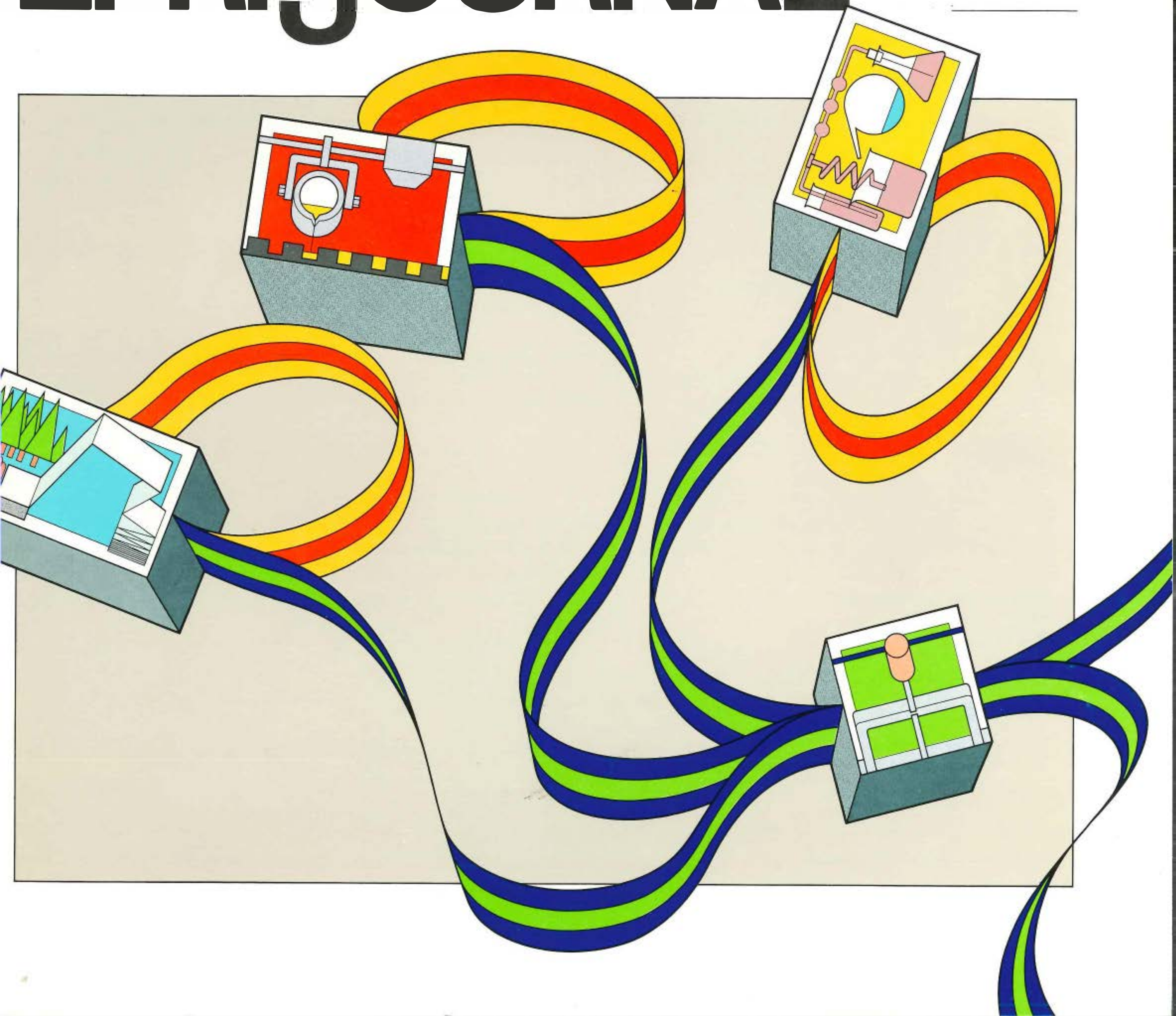

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EPRI was founded in 1972 by the nation's electric utilities to develop and manage a technology program for improving electric power production, distribution, and utilization.

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Cover: Cogeneration, the simultaneous production of electricity and process heat, is a growing practice among a wide variety of industrial firms. Electricity not consumed on site can be fed into the utility grid.

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Cogeneration: How Much?

Over the first 80 years of this century, cogeneration provided an ever-declining percentage of the electric energy used in this country. Today, less than 5% of the nation's capacity is of the cogenerating type. Cogeneration declined because energy users found it more attractive to purchase electricity generated with inexpensive fuels in larger and more efficient power plants. Since 1973, however, the economics of electricity supply have been changing under the combined impact of escalating fuel costs and inflationary cost increases of power plants and capital itself. In principle, cogeneration offers utilities and energy users a response to these cost pressures—by extracting the maximum amount of energy from fuels; by utilizing smaller, more rapidly constructed cogeneration facilities to provide needed capacity additions; and by shifting some of the power plant investment burden from utilities to energy users. With the National Energy Act, achieving this potential became part of national energy policy, and cogeneration is now being explored with renewed interest in many parts of the country.

But how robust is this revitalization? Can the cogeneration option become fully competitive in today's economic environment? Or is it based primarily on regulatory enforcement and, therefore, dependent on the political winds blowing from Washington, at the center of which is the issue of avoided costs? Or, finally, is it riding a wave of technology advances that will increasingly allow diverse and dispersed generation to be integrated economically into utility grids? While the answers to these questions will not be fully known for years, this month's cover story endeavors to shed some light on the issues surrounding cogeneration.

No discussion about the future of cogeneration is complete without consideration of the future industrial mix of the United States. Will industries that presently cogenerate expand or decline? If these industries survive, to what extent will their thermal requirements change? Will the much-talked-about industrial revitalization rely on new plants, or will it primarily involve modernizing existing facilities? Are new cogeneration opportunities emerging from established or newer industries? What will be the key fuels for future cogenerators, and will these fuels be as abundant as the fuels used by utilities? A critical and highly regional question is whether there is a need for additional generation capacity in the cogenerator's utility service area.

These are the types of questions that the electric utilities are attempting to answer for their service areas, and EPRI is assisting the industry in this effort while also developing a national perspective. Working closely with utilities and industry, EPRI is seeking to identify—and if appropriate, develop and demonstrate—new cogeneration technologies and applications that will benefit both suppliers and users of energy.

Robert L. Mauro
Program Manager
Industrial Applications
Energy Management and Utilization Division

Authors and Articles

Eighty years ago more than half of all U.S. electricity was produced by industry, along with the heat it needed for various manufacturing operations. Today's figure for such cogenerated electricity is less than 5%. **Plugging Cogenerators Into the Grid** (page 6), by science writer Mary Wayne, surveys the reasons for boosting the percentage up again, and it takes a long look at the problems involved.

Robert Mauro, who provided background for Wayne's article, heads a research program in industrial applications for EPRI's Energy Utilization and Conservation Technology Department. Before coming to the Institute in June 1978, Mauro was with the American Public Power Association (APPA) for more than four years, becoming its director of energy research. Because many industrial cogeneration units (actual or potential) have about the same capacity ratings as many municipal utility generators, Mauro is familiar with the technologies involved. He has concentrated on applications for relatively small, modular generating units. Mauro graduated in physics from Loyola College (Baltimore) and did graduate work, as well as research and teaching, in physics for four years at the University of Vermont.

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Absorption of laser pulse energy by a trace atmospheric gas is in proportion to the concentration of that gas. It sounds like a principle that could be put to work in air quality research. It has been.

Mapping Air Quality by Laser (page 15) is feature editor Ralph Whitaker's explanation of a new remote sensing system developed under EPRI guidance. Glenn Hilst, manager of the Institute's program for R&D in environmental physics and chemistry, furnished background on the concept and its application.

Hilst came to EPRI's Energy Analysis and Environment Division in October 1977 from The Research Corporation of New England (TRC), a research and consulting firm he had helped to form in 1960 and with which he spent 12 years as a department director and chief scientist. During the period 1970–1975 he was with Aeronautical Research Associates, Princeton, New Jersey. Hilst's research focus since 1960 has been the modeling of physical systems that control air and water quality. He was with General Electric Co. and Argonne National Laboratory between 1949 and 1960, developing and directing an atmospheric sciences program for the AEC Hanford Works. Hilst earned BS and MS degrees in meteorology at MIT and a PhD at the University of Chicago.

■

Synthetic fuels from coal will come on the scene much slower than first planned. Market interactions of other fuel prices and energy uses suggest that synfuels will foster, rather than suppress, the trend toward greater electrification.

The technologic bases for these and other conclusions are traced by Richard Balzhiser in **Synfuels and the Energy Transition** (page 21). His article, edited here by science writer John Douglas, was first developed as a speech for the 1981 annual convention of the Edison Electric Institute.

Now EPRI's vice president for R&D, Balzhiser was a part of the Institute's earliest management in 1973 as he organized, staffed, and directed the Fossil Fuel and Advanced Systems Division. For two years in the early 1970s he served in the White House Office of Science and Technology as assistant director for energy, environment, and natural resources. Balzhiser was on the chemical engineering faculty of the University of Michigan from 1960 to 1971, the last year as department chairman. He holds a BS and a PhD in chemical engineering and an MS in nuclear engineering, all from UM.

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High-strength alloys with nonuniform grain structure; big, thick, field-welded components; residual heat (thermal or radioactive) from reactor operation—all these converge to mean that in-service inspection of nuclear power plants is a special challenge.

NDE **Techniques and Technicians** (page 28) details the workings of a correspondingly special test and training center that is now completing its first year of operation under an EPRI contract. Nadine Lihach, a feature writer for the *Journal,* wrote the article, with guidance from Gary Dau, who is responsible for NDE development and applications in EPRI's Nuclear Power Division.

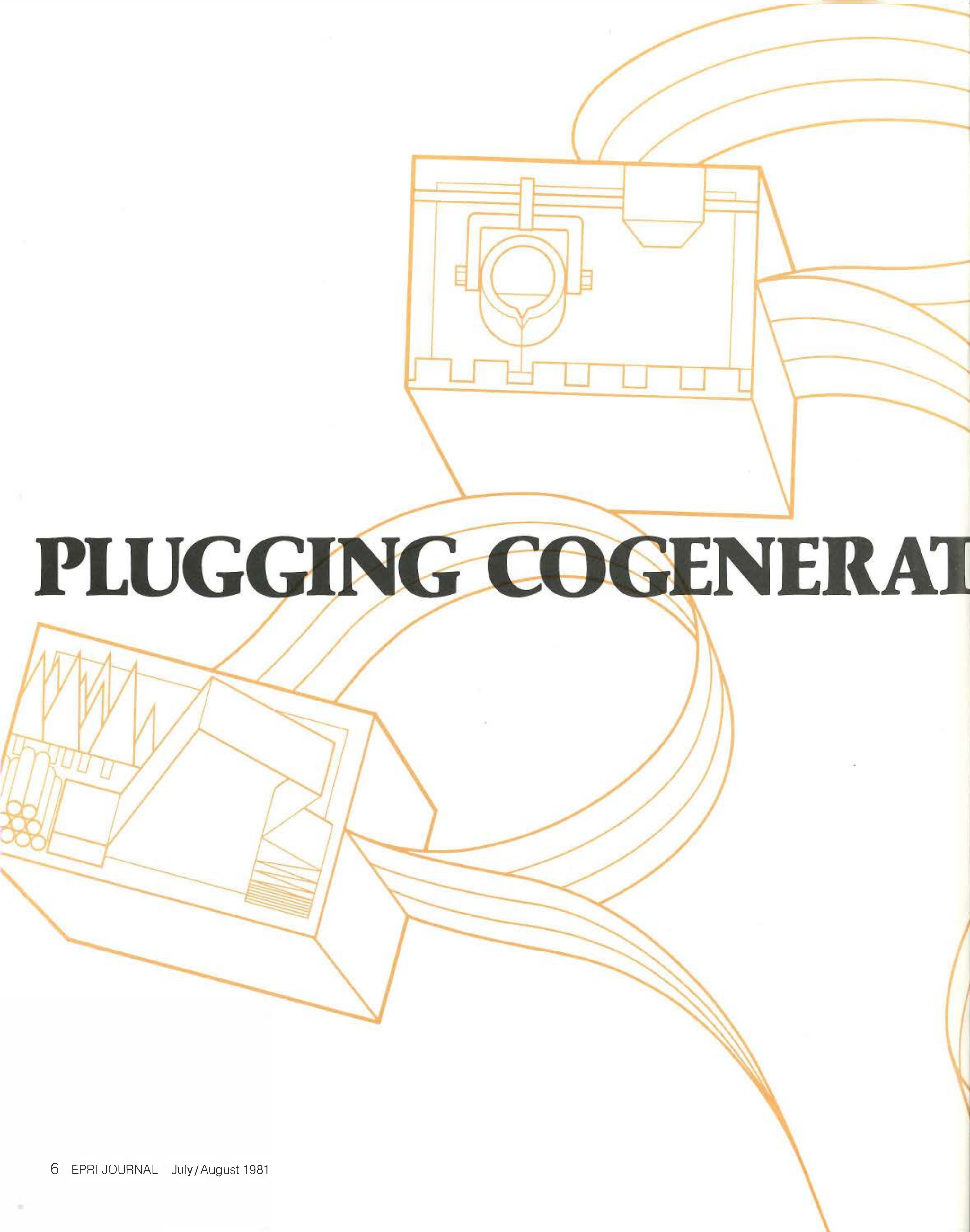
Dau has specialized in NDE techniques and instrumentation for most of his career, which began as a research scientist at Battelle, Pacific Northwest Laboratories in 1965. Between 1974 and 1976, including 17 months on loan to EPRI, he also managed research in nuclear waste management. Dau joined EPRI's staff in April 1977 as manager of a program to guide evaluations of NDE techniques, research improved or new techniques, and develop NDE instruments and systems. Dau holds a BS in mechanical engineering from the University of Idaho and a PhD in nuclear engineering from the University of Arizona.


Mauro


Dau


Balzhiser


Hilst



PLUGGING COGENERAT

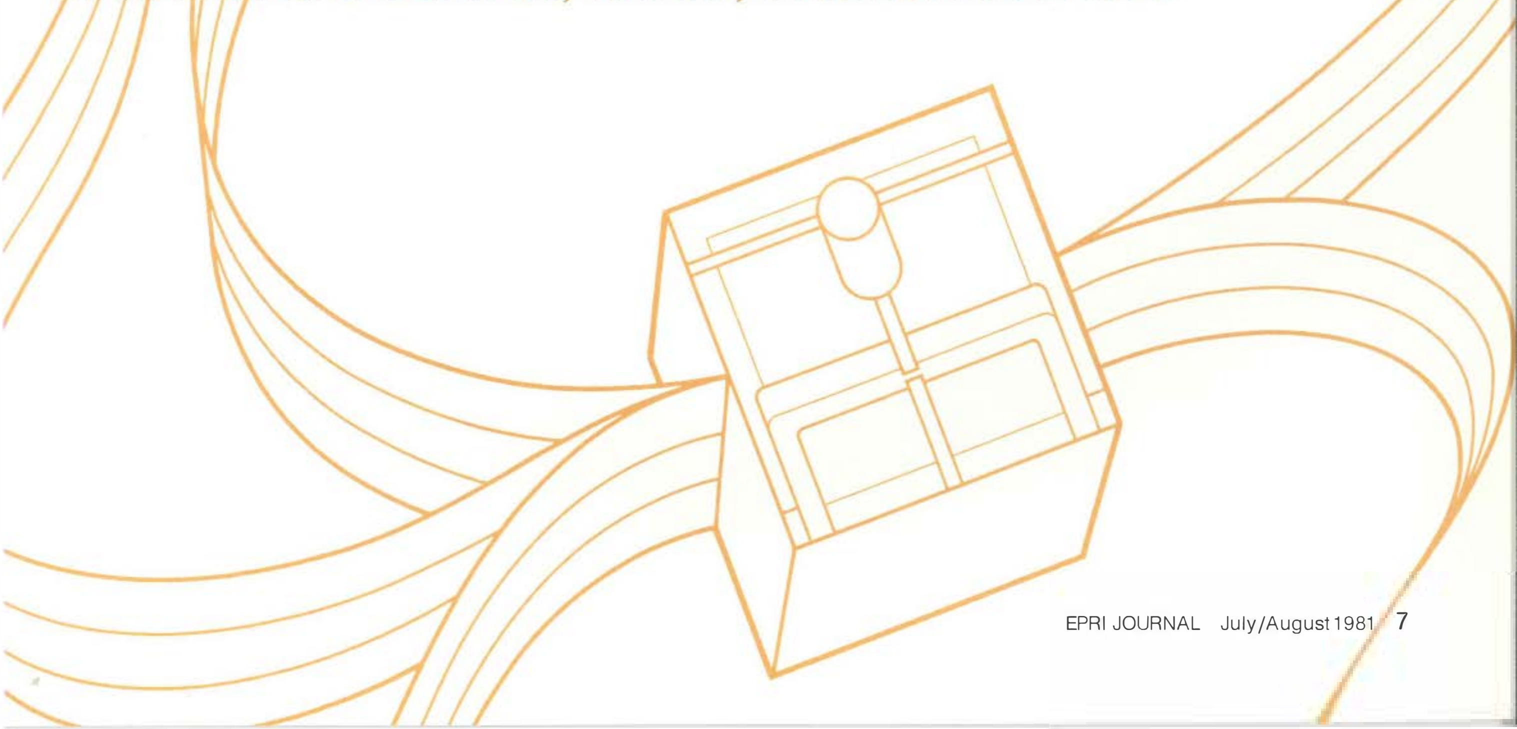
ORS INTO THE GRID

The ability to stretch fuel supplies and expand power generation capacity without costly delays has spurred renewed interest in industrial cogeneration. The technology for the dual production of electricity and process heat is well established, but integrating these diverse and dispersed sources of generation into utility grids raises a number of institutional, economic, and environmental issues.

Electricity as well as beer is being made at the Anheuser-Busch brewery in St. Louis. Shell Oil Co. is generating electricity as it turns out petroleum products from its Deerpark refinery near Houston, and the Potlatch Corp. in Idaho is producing power along with its paper and pulp. These arrangements place the brewer, the refiner, and the paper mill in the vanguard of American companies that are reviving the once common practice of industrial cogeneration.

Cogeneration can be defined as the simultaneous production of electricity and useful thermal energy in significant quantities from a common energy source. Its significance is that a cogenerator can stretch a fuel input to yield both electric power and heat—often in the form of process steam—thus boosting the overall efficient use of the primary fuel. Estimates prepared for DOE appraise the potential fuel savings at about 140 thousand barrels a day of oil and gas equivalent over the next decade. Robert L. Mauro, EPRI program manager for cogeneration research, says that industry could provide as much as 5–10% of the nation's installed generating capacity and up to 15% of total kWh by the year 2000 if conditions attractive to the development of cogeneration potential prevail.

Cogeneration promises substantial fuel savings and investment savings as well if it can postpone the need for the construction of new power plants. But what rates should utilities pay industrial cogenerators when buying their excess electricity, as federal law now says they must? And what rates can utilities charge in turn for the backup power that such industries will sometimes need? Compound these with questions about who may qualify for federal cogeneration incentives, which fuels will be used and which will be saved, impacts on air quality and water, and the complexity of the institutional issues surrounding industrial cogeneration becomes more evi-



dent. Realistic rather than idealized answers to questions like these will determine how much the nation can really benefit from the energy and investment savings that cogeneration has to offer.

Changing economics

Back in 1900 industry produced more than 50% of the nation's electricity. By 1950 industrial power output had fallen to about 15%, and today industry contributes less than 5%. What happened was a shift to reliance on utility-generated electric power, which looked more and more attractive as central station economies of scale and the development of modern power systems provided electricity at ever lower costs and higher reliability for industrial customers.

Selling the cogenerators' excess power to utilities became less feasible as utilities, effectively lowering the costs of generation, reduced the price they would pay for power produced by industry. Utilities spent 2.7¢ to generate a kilowatthour in 1926, but only 1.54¢ in 1968. Over the same period, utility standby service to industrial cogenerators became more expensive. By the 1960s about the only industrial cogenerators left were those, like pulp and paper producers, who could beat the price of purchased power by burning their own waste products to make electricity.

With rapidly escalating oil and gas prices, the economics have now changed again. Because the industrial cogenerator can usually produce electricity with less fuel per kWh generated (after credit for usable thermal energy) than the utility can, oil and gas price increases have hit the utility proportionately harder. The increased financial and environmental constraints on utilities, plus the uncertainty of long lead times for building new coal and nuclear generating stations, also help explain why attention is once again on industry as a source of electric power.

Cogeneration potential is greatest in several major industries: chemicals, steel, petroleum refining, pulp and paper, food processing, and textiles. They are all high energy consumers, together accounting for about 75% of total energy use in the industrial sector. What's more, they all require large quantities of heat/steam that offer the opportunity for simultaneous production of electricity. Recent estimates for DOE suggest that actual cogeneration capacity in these selected industries, textiles excluded, could double over the next decade, rising from a current level of 6 GW to over 12 GW by 1990. (EPRI's estimates for current and projected capacity are somewhat higher.)

Besides prompting a revival of cogeneration in those industries that have been historically receptive, recent efforts to expand the nation's energy options have created some new possibilities. The use of steam-injection techniques for enhanced oil recovery is one: such operations run 24 hours a day, requiring large amounts of process steam that could be harnessed to generate electricity at the same time. Another possibility is the synfuels industry, where relatively low-temperature exhaust from power operations could be used to distill methanol from biomass.

Regional differences are also a factor in the cogeneration outlook. Cogenerating plants tend to cluster in areas that are still heavily reliant on oil and/or natural gas—notably California, the Gulf Coast states of Texas and Louisiana, and parts of the North and Northeast. The more expensive the fuel used by industry and utilities in a given region, the greater the dollar savings that cogeneration can yield.

Technology variations

The fundamental objective of any cogeneration system is to cut energy waste by putting more of the heat energy contained in the fuel to productive use. Because each system is designed especially for the industrial plant it serves, each tends to be unique, but there are several general types of cogeneration configurations. They are usually categorized in terms of the prime mover (the primary energy conversion device): steam turbine, gas turbine, combined cycle, or diesel.

Steam turbine systems customarily operate in a topping cycle mode, which means that the steam issuing from the industrial boiler at high temperature and pressure is first used to generate electricity. Then the remaining steam leaves the turbine at lower pressure and is used in the industrial process. This procedure is much the same as utility power generation with a steam turbine, except that industry must leave more heat in the steam for process use. For high-temperature industrial processes, cogenerators may employ a bottoming cycle instead. In this variation, fuel is burned for industrial heating, and the exhaust heat from that process is used to raise steam in a waste heat boiler. The steam is then run through a turbine to generate power.

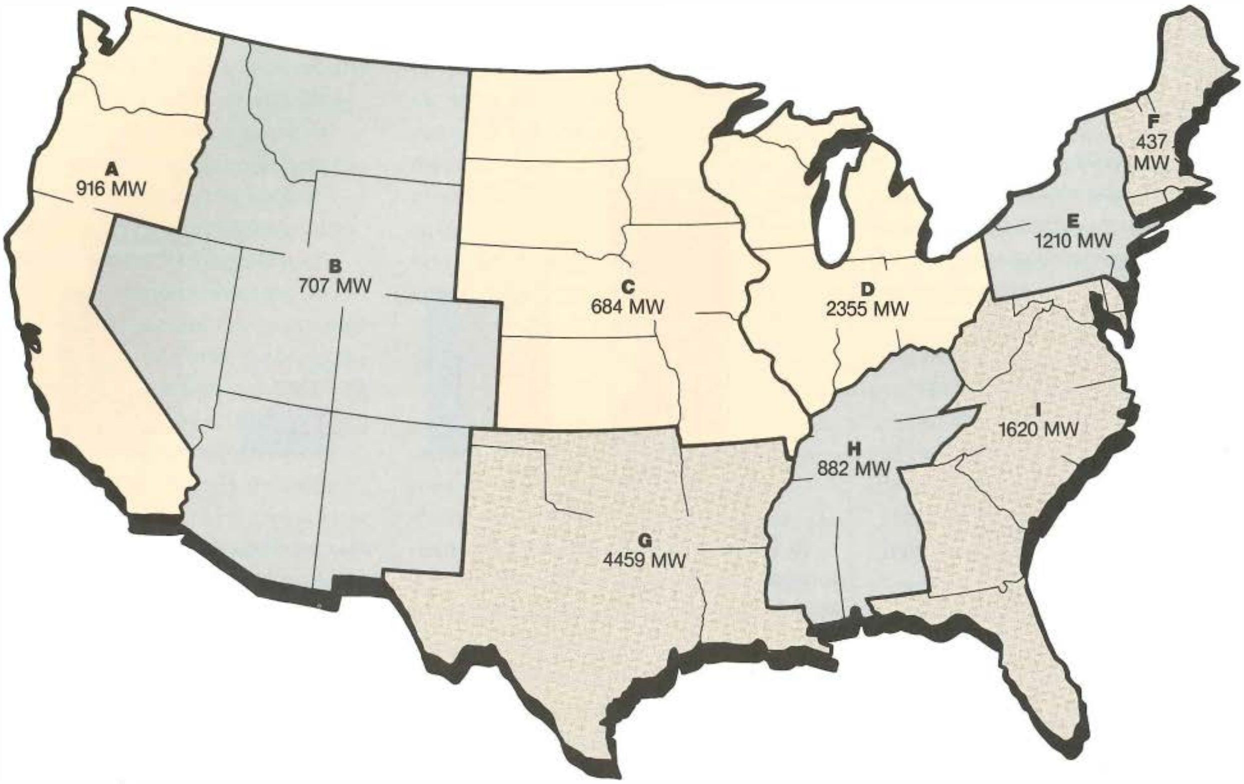
Cogenerating fuels for steam turbine systems may be oil, gas, coal, or any of a variety of waste products. In 1978 some 85–90% of industry's cogenerated electricity in the United States came from steam turbines.

In a gas turbine cogeneration system, the hot gases from fuel combustion first drive the turbine to produce electricity. Then the gases, still very hot when exhausted from the turbine, are used to raise steam in a waste heat boiler to temperatures suitable for process use.

To boost electricity production, it is also possible to link the gas turbine with a steam turbine in a combined cycle. The steam from the waste heat boiler, rather than going straight into process use, passes through a steam turbine on the way, thus generating more electricity from the initial fuel input. The trade-off for gaining this extra electricity is the diversion of steam that could otherwise be used directly in the industrial process.

Diesel systems have little application for large industrial plants. The units are smaller than gas turbines and costlier. What's more, they are more efficient

U.S. COGENERATION CAPACITY (MW)*

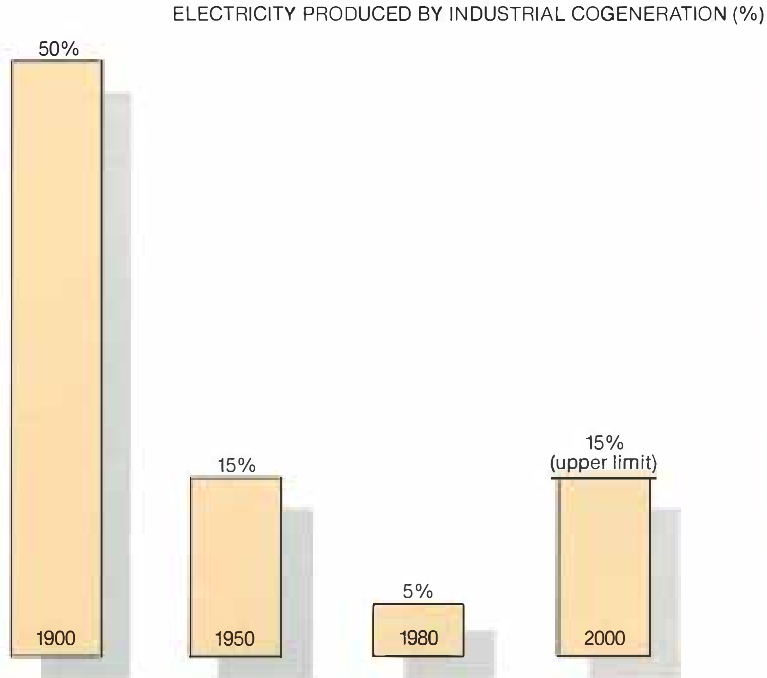


Geographic Area	Food Products	Pulp and Paper	Chemicals	Petroleum Refining	Stone, Clay, and Glass	Primary Metals	All Other
A	94	238	184	0	15	0	385
B	18	31	166	9	0	451	32
C	35	83	135	21	0	0	410
D	59	406	292	44	76	1100	378
E	18	204	211	60	0	653	64
F	7	165	0	0	3	0	262
G	0	754	1031	656	37	1644	337
H	1	507	181	53	0	102	38
I	26	1028	93	183	2	140	148

*Data obtained from EPRI survey.

engines and thus favor electricity production over steam production, exhausting far less usable process heat per unit size than a gas turbine. Because of these differences, the steam capacity of diesel engines is inadequate for most industrial users. But diesel systems do offer some benefits for small cogenerators: the units are modestly sized, easily transported and installed, and provide instant electric power without the need for boiler warmup.

Because an industry's proportional needs for steam and electricity may vary, flexibility in energy output is a desirable feature in any cogeneration system, and there are various ways to accomplish it. In steam turbine systems, expansion valves can be used to divert varying amounts of steam away from the turbines and into direct process use. Gas turbine systems have the option of supplementary fuel-firing in the waste heat boilers to produce additional steam. Combined-cycle systems can boost the flow of steam by adding direct-fired boilers on-line. Unfortunately, achieving increased flexibility in the steam-electricity ratio means increased capital costs and complexity.



Efficiency bookkeeping

Efficiency in generating electricity can be gauged by the system's net heat rate—the amount of fuel required (in Btu) to generate 1 kWh of electricity. The higher the heat rate, the larger the amount of fuel used and the lower the generating efficiency of the system.

For a utility power plant, the heat rate is calculated by dividing the Btu content of the fuel consumed by the total kWh generated. For a cogeneration unit, determining the heat rate is somewhat more complex—it requires assigning part of the fuel consumed to electricity and the rest to thermal energy production. This allocation can be tricky because assigning a disproportionately low fuel input to one or the other output will make its production appear disproportionately efficient and cheap.

As long as fuel costs are low, their allocation is not a big issue. But not all cogenerators are paper companies that can burn their own woodwaste or walnut suppliers that can burn their own shells to produce process steam and power. Further, stringent air quality standards, as well as transport and handling problems, have discouraged coal use in many industries, although the number of coal-burning cogenerators is on the rise. The upshot is that most cogenerators still burn at least some expensive oil and/or natural gas. This is why the question of accurate fuel cost allocation between electricity and process steam production has grown increasingly important as oil and gas costs have climbed.

Two main choices exist for carrying out this energy bookkeeping. The incremental approach applies to retrofits—systems in which one type of capacity is added to the other. For example, electric capacity is added to an existing process steam production unit, then the additional fuel required to run the new system is allocated to the new product (in this case, the electricity). The reverse is true if process steam capacity is added to an existing electric power generation unit.

For new cogeneration systems, an equal discount method of accounting is coming into use. Take the most efficient steam capacity and the most efficient electric capacity and total the fuel costs in Btu. Then use the percentage that each contributes to the total to allocate the thermal/electric fuel cost of each component in a combined system. This method is not yet common because most cogeneration setups are retrofits, but it promises a fair treatment of fuel costs in the new systems now coming on line. It allows the user to determine separately whether the two components of the cogeneration system are cost-effective and to establish cost-based pricing of the two separate outputs.

EPRI's Energy Management and Utilization Division is now conducting systems and design studies to identify the conditions under which industrial cogeneration can be beneficial to utility operations, according to Mauro. Optimal adaptation of existing cogeneration technologies to utility systems is a major thrust. Meanwhile, development of such advanced technologies as fuel cells and fluidized-bed combustion could add new possibilities. Fuel cells come in all sizes and are environmentally benign, so they can be sited virtually anywhere. What's more, they have the potential to operate on coal-based fuels. Fluidized-bed combustion systems, which are also adaptable to industrial scale and siting requirements, use coal in a way that avoids the need for costly scrubbers to protect air quality. Either or both of these flexible new technologies could expand the options for cogeneration.

But the main barriers blocking increased cogeneration are not technological at all. There is no doubt that even today's cogenerating technologies have the potential for saving fuel and dollars. Once we have assured ourselves that comparable or scarcer fuels are being conserved, then what is in doubt is how the savings will be shared; and here we enter the policy arena. The real questions that will affect the growth of industrial cogeneration have to do with institutional costs and benefits—for utilities, for industry, and for the public at large.

Policies and prices

Generating electricity is primarily the business of the nation's utilities, so it is not surprising that proposals to draw significant supplies from another source have raised sharp controversy.

The federal government is actively backing industrial cogeneration as a means of boosting efficiency in the nation's fuel use. At the core of the federal push is the Public Utility Regulatory Policy Act of 1978 (PURPA). That act, according to EPRI consultant Dilip Limaye of Synergic Resources Corporation, is "the carrot to cogenerators and the stick to utilities."

PURPA and other parts of the National Energy Act of 1978 offer qualified cogenerators a number of important incentives. First, they are exempt from the regulations that would apply to utilities: they are not bound by financial disclosure requirements, nor are they regulated on the rate of allowable return on their electricity-producing activities. Second, selected cogenerators may be exempt from the provisions of the Fuel Use Act of 1978, which prohibits or limits the use of oil and natural gas in power plants and other major fuel-burning installations. Third, large gas-fired cogenerators are exempt from the incremental pricing of natural gas, which means that they may not be hit as hard as other industrial facilities by continually rising gas prices. Fourth, cogenerators get federal tax breaks to stimulate their investment in the necessary equipment.

Federal guidelines for setting PURPA power rates promise a windfall for some industrial cogenerators. No matter how cheaply the cogenerator can produce electricity—whether from oil and gas or rice hulls and walnut shells—the utility must purchase that electricity at a rate equal to its own "avoided cost," meaning the cost of generating the extra electricity itself or buying it from another utility.

This avoided cost reflects the utility procedure of economic dispatch. Those baseload units that are cheapest to operate are brought on-line first. The last units to be activated are often the least efficient, typically fired by oil or gas, and the cost of bringing them into service is the avoided, or marginal, cost. The electricity that comes from these units is often expensive, and it is this electricity that the power bought from the cogenerators is assumed to replace.

Determining the true avoided cost for some utilities can be difficult. One snag is the issue of the capacity credit. If buying power from cogenerators can save utilities the costs of building new power plants, goes the reasoning, then a credit for that capacity deferral should be included in the payments that utilities make to electricity-supplying cogenerators. Controversy over the capacity credit has slowed down some state regulators in ascertaining their utilities' full avoided costs and thus in approving the mandated PURPA purchase rates.

Once the purchase rates are in place, cogenerators under PURPA can shop around for the utility that offers the best price. Geography is no barrier. If a distant utility, because of its higher avoided costs, must hold out higher rates to cogenerators, then PURPA requires the intervening utilities to "wheel" the electricity through their transmission lines at the seller's expense to the intended buyer. For instance, power cogenerated in a part of Oregon where hydro-based utility power is relatively cheap is wheeled through utility lines to Southern California, where the predominance of expensive oil and gas-fired utility generation (with its higher avoided costs) makes a better price for the Oregon seller.

Utilities have greater latitude in setting their standby rates for backup power to cogenerators. Under PURPA, there is no firm guideline for utilities' standby rates, but they too fall under regulatory scrutiny. And while they vary considerably among utilities (from under $1 to over $6 per kW per month in recent case studies), it is unlikely that regulators would allow them to rise enough to offset the cogeneration incentive built into the PURPA purchase rates.

The PURPA incentives for industrial cogeneration also affect environmental issues. The hope has been that the more efficient fuel use possible in combined steam and electricity production will actually cut the amount of fuel consumed, with accompanying benefits in the form of reduced pollutant emissions and better air quality nationwide. But the reality may be somewhat different. PURPA may allow qualified cogenerators—even those in areas with air quality problems—to burn more oil and gas than they would for their industrial operations alone. Add to this the fact that most cogenerators cannot afford the highly sophisticated and efficient emis-

CHARACTERISTICS OF SELECTED COGENERATION SYSTEMS

Company	Fuels	Capacity (MW)	Annual Generation (million kWh)	Utility Relations[1]	System Type[2]	System Efficiency	Demand Met by Cogeneration (%)		Fuel Cost	
							Thermal	Electric	Thermal ($/$10^6$ Btu)	Electric (¢/kWh)
American Enka Co.	Coal	20.0	88	PO	STT	0.62	100	23	2.45	0.9
Anheuser-Busch, Inc.	Coal; natural gas	27.6	72	PO	STT	0.77	100	41	2.86	1.3
General Foods Corp.	Natural gas	7.5	26	GI	STT	0.73	62	100	3.16	1.8
Gulf States Utilities Co.	Natural gas; refinery gas	190.0	1078	GI	STT	0.73	—	—	3.43	1.5
Holly Sugar Co.	Natural gas	7.5	16	I	STT	0.70	73	100	3.32	1.9
Pacific Gas and Electric Co.	Natural gas; refinery gas	50.0	209	GI	STT	0.60	—	—	—	—
Potlatch Corp.	Natural gas; black liquor	20.0	102	PO	STT	0.64	82	23	1.86	0.7
Shell Oil Co.	Refinery gas; natural gas	60.0	342	PO	STT; GT	0.76	NA	21	3.15	1.1
Celanese Corp.[3]	Coal	30.0	189	GI	STT	0.67	NA	NA	1.80	0.6
Southern California Edison Co.	Natural gas; oil	14.5	78	GI	GT	0.65	—	—	—	—
Union Carbide Corp.	Natural gas	70.0	386	PO	STT; GT	0.68	100	100	3.60	1.7

[1]PO: parallel operation; I: isolated; GI: grid interconnected.
[2]STT: steam turbine topping; GT: gas turbine topping.
[3]Data estimated by Southwest Public Power District.

sions controls required for large central station utility power plants, and the result is a growing possibility of localized air pollution. National averages may improve, but this would provide little comfort in smoggy urban areas where industrial cogeneration may only make the problem worse.

Water use is a related issue, and also a local one. Where industry raises its fuel consumption to cogenerate electricity, cooling-water requirements will also increase. This may not be a hurdle in many areas, but in some western states where the cogeneration potential is greatest—notably, California—diversion of water resources from agriculture and other uses is a serious issue.

PURPA was recently challenged in a Mississippi federal district court, and the judge ruled parts of the act unconstitutional. But lawyers for the Federal Energy Regulatory Commission (FERC), which has requested review by the Supreme Court, called the judgment case-specific, meaning that it would have little application in other situations. And the Mississippi judge did not issue an injunction, so other states are still required to move ahead under PURPA.

Even in Mississippi, the state regulatory commission that initially brought the suit is now working on rates for cogenerators. The general feeling seems to be that even if parts of PURPA are thrown out, Congress could draft new legislation to accomplish the same ends. Despite its many controversial aspects, according to Limaye, PURPA is here to stay.

Institutional attitudes

Cogeneration under PURPA looks like a plum for industry. Yet many industrial managers express reservations about getting into the power business, even though PURPA's exemptions have now freed them from the long-held fear that this would subject them to regulation as utilities. Producing electricity is, after all, not the business they know best. It requires a substantial investment in new plant and equipment, and it requires personnel with special skills and know-how that their own staffs may lack.

Utilities also express mixed feelings toward industrial cogeneration, with common concerns surfacing even among those that favor the idea. Is cogenerated power reliable? Is it safe to funnel it into the utility grid? How will it affect the economics of utility operations?

Reliability and maintenance are twin concerns. Utilities want to be sure that cogenerators can deliver power when the utility needs it, so maintaining the generating equipment in good running order is a top priority. There are questions as to whether the cogenerators can or should do this themselves, or whether maintenance should be the responsibility of the utility, a responsibility that could be costly and keep utility personnel spread thin if they had to maintain cogeneration plants scattered over a large service area. Variable labor relations and the possibility of strikes or shutdowns in cogenerator-maintained facilities also make utilities wary on the reliability issue.

Linked to this issue is the potential for making cogenerators part of a power pool. Utilities can regard industrial power suppliers as separate sources of generation that may or may not come through with power when it is needed. Or they can regard them collectively, as a rather reliable single unit, almost as if they constituted a neighboring utility. Or there is the highly integrated point at which a utility might regard its cogenerators as part of its own firm capacity. Clearly, the reliability of cogenerated power will play a large part in determining how much capacity credit a utility will be willing to assign to cogenerating installations.

Integrating cogenerated power into the utility grid also raises questions about the safety of workers and equipment. For example, in the event of a utility power outage, cogenerated power still feeding into the grid could endanger utility employees working to repair the lines. To forestall such concerns, many utilities have developed standards to be followed for safe interconnection, and most perform the installation themselves, often bearing the cost and/or retaining control of the intertie.

The thorniest questions are the economic ones. How will the loss of cogenerating industrial baseload customers affect utility loads and revenues? When does the purchase of cogenerated power make economic sense for utilities? When does it not? And who should actually own the cogeneration facilities?

Answers to the first three questions depend largely on the capacity situation and fuel mix of the particular utility. Although no utility relishes the loss of baseload business, those that are already short of baseload capacity and/or forced to make heavy use of expensive oil- and gas-fired units are likely to see substantial benefits in supplementing their supplies with cogenerated power. The availability of cogenerating capacity can defer the need for siting and building new utility plants. For capacity-short utilities, purchasing cogenerated power can be an economic course that helps relieve a cash squeeze by postponing costly new construction.

On the other hand, those companies that have adequate or ample capacity and can produce relatively inexpensive baseload electricity in their new coal-fired or nuclear plants tend to be less enthusiastic. They have no need for the cogenerator's electricity, and they don't want to buy it at avoided-cost PURPA rates that are substantially higher than their own average generating costs. Oil- and gas-fired cogeneration can't compete economically with the utility's coal-based or nuclear output. Nor does it make sense from a conservation standpoint to save coal and uranium by purchasing electricity made from scarcer oil and gas—a significant issue in its own right when one assesses the pros and cons of industrial cogeneration on a national scale.

As for ownership of cogeneration

facilities, this is a key point—one that could possibly win over some utilities that are not now in a position to benefit much from cogeneration. All sorts of ownership arrangements are possible; joint ownership between an industrial concern and the local utility is not uncommon, and even third-party ownership is not unheard of. But PURPA's attractive incentives are currently limited to "qualified" cogenerators. And who is qualified? As of now, a qualifying facility must be one that is no more than 50% utility-owned.

Lifting the ban on greater utility participation could open new business opportunities and hasten the development of cogeneration potential. Estimates for DOE suggest that deregulating utility investment in this field could add another 700 MW of capacity, mostly in the chemicals and food-processing industries. In fact, legislation that would extend PURPA incentives to utilities is now on the way. Such legislation would have the additional benefit of giving utilities access to much-needed new sources of capacity financing through the industrial concerns that their cogeneration facilities would serve.

Opening the PURPA incentives to utilities would offer the ratepayer benefits as well. Compared with regular power plants, utility-owned cogeneration units could operate at substantial savings. Utilities still have not received a clear signal from regulators as to how the profits from such operations would be treated in contrast with the regulated revenues from single-purpose generating plants, but it is safe to assume in the utilities' case that some of these cogeneration savings would be passed along to the consumer.

Cogeneration gains

Those industries in which cogeneration was once standard practice are rediscovering its conservation potential. Meanwhile, new applications are growing, especially in the energy industries themselves, and technological advances continue. Yet nontechnological constraints remain.

Besides the financial and institutional issues, there are lingering questions having to do with fuel use and natural resources. Industrial cogeneration is sure to save fuel, but which fuels? If it saves coal and uranium but encourages the use of proportionally more oil and gas for power generation, then it will actually work against the intent of the National Energy Act. Air quality and allocation of water resources, both important on a local basis, are other unresolved issues.

A final contingency is whether the utility trend toward nuclear and coal-based power generation will dampen the prospects for industrial cogeneration by making currently feasible oil- and gas-fired cogenerating facilities uneconomic. There is every expectation that the marketplace will form the test. The costs of smaller, dispersed generation options (including industrial cogeneration) with their short lead times appear attractive when compared with the uncertain costs associated with the very long lead times for large coal and nuclear plants.

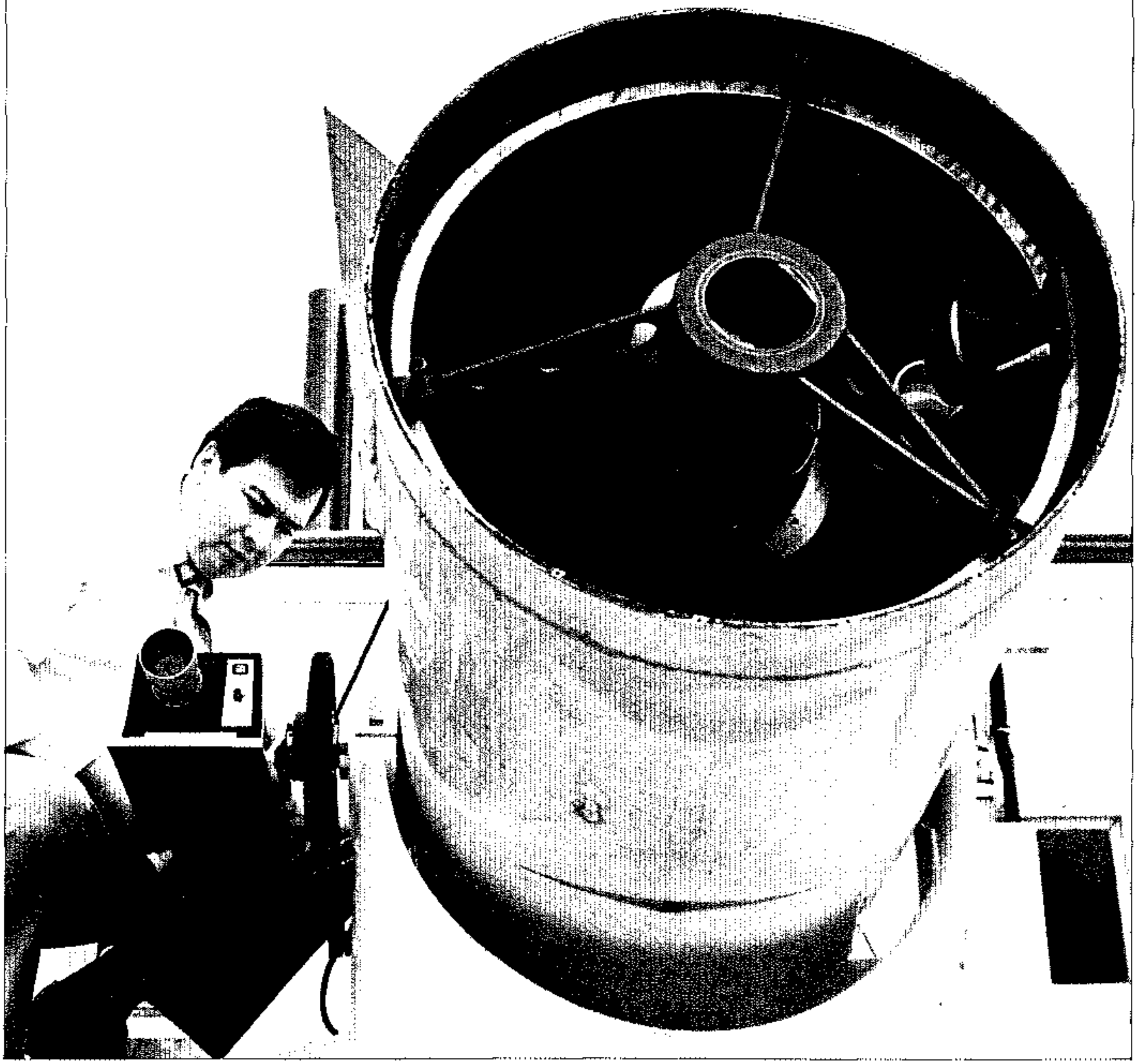
Many utilities today need more capacity or the cash to build more. Industries, in turn, need expertise in running electric power operations. The seeds of mutual interest seem to be taking root in a move toward greater cooperation between utilities and industry in the cogeneration field.

Who will reap what benefits remains to be determined, but the incentives and prospects for utility participation appear increasingly favorable over time. A revival of old-style industrial self-sufficiency for electric power needs is nowhere in sight: the new cogeneration is likely to become a form of cooperative energy conservation that can benefit industry and utilities alike. ■

This article was written by Mary Wayne, science writer. Technical background information was provided by Robert Mauro, Energy Management and Utilization Division.

Mapping Air Quality by Laser

An EPRI-sponsored system combines lasers and a computer to measure sulfur dioxide concentrations from as far away as two miles. Capable of several hundred measurements a minute, it is first being used to find out how exhaust gases rise and disperse from power plant stacks.



When new power plant generating capacity is planned, one of the many factors considered is the plant's expected environmental impact. In the case of a new coal-fired unit, for example, exhaust stack emissions can affect air quality. What will the ground level concentration of sulfur dioxide (SO_2) be at various points downwind from the stack? Will these concentrations exceed the legal limits for 3-hour, 24-hour, or annual averages?

The answers to these questions are important in the utility regulatory and licensing processes, and they often come from a mathematical model designed to simulate power plant exhaust plume behavior. Model analysis even assigns probabilities to various behaviors. But a model is only as good as the assumptions and data on which it is based. The data are usually collected at a few fixed monitoring stations in the vicinity of a stack, which is not even always in the same state as the planned new power unit. Because those fixed stations must be distributed beneath the paths of all likely plumes, they are widely scattered. Shifting winds can limit the volume of data collected at any one station and make gathering the data very expensive.

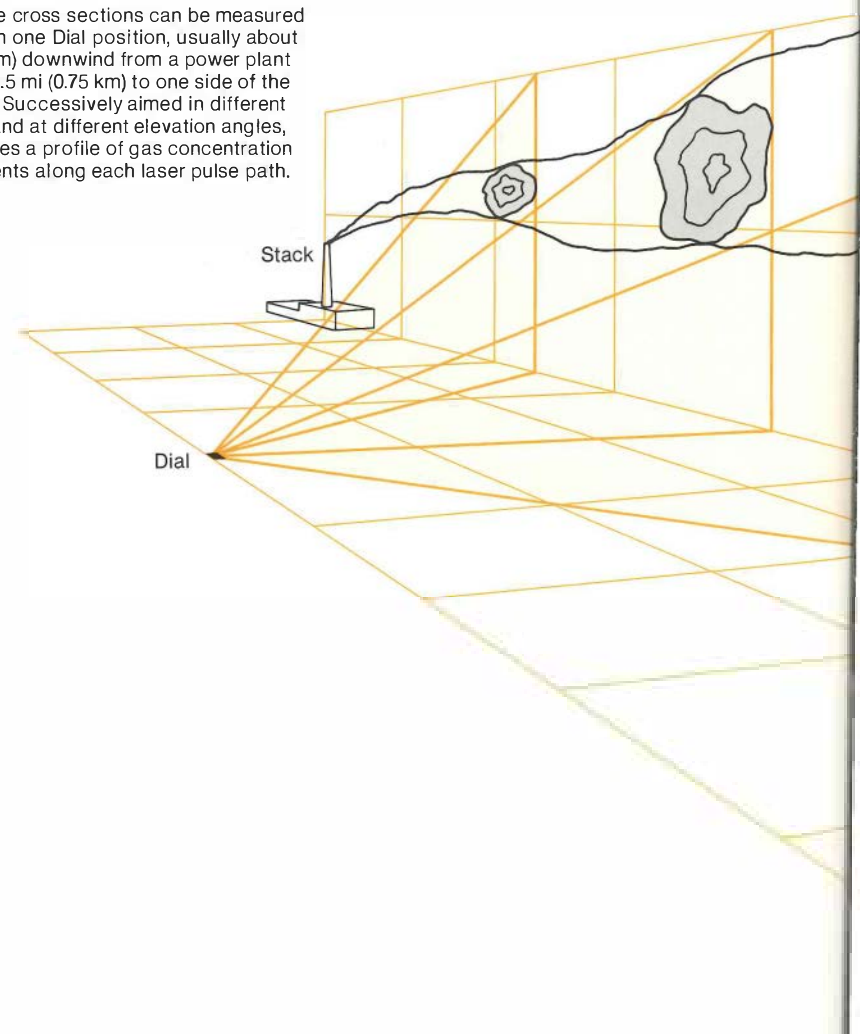
Thousands of data points

Now there is a remote sensing system based on a technique called lidar (light detection and ranging), which uses laser pulses in much the same way that radar uses radio waves. This new system, called differential absorption lidar, or Dial, can measure SO_2 concentrations to nearly 2 mi (3 km) in any direction and in increments as small as 50 ft (15 m) along each beam.

By means of pulse reflection times, lidar produces range and azimuth (or elevation) data describing a plume's shape and extent. The absorption of laser energy at any point in the plume is an index of the pollutant concentration there; the Dial system determines this absorption by comparing the energy content of outgoing and returning pulses. For such plume measurements, the laser wavelength is chosen on the basis of the energy absorption characteristics of the gas being measured.

Carried in a semitrailer with a computer and a 40-kW diesel generator, the self-contained remote sensing system can be quickly moved to a vantage point on one side of a plume. The system is able to map SO_2 concentrations throughout a 2.7-mi^2 (7-km^2) area in about 10 minutes. The equipment can be aimed upward at a nearby plume or horizontally to measure ground-level concentrations where a plume is thought to be touching the surface some distance downwind from an exhaust stack. In such an operation the system maps a quarter-circle segment with a series of 45 pulsed laser beams at 2° intervals. Data are collected from some 170 time-defined points along each beam to a range of 2 mi (3 km). The result is more than 7500 readings. The range resolution of data points is 165–650 ft (50–200 m), depending on the SO_2

Many plume cross sections can be measured quickly from one Dial position, usually about 1.25 mi (2 km) downwind from a power plant stack and 0.5 mi (0.75 km) to one side of the plume axis. Successively aimed in different directions and at different elevation angles, Dial produces a profile of gas concentration measurements along each laser pulse path.

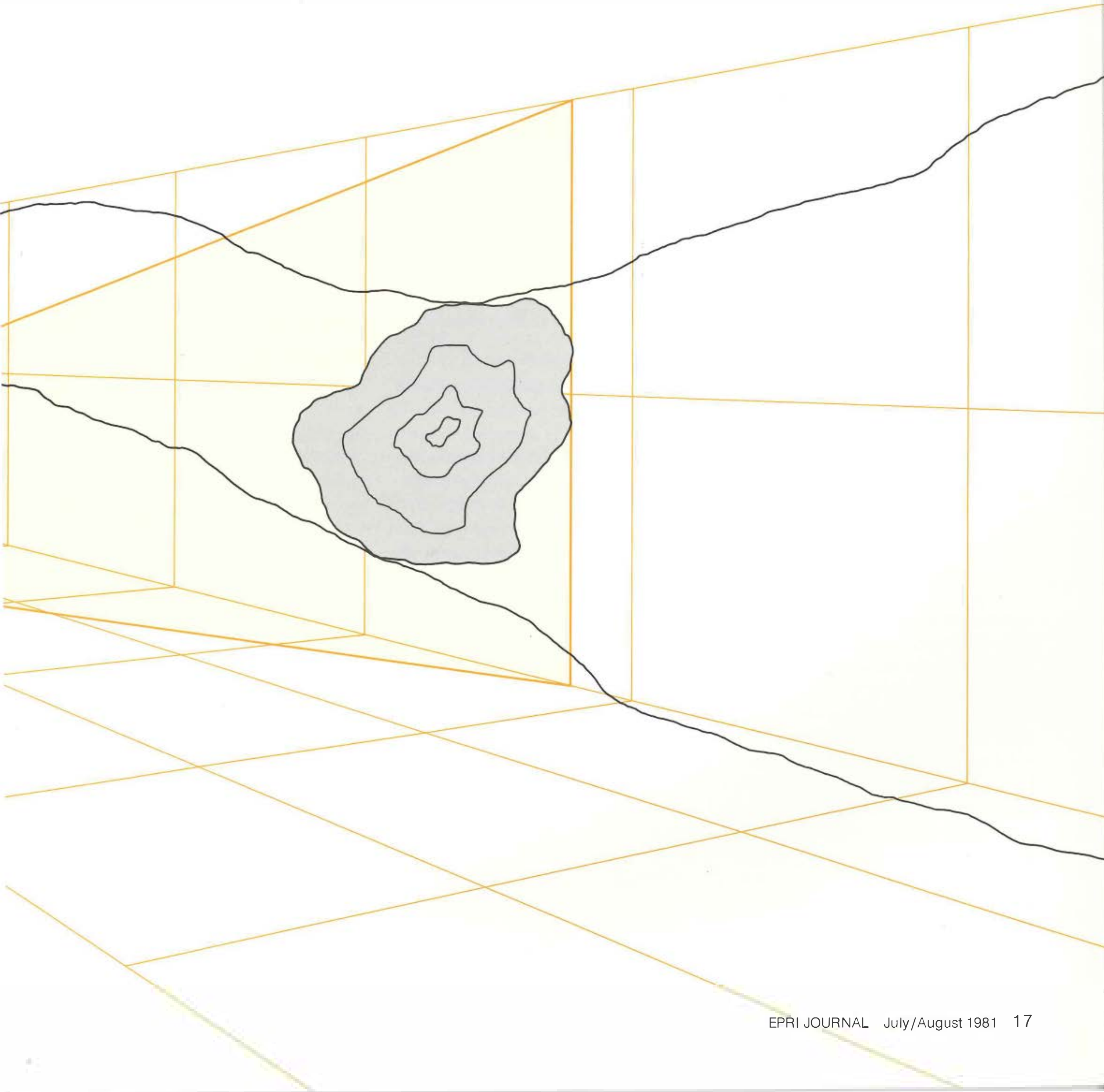


concentration. Creating an equivalent map by conventional means would require at least 170 standard fixed monitoring stations.

Dial system accuracy has been established in field tests against a standard SO_2 analyzer. Gas concentrations measured by the two systems agreed to within 6%.

Dial computer auxiliaries can include video terminals, plotters, and printers. Concentrations can be displayed as profiles along given azimuths, they can be presented as contour lines of equal values on maps, or they can be tabulated for comparison to the values predicted by a model.

The speed, volume, and accuracy of data acquisition, processing, and display are likely to carry this equipment well beyond its initial task, aiding EPRI-sponsored researchers as they check and validate some of the plume models now used in regulatory work. Dial could also help modelers make a few refinements here and there to deal more accurately with the plumes that flow from today's extremely tall power plant stacks. The system may even become an original data source for building entirely new models



or for tailoring existing models to new circumstances (i.e., making them site-specific).

Refining air quality models

The meteorologist faces an overwhelming task in the relatively new role of air quality specialist for utilities or their regulators. Meteorology has many facets, and even weather forecasting is complex, although it deals with gross patterns of air mass movement, continental or worldwide. But predicting plume behavior (and simulating it in a mathematical model) requires specific understanding of vertical and horizontal gas dispersion phenomena in several compass directions, over varied topography, under many weather conditions, and all within an area of just a few hundred square miles.

Not only are predictions of plume behavior at least as difficult to make as weather forecasts, but they have much more specific economic effects. Weather forecasts are acted on in many ways and in different degrees by many people and institutions. Predictions of pollutant concentrations in plumes, however, cannot be ignored. They can influence regulatory actions that virtually decide a power plant's location or its permissible regimen of operation, both of which are major factors in a utility's costs.

Glenn Hilst is a meteorologist who has seen how gas dispersion models work from at least three viewpoints: as a developer, user, and critic. Since 1977 he has been associated with the Environmental Physics and Chemistry Program (which he now heads) in EPRI's Energy Analysis and Environment Division. One research area of growing importance to him is the validation of plume models. Reliance on these models increases with every fossil fuel unit that is planned, designed, and operated to meet emission standards. Considering the utility costs and revenues that hinge on model predictions, model accuracy and certainty must be clearly established. Improving that accuracy and certainty would be a boon to modelers and utility management.

Research has followed recommendations of a 1978 EPRI-sponsored meeting for technical professionals from utilities, government agencies, national laboratories, universities, and other organizations. Four objectives were named.

- To establish model prediction accuracy and certainty for concentrations of pollutants emitted from tall stacks
- To assess a given model's performance over a range of meteorologic, topographic, and source conditions
- To develop (and validate) new models that will better deal with the likely variety and range of conditions
- To compile a data base of measured power plant plume behavior

One comprehensive set of field measurements taken at a power plant in 1980 illustrates the magnitude of the data collection problem and suggests the complexity of subsequent data processing.

Mapping typical plumes

Commonwealth Edison Co.'s 1320-MW, two-unit, coal-fired generating plant at Kincaid, Illinois, is surrounded by 10 fixed aerometric monitoring stations that the utility has operated for several years. These were augmented in 1980 by 20 more monitoring stations, many of them located at greater distances from the plant than the original stations. In addition, a 10-m and a 100-m tower were instrumented (the latter at four levels) for meteorologic data collection.

A central weather station accumulated precipitation, temperature, barometric, and solar radiation data; noted cloud cover; and took atmospheric measurements of temperature and wind velocity up to an altitude of 5000 ft (1500 m). Instruments in the 600-ft (183-m) Kincaid exhaust stack measured SO_2 emission rate, temperature, and velocity.

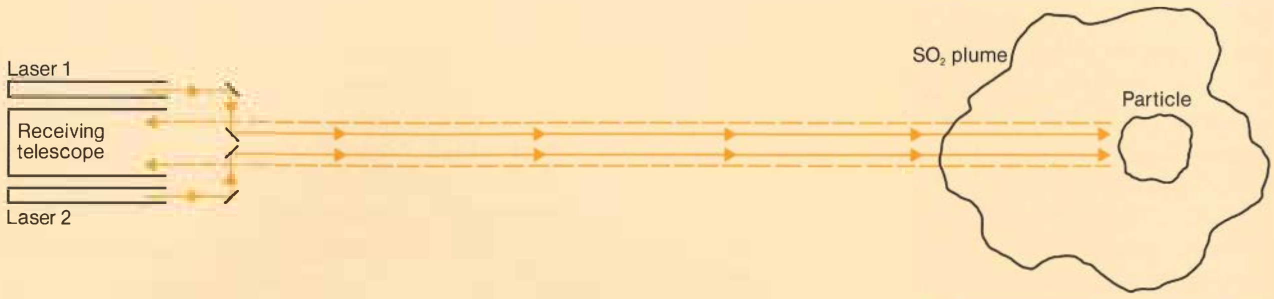
This instrumentation was routine for a six-month measurement period from March through August 1980 (and again for three months from April through June 1981). But for several periods of three weeks each, the effort was intensified. More than 1500 tracer-gas sampling sites were located in concentric circles around the Kincaid stack at 0.6-, 1.2-, 3.1-, and 6.2-mi (1-, 2-, 5-, and 10-km) intervals out to 31 mi (50 km). Then, sulfur hexafluoride (SF_6) was injected into the flue gas stream for periods as long as nine hours, and hourly air samples were collected in plastic bags at the approximately 200 downwind sites beneath or in the plume.

This latter work was to delineate the "footprint" of the plume: any characteristic pattern whereby it falls to the ground from 600 ft (183 m) and then bounces as it moves downwind, creating successive puddles of residual gas concentrations even within the gradually broadening mass of dispersed gas. Tracer gas was sampled for at least 100 hours during each intensive measurement period.

Each intensive period also included 33 hours of research aircraft flight to make meteorologic measurements and to conduct continuous sampling and chemical analyses in the plume. Not surprisingly, lidar was also used in the Kincaid effort. Two of the instruments (both mobile, one of them airborne) were lidar systems that measured the density of particulate matter at successive points in the plume cross section. These particle lidar units were used to measure plume height and geometry at points about 2 and 10 mi (3 and 15 km) downwind. The Dial system (the only one of its type in existence) also measured the plume and probed inside it for SO_2 concentrations as far as 2 mi (3 km) away.

The ground-based particle lidar and Dial systems closest to the Kincaid stack were most useful when atmospheric conditions produced what is called convective instability. The manifestation is the plume's pronounced vertical drop to the ground and upward movement after impact, with relatively little horizontal travel. When the wind is truly negligible and a thermal inversion counteracts the

WHAT'S THE DIFFERENTIAL?



Atmospheric gases absorb electromagnetic energy in proportion to their concentrations. To compute the SO_2 concentration at a remote point inside a power plant plume, the Dial system measures the energy difference between outgoing and reflected laser pulses. But this difference by itself doesn't define the amount of energy absorbed—the index to SO_2 concentration—and it is not the reason for calling the system a differential absorption lidar.

Laser energy is scattered by atmospheric particles as well as absorbed by SO_2 molecules in the plume. The system distinguishes absorption from scatter by the way a given concentration of SO_2 responds to different laser wavelengths. That is, assuming equal energy in two laser pulses, the atmospheric particles scatter the same amount of that energy but the SO_2 absorbs different amounts, according to its absorption coefficients at the two wavelengths.

Therefore, two lasers are used in the Dial system. They are tuned to selected wavelengths and their outputs are optically channeled to a single axis, essentially coaxial with a telescope that collects the reflected pulses, called backscatter. The two lasers are pulsed 5 μs apart so that their backscatters can be separately measured. Two backscatter figures from one distant point produce the differential absorption values that give Dial its name.

In theory, it is simple to measure output pulses from both lasers, measure backscatter from both of them after the same momentary intervals, and compute the absorbed energy on the basis of the ratio of known SO_2 absorption coefficients at the two wavelengths. One more known coefficient translates the absorbed energy value into SO_2 concentration.

In practice, this task is electronically difficult and complex. Depending on the gas and its absorption wavelengths, frequency-doubling circuits may be needed. Or lasers may be teamed in series, one laser exciting another to obtain the required output wavelength. Laser energies also attenuate drastically with distance. For the Dial system to function at 3 km means using very powerful lasers and a very sensitive receiving telescope. Output is measured in megawatts of pulse energy, and backscatter is measured in microwatts—a difference in magnitude of 10^{12}.

The system is complex because the electronic circuits must time, count, process, and store many absorption measurements from each pair of pulses. The differential absorption computation is simple only for the first measurement at the near edge of a plume. Increments of energy are thereafter absorbed and scattered throughout the plume cross section, first as the pulse travels out, then as its backscatter comes back. Computer logic must adjust all data to account for those losses elsewhere along the pulse path.

Energy losses are virtually doubled during the round trip of a pulse to a point at the far edge of a plume. With signal attenuation that results from the distance alone, these losses explain the reduction in energy at the receiving telescope. □

plume's normal buoyancy, the stack seems to simply overflow and its emissions to cascade downward—invisibly for the most part.

Thorough data collection in these circumstances calls for other than ground level azimuth scans. The particle lidar and Dial systems were aimed upward at successive angles of elevation to acquire data from which to construct a three-dimensional map of the entire plume in terms of its particulate density, SO_2 concentrations (and their change with time), and the heated plume's height of rise.

Height of plume rise is very important. Added to the actual stack height, it makes up the plume model measure known as effective stack height. The physics of plume rise is being closely studied today, and effective stack height is therefore a subject of more emphasis than when plume models came into general use for air quality regulation and control. How this measure influences the accuracy and certainty of tall-stack models is a specific objective of EPRI's plume model validation research.

Precision in remote sensing

Reciting the number and variety of data collection instruments at Kincaid emphasizes the complexity of air quality monitoring and especially of research into plume behavior. Many meteorologic parameters go into plume model equations. To validate models (especially if they are to be used with taller stacks), the data base must be enlarged. But to do so requires a system that can collect more data. The immobility of the monitoring instruments used at Kincaid, their consequent redundancy of capability, and the cost of moving the tracer-gas collectors whenever the wind shifts direction thoroughly justify the $1 million invested in development and construction of a system that can be aimed directly at any plume and map its SO_2 concentrations at ground level or at any chosen elevation to a distance of 2 mi (3 km). In addition, the Dial system can measure and map nitrogen dioxide (NO_2) or ozone (O_3) concentrations with equal precision by a change of laser optics.

The great number of possible Dial data points permits extremely detailed mapping of SO_2 concentrations, even without reliance on the accuracy of any single measurement. The electronic design provides a sampling interval of 50 ft (15 m). Three successive points are needed to quantify a change in SO_2 concentration. Thus, 150 ft (45 m) is the best resolution of the system, representing the shallowest plume cross section the system can reliably map.

As it travels downwind, the plume usually spreads over hundreds of meters, its contents mixing with the atmosphere and becoming diluted. When circumstances permit, Dial accuracy is improved by averaging its data over longer distances. This permits detection of smaller concentrations; for example, 20 parts per billion (ppb) over 330 ft (100 m), but 2 ppb over 3300 ft (1 km).

The flat plains that surround Commonwealth Edison's Kincaid plant represent only one site category for which plume models are under investigation. Sites in rolling and mountainous terrain will be covered in 1982 and 1983, making more use of remote data acquisition by Dial and other lidar equipment.

Related instruments

EPRI's sponsorship of the Dial system is a sequel to research that the Institute sponsored at Stanford University some six years ago. That research, stemming from fundamental investigations under National Science Foundation (NSF) and Environmental Protection Agency (EPA) auspices, identified and developed several of the laser sources and accessories (e.g., fluids, wavelengths, crystals) that would be needed to measure air pollutant gases. SRI International, one of the NSF research contractors, had also been doing basic lidar research since the invention of the laser in the early 1960s. SRI has held two instrument development contracts with EPRI.

SRI's first prototype system successfully measured NO_2 but not SO_2; as recently as three or four years ago the available laser technology did not permit it. The technology has continued to develop rapidly. Already, James Hawley, senior research engineer and principal investigator in SRI's Systems Techniques Laboratory, sees further Dial refinements. One would be more powerful lasers, so the system could work beyond its present 2-mi (3-km) range. (The major restriction in this regard is eye safety.) Another would be optical modules permitting remote measurements of many other materials.

SRI has now completed hardware R&D for EPRI that addresses all three major categories of exhaust plume measurement: density of particulate matter, concentrations of gas species, and impairment of visibility.

The particle lidar measures the density of a plume relative to that of the clean atmosphere. The Dial system measures the absolute concentration of SO_2, NO_2, or O_3 at intervals through a plume. An automated telephotometer measures visibility degradation caused by a plume, doing so objectively and reproducibly (unlike the records of even trained human observers). Like the Dial system, the photometer got its first field trial in 1980 and is now in its second season.

All these systems grew from ideas pioneered about 30 years ago. The Dial system has its origin in research done in the 1950s by a meteorologist at the University of Arizona. Richard Schotland hit upon the use of searchlight beam reflections to measure the water vapor and ozone content in the atmosphere. The advent of the laser made the idea practical, and Schotland continued work on it, ultimately becoming one of SRI's consultants on the Dial project for EPRI. The searchlight image is still appropriate as researchers continue to illuminate the problems of air quality control.

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

Adapted from a speech delivered at the 49th Annual Convention of the Edison Electric Institute.

Synfuels and the Energy Transition

by Richard E. Balzhiser

The growth of synfuels capacity will be slow; and these fuels will complement, not replace, other sources of energy. The real energy transition for this country, which is still just commencing, is from natural fluid fuels to solid fuels and renewable energy resources. Electrification is the key to this transition, able to encompass both nuclear and renewable resources, centralized and dispersed technologies.

After four years of frustration in dealing with U.S. energy problems, the Carter administration finally gained congressional support for launching a crash synthetic fuels program to replace imported oil. This effort, coupled with conservation, was to augment our declining oil and gas production sufficiently to sustain present end-use patterns until renewable energy resources could make a significant contribution. Nuclear power was declared the option of last resort. And coal—while acknowledged to be the only viable near-term alternative—was confronted with increasingly stringent emissions requirements.

Clearly a period of energy transition away from dependence on imported oil is essential, but I believe that the role synfuels will play in the next two decades was seriously overstated by the Carter administration. An approach that assumes no change in use patterns when markets are freed ignores American ingenuity and adaptability. It also fails to recognize that synthetic oil and gas are manufactured forms of energy like electricity. They will thus require capital-intensive industries that face many of the same financial, environmental, and regulatory problems as electric utilities.

The Reagan administration has promised to reexamine the nation's energy policy, including the role of synthetic fuels. In doing so, I trust it will take cognizance of just how sharply past U.S. policy has contrasted with those of most other nations. In many industrialized and developing countries alike, increased electrification utilizing nuclear energy, coal, and hydropower is being emphasized as the best way to increase productivity and reduce dependence on foreign oil. For the United States, electricity has

Independent of the OPEC shock, the fraction of total energy converted to electricity has risen steadily for the last 30 years, reaching 33% last year. If this trend, established during decades of cheap and abundant oil and gas, were to continue, by 2000 energy conversion to electricity would reach 45–48%. As we have seen, increased scarcity and expense of such fluid fuels only tends to accelerate the shift to electricity.

U.S. Proven and Recoverable Resources
(10^{15} Btu)

Natural gas	200
Petroleum	160
Heavy oil	25
Tar sands	15
Oil shale	430
Coal (all types)	4800

the unique ability to facilitate a shift toward more abundant domestic resources of uranium, coal, and renewables. Indeed, OPEC oil shocks have already stimulated a trend in this direction.

The transition begins

The first OPEC shock, 1973–1974, produced a decline both in GNP and in total U.S. energy consumption. During the next four years, economic growth resumed, but with less energy consumed per unit of GNP. Recent data released by the Energy Information Agency indicate that the sharp oil price increases of 1979 brought economic growth to a halt in 1980 and produced another sharp decline in total energy use. The net impact of these two jolts has been to push total energy use roughly 10% below what would have been expected from a continuation of the preembargo trend line of the early 1970s.

In sharp contrast, consumption of electricity per unit of GNP increased during 1974–1975 and again in 1980. The reason, I believe, is clear: The U.S. economy has responded to rising oil prices by shifting naturally toward greater use of electricity. This substitution continued throughout the last half of the 1970s, tempered only slightly by increased conservation during 1978–1979.

Independent of the OPEC shock, the fraction of total energy converted to electricity has risen steadily for the last 30 years, reaching 33% last year. If this trend, established during decades of cheap and abundant oil and gas, were to continue, by 2000 energy conversion to electricity would reach 45–48%. One must, of course, be cautious about extrapolating from past trends, but as we have seen, increased scarcity and expense of such fluid fuels only tends to accelerate the shift to electricity.

With regard to energy transition, then, I believe that electricity is likely to play a far more important role than synthetic fuels. However, having thus revealed my ultimate conclusion, I think it is reasonable to ask what can be expected from synthetic fuels, and how their development will affect the electric utility industry.

Resource choices

It is important to recognize that nature has provided the United States with a real wealth of fossil energy resources. To choose among them requires a knowledge of how abundant they are and how easily they can be extracted and made usable in fluid form (listed here in order of ascending difficulty of conversion).

- Natural gas (200 quadrillion [10^{15}] Btu) and petroleum (160 quadrillion Btu). Since these resources are fluid in their natural state, they are the most easily extractable and usable as fuels and feedstocks.
- Heavy oil (25 quadrillion Btu). More viscous than conventional crudes, heavy oils require thermal or chemical treatment before they can be pumped to the surface.
- Oil shale (430 quadrillion Btu). This resource is a solid that must be mined and then heated to recover its hydrocarbons in fluid form.
- Coal (4800 quadrillion Btu). Conversion of coal to oil or gas is particularly costly because hydrogen must be added. It thus belongs at the bottom of this list of difficulty and expense, except for production of medium-Btu gas.

Because costs rise steeply as one goes through the list, it is not surprising to find that oil companies have turned first to the residual fractions of natural crude already at their refineries as they search for alternatives to high-priced, insecure supplies of foreign oil. Simultaneously, they have employed more sophisticated recovery technology to increase the historical average of 35% recovery from domestic petroleum reservoirs.

The next most attractive resource is heavy oil, and we can already see active exploitation of this resource in California. Once refining capacity is in place to upgrade residual and heavy oils to transport fuels and distillates, current pressures on the world crude oil supply should ease somewhat. However, this shift will also probably tighten the supply of boiler fuel for electric utilities.

It is important to recognize that these supply alternatives, which are already being vigorously pursued, will precede a substantial commitment to more complex and expensive synthetic fuels. However, given our present level of dependence on foreign oil and the time required to commercialize any new technology, the time has come to move more aggressively with synfuels development.

Oil shale

The United States possesses enormous oil shale resources, with the richest formation located in the Green River basin area of the Rocky Mountains. These premium resources will yield 30–40 gallons a ton of shale—less than one barrel per ton. Thus, even with the best shales, 60,000–65,000 tons of shale must be mined, processed, and disposed of each day to yield 50,000 barrels of syncrude, which is the equivalent of the input to a refinery of modest size or the output of a couple of good Saudi oil wells. Eastern shales average less than 15 gallons a ton and are generally regarded as marginal for commercial development.

The most attractive shale formations are up to 1000 feet (305 m) thick, with overburdens of 1000 feet or more. Open-pit mining requires a gigantic earth-moving operation, storage of overburden, dust control, and eventually recovery at depths approaching half a mile (0.8 km). Underground mining of seams this thick would recover only a fraction of the shale. In locations with thinner or deeper shale formations, underground mining would clearly be preferable, but the production rates from these mines would be substantially lower.

After mining, shale must be crushed and heated to liberate the oil. This process, called retorting, has thus far been done on the surface in vessels that resemble large kilns. Typical pilot units produce 600–800 barrels a day and must be scaled up by a factor between 5 and 10 for commercial use. The raw shale oil must then be upgraded before it can be piped to a refinery, where it is most easily processed to yield diesel, turbine, and jet fuels. (Combustion tests conducted for EPRI by Long Island Lighting Co. have demonstrated its acceptability as a utility turbine fuel.)

A host of environmental problems arise in disposing of the spent shale and reclaiming the land. Ideally, one would like to dispose of the spent shale in the mine from which it came, but it expands in volume by 20–30% in the retorting process, complicating an already difficult disposal problem. Substantial amounts of water are required, and contamination of aquifers or surface waters must be avoided.

In situ retorting, where most of the action takes place beneath the surface, appears to offer an attractive solution to the problems of moving massive amounts of material and disrupting the environment, but the technology is not yet sufficiently developed for commercial application. A combination of surface and in situ retorting, currently being considered by some potential shale oil producers, could substantially reduce the solids' handling and disposal problems.

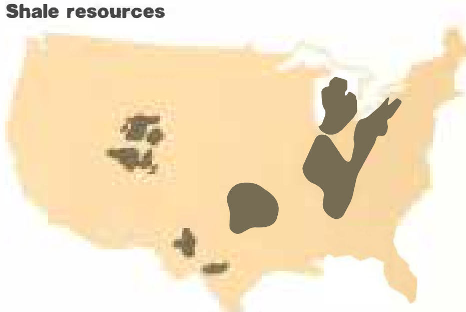
Whether oil shale will ever yield more than 2 million barrels a day when fully developed, as Exxon now projects, remains to be seen. Many knowledgeable people doubt it. Not until a plant is operated at commercial scale can we really evaluate oil shale technology, its economics, and its potential impact on the environment. The time has clearly come to scale up this technology to commercial size and separate fact from fiction because as challenging as oil shale development appears to be, it still looks like the lowest-cost syncrude option.

Coal

Coal is our most abundant fossil energy resource and has the advantage of being distributed over much of the United

Whether oil shale will ever yield more than two million barrels a day when fully developed, as Exxon now projects, remains to be seen. Many knowledgeable people doubt it. Not until a plant is operated at commercial scale can we really evaluate oil shale technology, its economics, and its potential impact on the environment. The time has clearly come to scale up this technology to commercial size and separate fact from fiction.

Shale resources



EPRI analyses indicate that an integrated gasification—combined-cycle (GCC) power plant that meets current cost and performance estimates could be competitive with conventional coal plant technology equipped to meet current environmental standards. GCC plants would use only about half the water of current coal-fired plants; they could meet even tighter sulfur emissions standards; and with the preferred gasifiers, they would produce a vitreous ash that is less leachable than the ash from today's coal plants.

Coal resources

States. Its use in producing liquid fuels avoids many of the infrastructure and water problems facing shale. Coal also yields about three times more syncrude per ton mined than shale, and the volume of ash to dispose of is substantially less. Syncrude from coal is particularly well suited for refining into gasoline and chemical feedstocks—those uses for which substitution of other energy forms is most difficult.

Coal is also a far more versatile resource than shale. Traditionally, we've burned it to provide process heat and electricity. Before natural gas became available, gasified coal was used as a fuel. The development of air separation technology permitted oxygen blowing of gasifiers to yield a medium-Btu gas. This synthesis gas, as it's called in the chemical industry, consists primarily of carbon monoxide and hydrogen. It is both a versatile feedstock and a fuel. It can be burned to produce electricity or process heat, or it can be chemically reacted to produce synthetic pipeline gas, chemicals, or petroleumlike liquids. Coal can be reacted directly with hydrogen to produce either a clean, low-ash solid fuel or a synthetic crude oil. The solid product can also be further hydrogenated to yield a liquid fuel. Coal's versatility is important to the electric utilities, and EPRI's research efforts have focused on exploring the power generation applications of synfuel technology.

Gasifier technology is pivotal in producing synthetic fuels from coal, whether they are finally used in the form of a gas, a liquid, or electricity. Today, only Lurgi and Koppers-Totzek gasifiers are commercially available for the large plants required by the petroleum and utility industries, and neither is optimal for use with American coals. For future use in medium-Btu gas production, three gasifiers have now been operated successfully at the large pilot scale (150–350 tons a day): Texaco, Shell-Koppers, and British Gas Corp. (BGC). All have demonstrated high throughputs and good efficiencies with a broad variety of U.S. coals, and they show no particular environmental problems. To compete with them, Allis Chalmers, Combustion Engineering, and Westinghouse also have aggressive gasifier development programs.

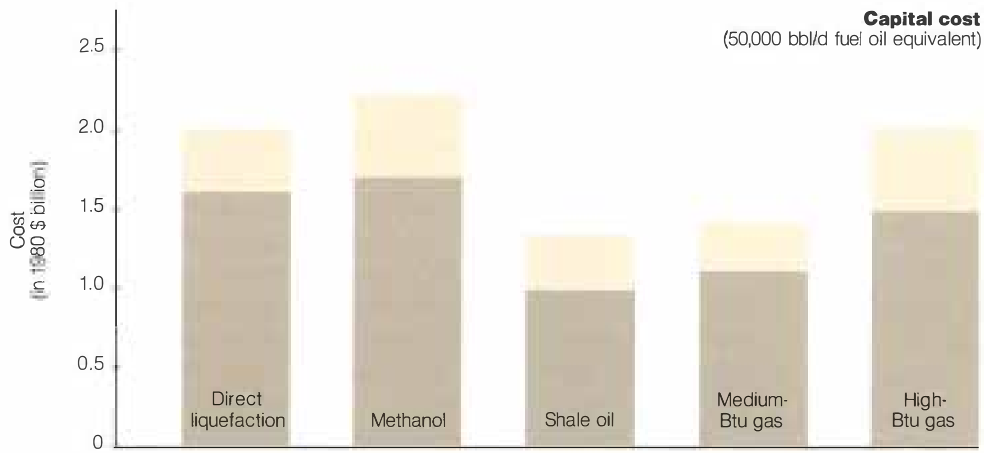
Their primary interest, as well as ours, is to develop gasifiers for use in power generation, either as a source of gaseous fuel for oil or gas plants not convertible to coal or coal slurries or as part of a new integrated gasification–combined-cycle (GCC) power plant. In a GCC plant, the fuel gas leaving the gasifier is cooled; scrubbed to remove sulfur, nitrogen compounds, and particulates; and fired in a combustion turbine. Hot exhaust gases are then used to produce steam in a waste heat boiler for use in a steam turbine. By appropriately integrating the gasifier with the power generation train, much of the heat otherwise wasted in the gasification process is used to generate electricity.

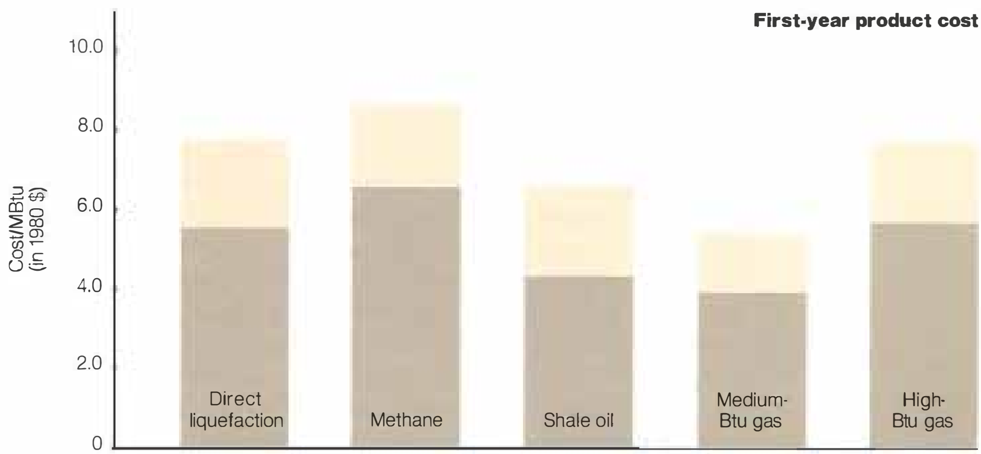
EPRI analyses indicate that such a system that meets current cost and performance estimates could be competitive with conventional coal plant technology equipped to meet current environmental standards. GCC plants would use only about half the water of current coal-fired plants; they could meet even tighter sulfur emissions standards; and with the preferred gasifiers they would produce a vitreous ash that is less leachable than the ash from today's coal plants.

EPRI has conducted sustained tests of Illinois No. 6 coal in the BGC slagger at Westfield, Scotland, and the large Texaco unit at the Ruhrchemie plant in the Federal Republic of Germany. These tests and others being conducted for Texaco and Southern California Edison Co. (SCE) at Ruhrchemie provide the design basis for the 100-MW Cool Water GCC demonstration project on the system. Bechtel Corp. and General Electric Co., along with SCE, Texaco, and EPRI, have made major financial commitments to the project. Discussions with other potential participants are under way.

As I mentioned before, medium-Btu

PLANT COSTS AND PRODUCT PRICES





Capital costs vary considerably among different kinds of synfuel plants, and considerable uncertainty will remain until experience is obtained at commercial scale. These estimated capital costs (in 1980 dollars) are for mature plants producing 50,000 barrels a day of syncrude or its equivalent. Early plants could cost up to twice as much as the fifth or sixth plant of a kind. Despite such uncertainties, however, I believe we can draw an important conclusion: Shale oil plants and medium-Btu gas plants should cost significantly less than plants for other coal-derived synfuels.

To translate plant costs into product cost or price, one must be precise about assumptions. Here we will assume private financing (100% equity) and include a 15% return on investment. To realize this return over a 25-year period, a producer would have to receive at least the initial selling prices shown, assuming that the market will permit a future 6% annual increase for the period. (Given today's rate of inflation, the 6% annual increase seems reasonable, but a 15% return on investment is not likely to be acceptable to many private investors.) Under these assumptions, only shale oil and medium-Btu gas appear competitive without subsidies to fully develop the technology. □

The 1980s will be a period of adjustment and learning for the embryonic synfuels industry. Activity will be stimulated by Synfuels Corp., a government group set up during the Carter administration to support commercialization of synfuel technologies, but progress will be slow—even $17 billion won't go far in this game. Major commitments of private capital will be made cautiously until markets stabilize and other, less risky sources for refinery feedstocks have been explored.

gas is not only an excellent turbine (or fuel cell) fuel, it is also used to produce petroleumlike Fischer-Tropsch liquids, methanol, and synthetic natural gas (methane), as well as various chemicals. Technology for converting it to any of these end products is commercially available today. However, the only significant commercial coal-based synfuels plant now in operation is the Sasol plant in South Africa, which uses Lurgi gasifiers. The off-again/on-again Great Plains gasification project could be the first in the world to produce commercial quantities of synthetic natural gas if the remaining issues related to product pricing and federal loan guarantees can be resolved. Methanol makes an excellent fuel for use in turbines or fuel cells. It could also be produced along with electricity in a GCC plant, quite possibly with relatively little added complexity or cost.

The second approach to converting coal to liquid fuels builds on old German technology to produce fuels and other critical products for their World War II effort. The solvent-refined coal (SRC) processes developed in the United States are improved versions of this German technology. Either a clean, solid boiler fuel or a liquid syncrude can be produced, depending on the extent of hydrogenation. Both are acceptable fuels for power generation, and utilities became involved in the SRC-I (solid) and SRC-II (liquid) demonstration projects started during the Carter period. The future of these projects under the Reagan administration is uncertain.

More advanced technologies for liquefying coal utilize catalysts to aid in the hydrogenation. EPRI is participating in two such projects: the H-Coal and Exxon Donor Solvent (EDS) large pilot plants. Successful operation at this scale (about 250 tons a day) will provide the design basis for commercial plants by the mid-1980s. A commercial plant, as currently conceived, would have multiple trains, each processing about 10,000 tons a day of coal, some 40 times the capacity of the pilot plants. Three such trains would be needed to produce 50,000 barrels a day of syncrude.

Progress to the year 2000

What is all this likely to mean? The rest of the 1980s are likely to show oil prices continuing to increase at a somewhat reduced rate, while demand continues to decline. It will be a period of adjustment and learning for the embryonic synfuels industry. Activity will be stimulated by Synfuels Corp., a government group set up during the Carter administration to support commercialization of synfuel technologies, but progress will be slow—even $17 billion won't go far in this game. Major commitments of private capital will be made cautiously until markets stabilize and other, less risky sources for refinery feedstocks have been explored.

During this decade, the most significant capacity commitments will probably be made for shale oil and medium-Btu gas. Given Synfuels Corp. impetus, we can also expect to see some coal-derived liquids and high-Btu gas come on-line. Realistically though, I do not expect to see more than about 250,000 barrels a day (fuel oil equivalent) as the total synfuel capacity operating before 1990, including the medium-Btu gas that can be expected to fire some utility units.

Higher oil and gas prices will make coal an increasingly attractive fuel, particularly as technology to use it more cleanly advances. Oil plants will be converted to coal where possible and affordable. And slurry fuels, perhaps coal-water slurries, may displace oil in other plants. Cogeneration will become more attractive economically and technically as fuel cells and energy storage permit a better match between the thermal and electrical requirements of users and utilities.

If we are fortunate enough to avoid the worst disasters sometimes projected for the 1980s, we should have come to equilibrium with energy realities by the 1990s. The United States will have become a more efficient and electrified society, relying increasingly on domestic supplies of coal and uranium. Liquid hydrocarbons, natural and synthetic, will be used primarily for transport fuels and feedstocks.

The synfuels industry will remain on the steep part of its learning curve during the decade, with capacity additions heavily dependent on lessons learned during the 1980s and on the outcome of accelerated resource exploration now under way. Production of shale oil and medium-Btu gas for utility and industrial use will expand. Coal-derived methanol and syncrude will gain momentum by the late part of the decade and may well surpass shale oil early in the twenty-first century.

I'm less optimistic than some that the still-developing synfuels industry can be expected to cap OPEC oil prices within this period, although its presence will at least be a factor in pricing. Demand accommodations, if they continue, will have a greater impact on prices. Conversely, increasing demand for coal will raise its price and make nuclear power increasingly valuable as a source of electric power. Therefore, to ensure the availability of electricity supplies in the 1990s, it is vital that the way be cleared for a substantially increased nuclear contribution in the next decade. This need far transcends the importance of synfuels in the long run.

As we approach the next century, the United States will be a far more energy-sophisticated society, in terms of both supply and utilization. Electronics, robotics, lasers, microwaves, heat pumps, and advanced electrochemical systems for industry and transportation will contribute to a continuous shift to electricity of end-use patterns. If we make the right decisions now, sufficient nuclear power can be available to help meet this demand, while clean, efficient GCC systems will make up an increasing fraction of coal baseload additions. Synfuels will be used very selectively to meet the peaking and cycling needs that cannot be accommodated by increasingly sophisticated load management, energy storage systems, and regional interconnections.

Synfuels in perspective

EPRI will have an important role to play in laying the groundwork for electric power industry utilization of synfuels. I believe that the expertise of our staff can help member companies apply the results of R&D in much the same way that our Nuclear Power Division and NSAC have. My purpose here has been to explore the synfuel options that face us and assess their impact on the electric utility industry.

Certainly, the availability of synfuels will help ensure that utility cycling and peaking generation needs are met, for they make excellent fuels for turbines, boilers, and ultimately fuel cells. GCC power generation is also quite promising, because it offers attractive environmental and economic features for near-term application.

Nevertheless, the growth of synfuels production will be slow, and capacity within this century will fall well short of the initial Carter administration projections. Synfuels will complement—not replace—other sources of energy in the continued electrification of America. The real energy transition for this country, which is still just commencing, is from natural fluid fuels to solid fuels and renewable energy resources. Electrification is the key to this transition, able to encompass both nuclear and renewable resources, centralized and dispersed technologies.

Continued development of synthetic fuels thus deserves continued support, for they will play a limited, but increasingly important role in the U.S. energy mix. But we must not lose sight of a far more important theme: Electrification is the best way of providing clean, secure, and sufficient energy to meet our future societal needs. ■

This article was adapted by science writer John Douglas from a speech delivered by Richard E. Balzhiser, EPRI's vice president for research and development, at the 49th Annual Convention of the Edison Electric Institute, April 7, 1981, in New Orleans.

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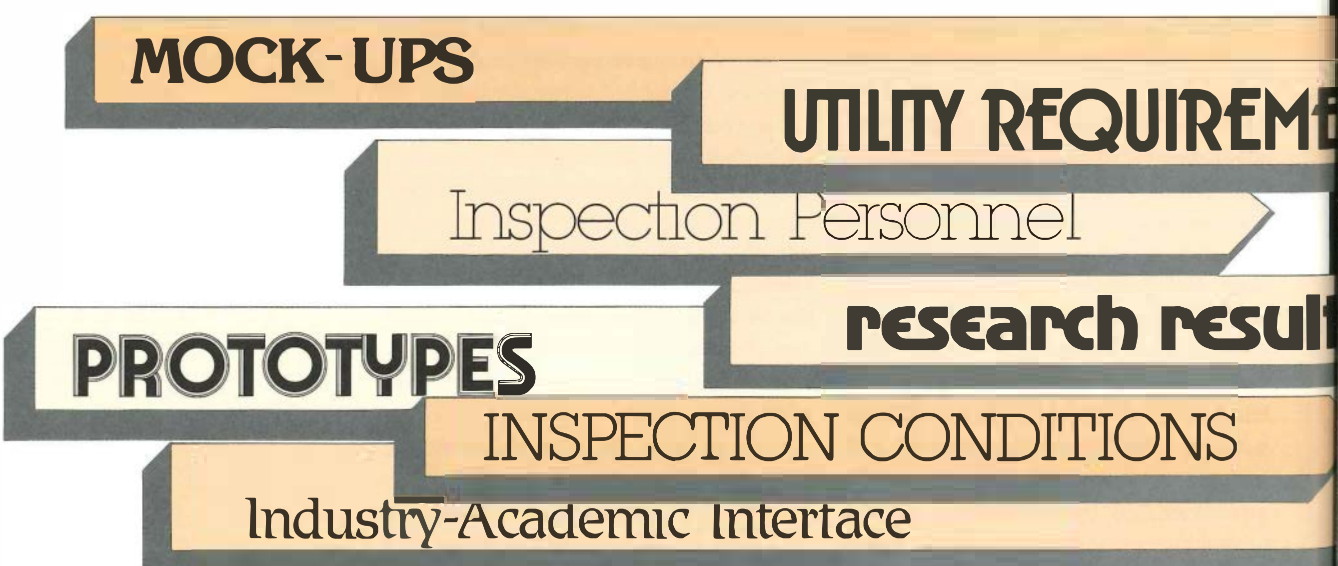
At EPRI's unique new NDE Center in Charlotte, North Carolina, the results of completed research can be transformed into field-qualified NDE techniques and equipment for the nuclear power industry, and technicians can be trained to work with these improved techniques and equipment.

NDE Techniques and Technicians

Within a brand-new building in Charlotte, North Carolina, an unlikely scrapheap has accumulated. The accumulation—which includes a 100-ton segment of a pressure vessel shell, sundry feedwater nozzles, scores of stainless steel pipes, two retired steam turbine rotors, and other equipment from nuclear power plants—is not awaiting pickup for disposal. This hardware collection forms an important element in EPRI's Nondestructive Evaluation (NDE) Center.

The NDE Center is a unique new facility where the results of completed Institute research can be transformed into field-qualified NDE techniques and equipment for the nuclear power industry, where technicians can be trained to work with these specialized techniques and equipment, and where the manpower pool of future technicians can be fostered. This $4 million center for technology transfer, constructed and operated by J. A. Jones Applied Research Co., is the first and only facility dedicated to fulfilling the specialized NDE equipment and training needs of a



single industry.

There are strong reasons why the nuclear power industry needs its own NDE facility. The utilities that own nuclear power plants currently contract most in-service inspections through outside agencies. The same methods, equipment, and technicians may be used to inspect power plants one day, jet planes the next, and pipelines the third. However, there are crucial differences between power plants, planes, and pipelines, and by paying close attention to those differences in the development of equipment, techniques, and technicians, power plant in-service inspections can be improved.

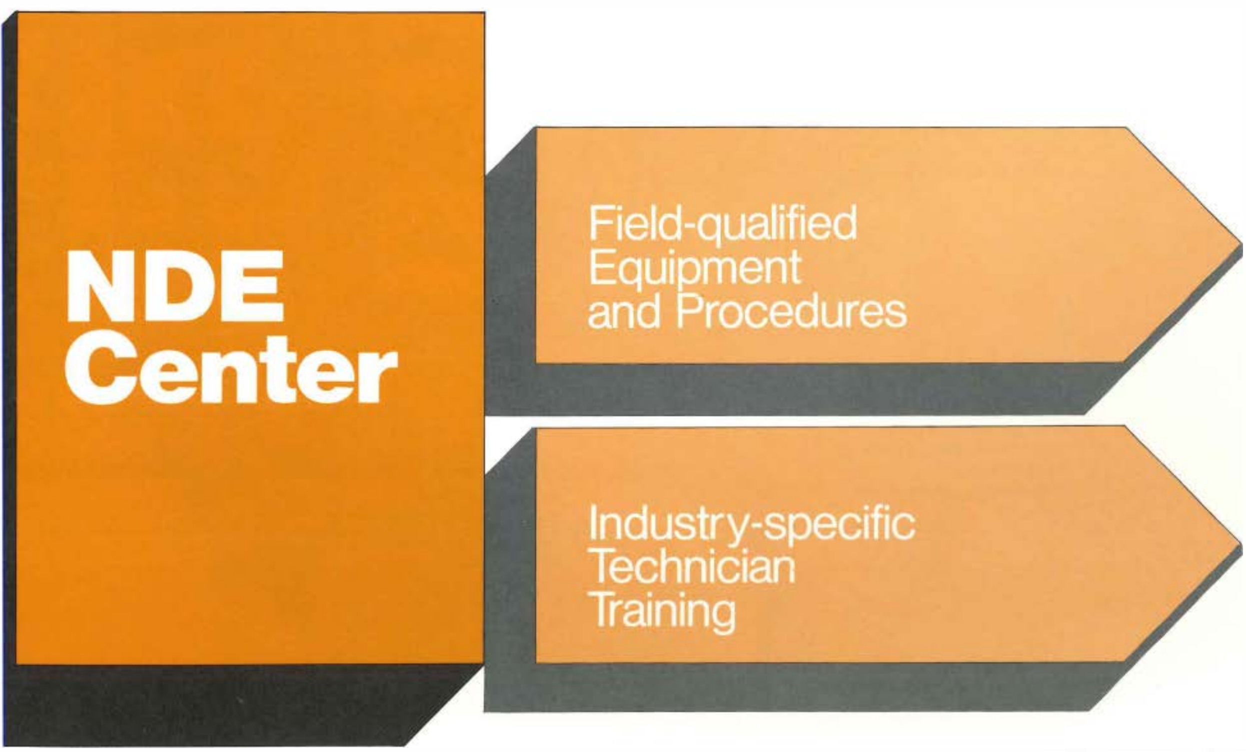
Gary Dau, program manager in charge of the NDE Center, which is part of the Nuclear Power Division's Systems and Materials Department, summarizes the big differences between the nuclear power industry and other industries in three words: materials, size, and environment. Nuclear power plant vessels and piping are usually constructed of carbon or stainless steel, in contrast with the aluminum used for aircraft, for instance. Unlike aluminum and certain other metals, steels often have nonhomogenous properties. During ultrasonic or eddy-current examinations, their large, uneven grain structure can produce signals that mimic those of flaws. Therefore, highly skilled inspectors are necessary to interpret the sometimes confusing signals.

The fabrication techniques used to construct power plants also differ from those used for aircraft. Because of their bulk and immobility, many power plant components are welded in the field—sometimes under difficult conditions—and this results in a wide range of welds that can be difficult for a technician to accurately examine. Aircraft is more or less mass-produced in factories, so technicians can expect much more uniformity from unit to unit than is possible for power plants.

Size is another important distinction between nuclear power plants and other hardware that NDE is used to inspect. Power plant components can be mammoth: the wall thickness of pipes may be anywhere from 0.5 to 2.5 in (12.7–63.5 mm); pipe diameters can be over 3 ft (0.9 m). Pressure vessels average 70–80 ft (21–24 m) in height, range up to 20 ft (6 m) in diameter, and have steel walls 4–12 in (102–305 mm) thick. These unusual dimensions magnify inspection requirements, making application of certain techniques, such as ultrasound or X rays, more difficult.

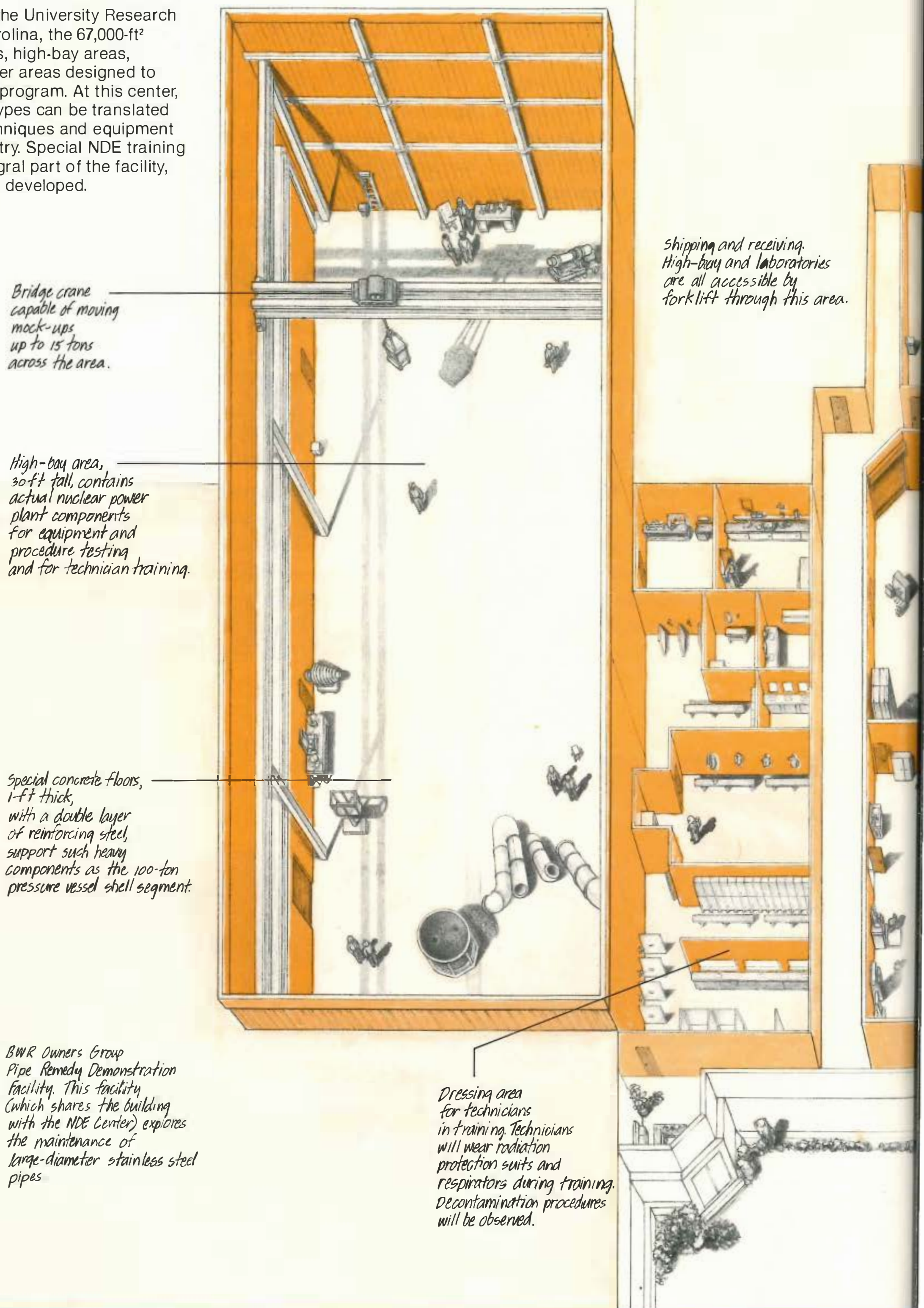
Environment is the final critical distinction. Performing an in-service inspection on a nuclear power plant is by no means the same as examining aircraft in a factory or on a runway. In many cases access to power plant components is very limited: the approach to an important weld may be barricaded by such obstacles as piping and concrete foundations. (Access to components in plants built before in-service inspections were required may be even more limited.) Not only may inspectors have a difficult time getting to the inspection area but the equipment they use may not be designed for such close quarters, and adherence to inspection procedures is thus more difficult.

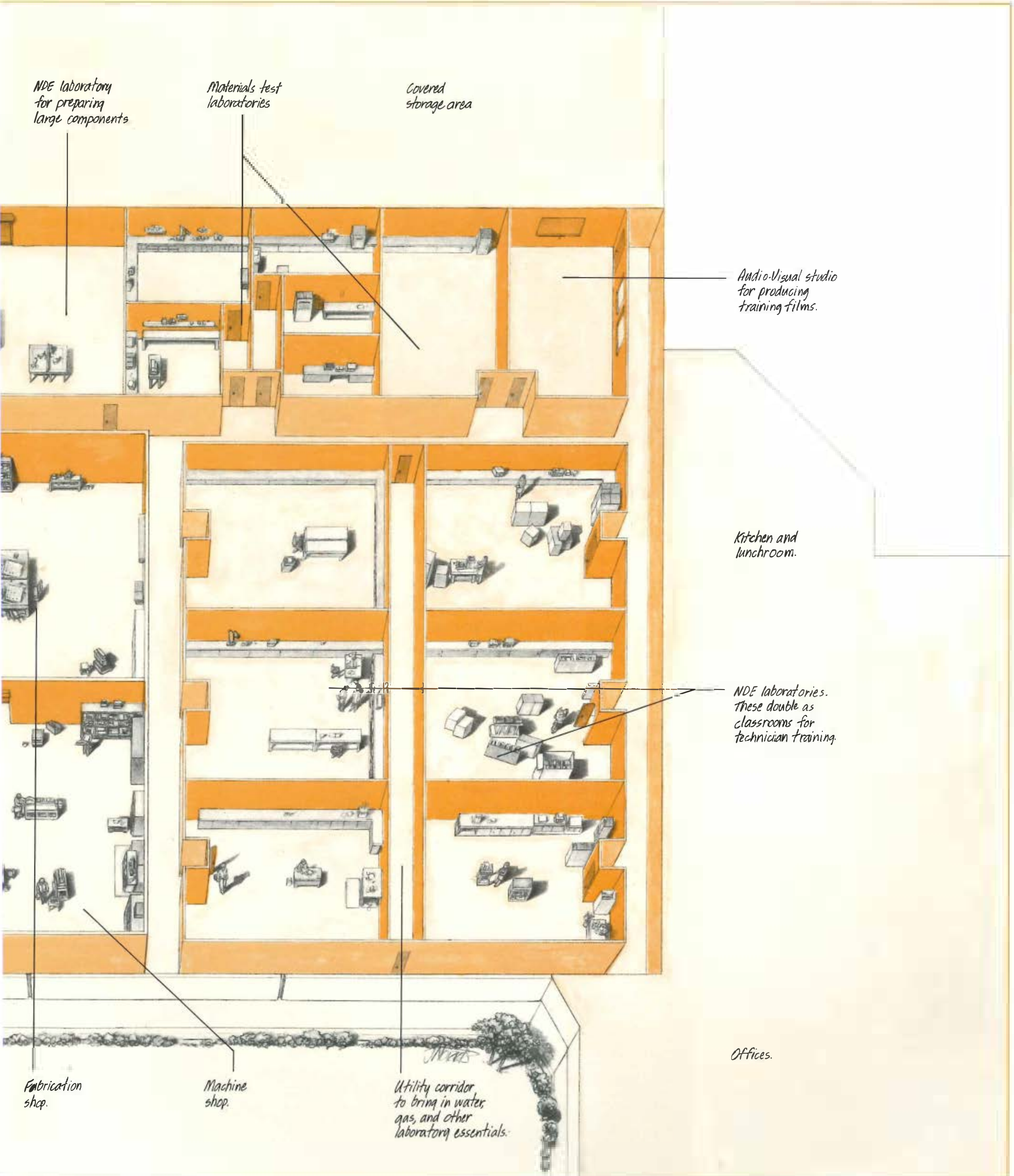
Other environmental restrictions include radiation, heat, and humidity. The

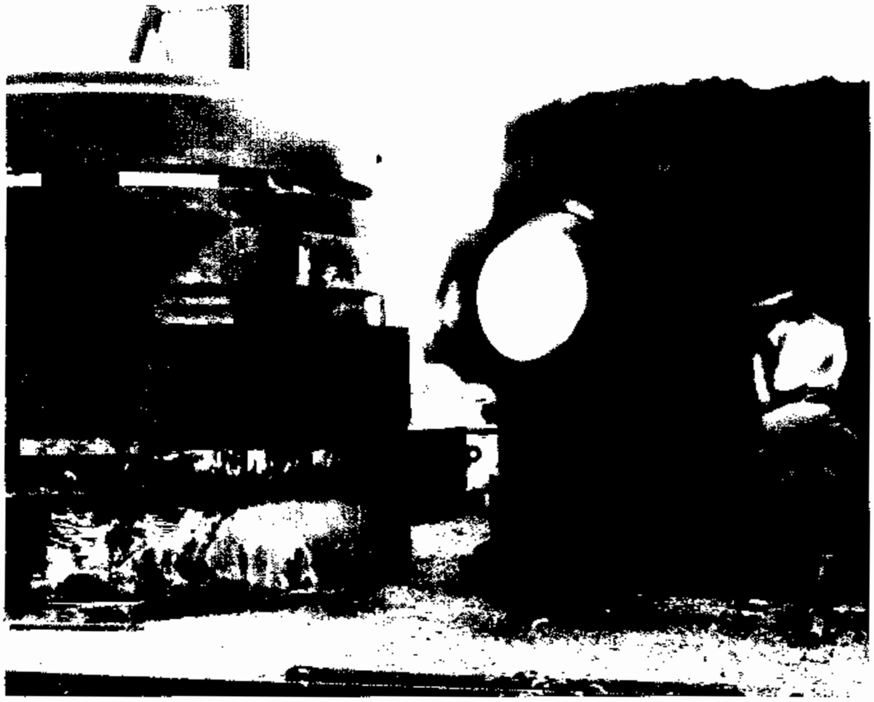


A Look Inside the NDE Center

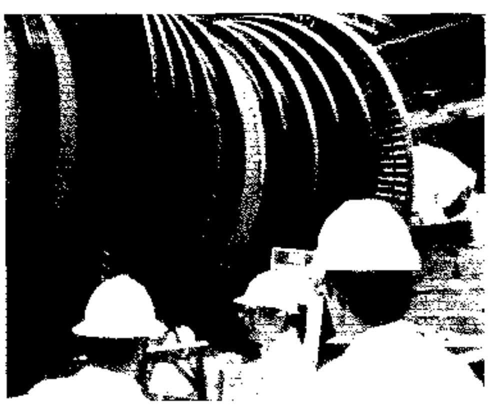
Located on a 9-acre site in the University Research Park in Charlotte, North Carolina, the 67,000-ft² center includes laboratories, high-bay areas, classrooms, shops, and other areas designed to meet the needs of the NDE program. At this center, research results and prototypes can be translated into field-qualified NDE techniques and equipment for the nuclear power industry. Special NDE training courses will also be an integral part of the facility, and curricula are now being developed.




NDE laboratory for preparing large components
Materials test laboratories
Covered storage area
Audio-Visual studio for producing training films.
Kitchen and lunchroom.
NDE laboratories. These double as classrooms for technician training.
Offices.
Fabrication shop.
Machine shop.
Utility corridor to bring in water, gas, and other laboratory essentials.



Nuclear power plant components are a vital part of the NDE Center. The facility's 100-ton pressure vessel shell segment, miscellaneous feedwater nozzles, stainless steel pipes, steam turbine rotors, and other components are used for equipment and procedure development. They will also be used to train technicians to perform in-service inspections. When possible, components with service-induced flaws are acquired from U.S. and foreign utilities; when impossible, flaws are "grown" with newly developed techniques and welded into the proper components.



components of greatest inspection interest are those that make up the plant's pressure boundary—the system of pipes, pumps, vessel, and valves that contains the water used to cool the radioactive core. Inspectors entering that region must wear cumbersome radiation-protection suits and respirators and work under radiation exposure limitations strictly prescribed by federal regulation. Because outages must be brief for economic reasons, inspections must be performed as soon after cooldown as possible. Thus components may still be hot, and the surrounding air is likely to be uncomfortably warm and humid.

Center's role

All three distinguishing characteristics of nuclear power plants—materials, size, and environment—need to be reflected in NDE equipment, techniques, and training. EPRI's NDE Center is well equipped for the job. Inside the 67,000-ft^2 (6225-m^2) building, which includes laboratories, high-bay areas, workshops, classrooms, and offices, new examination equipment can be tested to quantify its performance. Prototypes can be modified as necessary for field use and then evaluated; the performance data bases necessary to set realistic inspection requirements can be developed; technicians can be trained to use the new equipment and procedures. Also in the center is the BWR Owners Group Pipe Remedy Demonstration Facility, occupying 13,000 ft^2 (1208 m^2), which will explore the maintenance of large-diameter stainless steel pipes.

Actual components and realistic working conditions at the center ensure that equipment and procedures can be accurately evaluated, and technicians thoroughly trained. The center is acquiring dozens of power plant components, or mock-ups. These mock-ups will be used for equipment and procedure development, and will also be used to train technicians to perform in-service inspections. Because of their considerable weight, the mock-ups sit on custom-built 1-ft-thick (0.3-m) floors made of concrete and a double layer of steel reinforcement.

Where possible, components with actual service-induced flaws are being obtained from U.S. and foreign utilities and agencies. These flaws occur infrequently in service, but technicians need to be familiar with them before they try to discover others in power plant inspections. When specimens with real flaws cannot be acquired, flaws are "grown" with newly developed techniques and welded into the proper components. These flaws afford researchers and technicians much better working experience than do relatively crude saw cuts or machined notches.

The center's mock-up inventory includes a 100-ton pressure vessel shell segment in which mechanical fatigue flaws and slag inclusions will be implanted; a BWR feedwater nozzle with thermal fatigue cracks; about 100 samples of stainless steel piping with intergranular stress corrosion cracking; a variety of steam generator tubes in three current design configurations; two steam turbine rotors with cracks; and several turbine disks and wheels (which also exhibit stress corrosion cracking). The smaller, transportable mock-ups will be available to utilities on loan, Dau explains, in exchange for data and information. Access to the larger mock-ups may also be possible.

Besides these specimens of actual plant components, the center will also boast mock-ups that will help acquaint technicians with the logistic problems involved in examining nuclear plants. One mock-up constructed of fiberglass will duplicate the huge main coolant pump of a PWR. Because of the large size of these pumps, scaffolding must be specially erected for their inspection, and the X-ray inspection itself requires considerable skill in positioning equipment and film. The mock-up will allow technicians to assemble the necessary scaffolding, position X-ray equipment within the pump, and properly attach X-ray film to the pump's walls. Simpler mock-ups of wood or plywood will be constructed, as needed, around other component mock-ups to simulate the crowded conditions that inspectors will encounter within real power plants.

To further duplicate the working environment of the nuclear plant, technicians will go through their training outfitted in radiation-protection suits and respirators. The time constraints imposed by radiation exposure limits will be simulated by stopwatches or electronic timing devices. Even decontamination procedures will be observed: the center's change-rooms include step-off pads and other paraphernalia necessary for these procedures.

Work in progress

Although many of the center's mock-ups are still being assembled, development of new NDE equipment is already under way. In recent months, for example, evaluation of a signal-processing device for use with ultrasonic inspections of piping and pressure vessels was completed by work on 40 flawed pipe samples. A technician equipped with this portable device will be able to perform his usual inspection, moving the transducer manually and watching an oscilloscope for signals. The technician can then augment his own judgment with analyses from this portable unit.

A more advanced system developed by EPRI performs ultrasonic and eddy-current inspections in addition to analyzing and interpreting inspection data. The system will arrive at the center later this summer for evaluation on pipe samples. It consists of two microprocessors: the first controls a mechanical scanner that moves the transducer to gather data; the second microprocessor analyzes and interprets the data. With appropriate modifications, the system can be put to work in either ultrasonic or eddy-current inspections. A pattern-recognition technique called adaptive learning is used to train the second microprocessor to recognize important flaws.

Once equipment and expertise are developed, the center will see that they reach utilities faced with complex inspection and repair problems. For example, a high-power, lightweight X-ray source nicknamed Minac (miniature accelerator) is now available to utilities through the center and is, in fact, scheduled for use at power plants through 1983. EPRI developed this mechanism for use in confirming ultrasonic findings and inspecting components that are not amenable to ultrasonic methods. A powerful radiation source is necessary to overcome a nuclear plant's background radiation and to penetrate dense components, but previously available X-ray equipment was too heavy and bulky for practical use within plant confines. EPRI developed this compact, lightweight X-ray source to fulfill these specialized inspection requirements at nuclear power plants. The X-ray mechanism of this portable source weighs only 200 lb (97 kg), compared with 3000 lb (1360 kg) for a conventional source with equivalent strength. The new device will be able to X-ray plant equipment in minutes, minimizing personnel exposure to plant radiation. Minac was recently field-tested on a coolant pump at Rochester Gas and Electric Corp.'s Ginna plant with outstanding results.

Training grounds

While new hardware and software are being developed at the center, the curricula that will train technicians how to use these developments are being organized. Utility NDE personnel or NDE contractors will attend seminars or workshops at the center for training periods of several days to several weeks in specific aspects of power plant inspection. Staff from the center may also conduct seminars at individual utilities. Technicians will receive recognition in the form of certificates or continuing education credits. The first training seminars—probably for pipe inspection—will be held at the center this fall.

Besides acquainting technicians with new technology and techniques, the center will also take an active part in human resource development. Most individuals qualified in NDE developed their skills through on-the-job experience. Engineering school training provides technical background that is certainly applicable, but it is not always sufficiently specific. At the same time, NDE requirements in many industries are growing, and people skilled in inspection and repair are increasingly in demand. "If NDE as a discipline is offered by engineering schools, many students will be encouraged to pursue NDE as a career," says Dau. To further this objective, the center will work closely with engineering and vocational schools to encourage the development of curricula that will ensure the future availability of qualified people to perform NDE inspections.

It is difficult to estimate the dollar value of the NDE Center to the nuclear power industry and to the public. But any calculation must include an estimate of the value of a smoothly running plant with minimal time out of service. Whenever a power plant is off-line for inspection, maintenance, or repairs, the utility that owns the plant must replace the plant's forfeited electricity output with electricity from other sources. The price of replacement power for electricity varies, depending on fuel prices, transmission costs, and other considerations. But the price is always high, ranging from $500,000 to $1,000,000 a day for a 1000-MW plant—the amount of electricity needed to supply the needs of a city of half a million people. This high price is reflected in higher electricity bills for ratepayers. Better ways to inspect plant components for flaws that might affect the safe and economic operation of the plant will quickly offset the investment in the NDE Center, benefiting utilities and ratepayers alike.

This article was written by Nadine Lihach. Technical background information was provided by Gary Dau, Nuclear Power Division.

The Washington Research Institutes

Studies by research institutes have long influenced government policymaking. Today the work produced by these organizations may have more effect on decision makers than ever before, particularly in the area of energy policy.

Research institutes marshal the work of scholars to study timely issues, to solve complex problems, and to predict future developments in every aspect of social endeavor. Today, world energy use has become an increasingly important factor in domestic and foreign affairs. This topic is being addressed by six Washington, D.C., research institutes—the Brookings Institution, the American Enterprise Institute for Public Policy Research, Resources for the Future, the Aspen Institute for Humanistic Studies, the Center for Strategic and International Studies, and the Heritage Foundation. An examination of these institutes and their energy policy studies shows why the work of such organizations is important in government policymaking.

Policy Studies

The Brookings Institution, the American Enterprise Institute, and Resources for the Future are known particularly for the detailed policy studies they produce. The oldest, and possibly the best known, the Brookings Institution is a private, nonprofit organization devoted to research in economics, government and foreign policy, and the social sciences. Incorporated in 1927, Brookings was named for Robert Somers Brookings, a St. Louis businessman who helped to shape two earlier research institutes on government and economics and a graduate school, which all merged to become the Brookings Institution.

There are approximately 50 senior fellows and research associates at Brookings, and the full staff numbers around 240. Bruce K. MacLaury has been president since 1977. The research is grouped into three program areas: economic studies, governmental studies, and foreign policy studies, where most of the energy research occurs.

The institution also sponsors an advanced study program in which government, business, and professional leaders learn more about public policy issues through such activities as conferences, seminars, and round tables. Brookings estimates that 2100 people—journalists, business people, policy analysts, and senior government officials—participated in some aspect of the advanced study program in 1980. In addition to this program, Brookings provides fellowships and guest scholar appointments to academicians and others engaged in research activities related to the organization's purposes.

Brookings' annual budget is approximately $10 million, which is provided mainly by endowment and support from foundations, corporations, and private individuals. Under the terms of its charter, the organization may not make studies for private clients. The institution states that each of its studies is offered as a competent scholarly treatment of a subject worthy of public notice; Brookings itself does not take a position on policy issues.

In contrast to Brookings' more liberal studies, the American Enterprise Institute for Public Policy Research operates from a moderate, Republican base. Although AEI is an independent, nonpartisan organization and does not take a position on policy issues, much of its past research has focused on government deregulation, particularly in the air transportation and trucking industries and in economics. These studies support the Reagan administration's goals, and some of AEI's staff members have taken positions in the new administration, most notably, Jeane Kirkpatrick, ambassador to the United Nations; Murray Weidenbaum, chairman of the Council of Economic Advisers; and James C. Miller, III, at the Office of Management and Budget. Former President Gerald Ford is a distinguished fellow at AEI and participates in conferences at university campuses as part of AEI's academic outreach program.

There are approximately 45 full-time scholars at AEI, and their areas of research include defense, economics, education, government regulation, tax policy, international affairs, legal policy, health policy, energy policy, and political and social processes.

Established in 1943, AEI has grown tremendously in the last 10 years, and its budget has risen from $1 million to $10.5 million in that time. Most of its funding comes from grants and contributions from foundations and corporations, including the Lilly Foundation, the Ford Motor Co., and *Reader's Digest.* William J. Baroody, Jr., has been president since 1978, when he took over the position from his father, who retired after 24 years with the institute.

Founded in 1952, Resources for the Future has conducted research in U.S. natural resource problems and policies. But as the demand for energy and the concern for maintaining our resources increased, the organization broadened its research to encompass both domestic and international energy concerns. Current research at RFF studies energy in developing countries, energy and national security, energy consumption relative to overall economic activity, substitution between energy and nonenergy resources in the manufacturing sector, and the influence of changes in the patterns of the nation's household expenditures on energy. These last three projects are all funded by EPRI.

Three RFF divisions—the Center for Energy Policy Research, Quality of the Environment, and Renewable Resources—conduct the studies, most of which are carried out by resident staff. The divisions share staff and expertise for certain projects, but each division administers its own projects. There are currently 40 fellows and senior fellows at RFF, as well as visiting scholars, research assistants, administrative staff, computer services staff, and publications and public affairs staff. Emery N. Castle is president.

Because support from the Ford Foundation, which formerly was the principal source of RFF's funding, has been reduced, RFF is now funded by a variety of sources that provide either restricted or unrestricted funds. Unrestricted funds provide general institutional support. Some of this money is obtained from RFF's reserve fund, which functions as an endowment, and the remainder comes from industry, foundations, and government. All grants to RFF are made with the understanding that the staff must be free to conduct research without interference and to make all findings available to the public. Support is not accepted from individual corporations or corporate foundations for specific research projects.

Two books produced by RFF have contributed to its success in researching energy policy. *Energy in America's Future* is the result of three years' work by a team of RFF researchers directed by Sam Schurr, then codirector of RFF's Center for Energy Policy Research and now with EPRI's Energy Study Center. The second book, *Energy: The Next Twenty Years,* published with support from the Ford Foundation, was the product of a study administered by RFF and directed by Hans H. Landsberg, senior fellow in the Center for Energy Policy Research.

Forums of Reason

The Aspen Institute for Humanistic Studies is unique in that it does not actually conduct research but rather holds conferences where individuals with diverse viewpoints can discuss alternative approaches to major issues. Since 1950, Aspen, which does not have a full-time research staff, has brought together world leaders to consider interrelated issues that affect individual and social endeavor.

These conferences and meetings produce many publications that report on the institute's diverse activities. Many of the publications written on energy issues have resulted from the work of the institute's Committee on Energy, which is made up of representatives from both the public and the private sector. The participants try to arrive at consensus findings and develop initiatives that would be feasible for both government and industry use.

The Energy Committee has contributed to the energy policy debate through workshops on gas use, decentralized electricity and cogeneration, and transportation fuel options. The 1981 program focuses on utilities. The July forum was designed to help in the understanding of the current environment in which utilities operate, including investment requirements, financial health, and future supply and demand prospects. The forum also considered options for load management, least-cost supply, and changes in the regulatory and management structure of the industry.

Aspen also prepares an annual summer seminar in Aspen, Colorado, with EPRI's Advisory Council. Coordinated by Dana Orwick of Aspen's Washington Office, the seminar this year dealt with federal and state regulation.

The Aspen Institute also sponsors executive seminars; programs on such areas of social concern as education, international affairs, justice, and science and technology; projects that emphasize the broad theme of governance; and fellowship programs.

The Aspen Institute's main offices are in New York, but the institute's summer headquarters are in Aspen, Colorado. Other facilities are scattered around the world—in Washington, Berlin, Tokyo, and Hawaii. The most recently acquired Aspen facility is the Wye Plantation, an estate on Maryland's Eastern Shore. The program staff numbers around 90 full- and part-time members, and its annual budget is $6.8 million. Aspen's president is Joseph E. Slater.

The Center for Strategic and International Studies was founded in 1962 to foster scholarship on emerging international issues and, like the Aspen Institute, to sponsor forums on controversial issues. Affiliated with Georgetown University, CSIS is a public policy research organization that is nonpartisan and nonprofit. It does no classified work. The term *strategic* in the name does not imply studies on only military strategy or military/political issues; rather, it refers to priorities, methods, and resources disciplined by objectives, explains David M. Abshire, current chairman of CSIS. The research program also strongly emphasizes an interdisciplinary approach; it strives to link policy issues that must be grasped to understand and respond to today's complex problems.

CSIS is directly responsible to the president of Georgetown University, although its finances are independent of the university's. Its budget of more than $4.5 million comes from foundations, individuals, corporations, and corporate foundations, as well as from a small amount of government funding.

With a staff of more than 100, the center is involved in conferences, workshops, publishing, and over 50 research projects. The projects come under four major program areas, each headed by an executive director: maritime studies, Third World studies, world power studies, and international resources.

Assisting the center in the identification of additional research efforts, the International Research Council, formed in 1968, brings to CSIS the expertise of distinguished scholars from universities around the world. Composed of 40 members, the council meets annually to review ongoing CSIS research and to develop new program ideas. The members of the council serve for two years and may be called upon to chair specific projects and to serve as outside consultants and advisers. Also organized to advise the center, specifically on business and economic policy issues, the Future of Business International Councillors is a group of 30 of the world's leading corporate executives. The chairman of the group is Henry Kissinger, a counselor-in-residence at the center.

CSIS often brings together people with different views on an issue. One of the first energy projects the center sponsored—the National Coal Policy Project—was such a meeting. The project brought together a group of industry and environmental representatives that ranged from the executive director of the Sierra Club to the former chairman of Consolidated Coal. The purpose of their discussions was to find ways to accelerate coal use in the United States. The participants formed task groups on major coal issues and met regularly through 1977. In 1978, a 900-page report was released with recommendations on major issues.

Conservative Counsel

The Heritage Foundation was formed in 1973 with a $250,000 gift from Joseph Coors, owner of the Coors brewery. With a current budget of over $5 million, primarily from individual donations, the Heritage Foundation has been providing intellectual support for the conservative community since it was formed. The foundation's original aim was to offer the conservative view on the economy and the military, but its program has expanded, and it now studies urban and health-care issues, Latin American affairs, international terrorism, national security, education and family issues, and energy and the environment.

The foundation program is based specifically on problem solving. The research staff produced over 100 policy papers last year in many subject areas and gained a reputation for providing quick responses to problems. The staff analyzes Washington policy directives and provides critiques and alternatives on very short notice. The Heritage Foundation specializes in short newsletters and bulletins that congressional staff members can read quickly.

Heritage also holds a Washington briefing series, at which members of Congress can meet with business leaders, lobbyists, and trade association representatives, and a congressional staff training seminar, which addresses the intricacies of lawmaking.

The Heritage Foundation has recently been most influential with the publication of a 3000-page document it prepared for implementing conservative policy goals under White House leadership, which was used by President Reagan's transition team. The document consisted of 20 separate reports and included a discussion of each federal agency.

Center for Strategic and International Studies: Charles Ebinger and Richard Kessler; The Heritage Foundation: Milton Copulos; The Brookings Institute: William Quandt; Resources for the Future: Douglas Bohi, Hans Landsberg, Joel Darmstadter, and David Montgomery.

Ebinger Kessler

Copulos

Quandt

Bohi Landsberg Darmstadter Montgomery

Located in a bright blue townhouse on Capitol Hill, the Heritage Foundation employs a staff of 63. The president is Edwin J. Feulner, who has been with Heritage since 1977.

Energy and National Security

Three of these institutes are conducting research that assesses the relationship between national security and the uncertainty of the world's future oil supplies. CSIS is moving into the second phase of its project on energy and the national security, which has been in progress for two years. With funding from the Department of Energy, Brookings and RFF are undertaking a joint study to examine political and economic forces that link energy and security.

William B. Quandt, senior fellow in the foreign policy studies program at Brookings and director of the joint project, explains how the study is organized. "RFF will look at the kinds of things that can be done in America's economic policy setting for dealing with the threat of large-scale disruptions of oil supplies, such as strategic stockpiling and disruption tariffs. Brookings will focus on the foreign policy consequences of a large-scale disruption, the likely sources for the disruption, and the possible strategies for minimizing the loss of oil internationally."

The project is part of the foreign policy program at Brookings because the staff will study the major oil-producing region of the world—the Persian Gulf—and will specifically analyze the internal political and economic situations in Saudi Arabia, Iran, and Iraq. This part of the project will study the financial situation of the international energy problem and how the United States can reduce the problems associated with energy-related balance-of-trade deficits.

By reviewing the arrangements made under the International Energy Agency for sharing, for stockpiling, and for managing shortfalls, the Brookings staff will study what the Western oil consumers can do to reduce vulnerability to disruptions in the oil supply. Another aspect of the Brookings portion of the study will analyze Soviet and East European developments.

Quandt emphasizes the importance of this study to Brookings. "It was a very conscious decision on the part of the foreign policy staff to move into the energy arena because it is such an important and interrelated issue and will be even more important in the years ahead. What we bring to this new area of research is not much expertise in the field of energy but years of study on specific parts of the world, such as the Middle East. So we make the argument that many of the uncertainties about energy in the future are going to be related to political problems abroad."

The RFF portion of the study is under the direction of Milton Russell, director of the Center for Energy Policy Research. Russell and Douglas Bohi, a senior fellow at the center, will undertake a study of the economic problems posed by oil imports. Their work will focus on the domestic and economic side of the issue and will supply a model that can trace the economic relationships tied to oil supply. Bohi explains further, "There are two aspects of the study. One is to analyze alternative long-run oil import policies that will serve the interests of the United States by restraining world price increases and by reducing risks of disruptions. The other is to assess how a disruption will affect various parts of the economy in order to evaluate the policy options that may be implemented to ameliorate the effects of a disruption." RFF will also be responsible for analyzing the impact of oil market disruptions on other fuel prices.

The joint project should result in several publications. Quandt feels that the Brookings studies will produce a book on the political dynamics of the Persian Gulf area and how they will affect energy supplies in the 1980s. Brookings may also produce a monograph on Soviet energy and another on the energy policies that the United States, European nations, and Japan can undertake to protect themselves against reliance on oil imports. RFF will produce three monographs in the next year and an additional one the following year. At the end of the entire project, the two organizations may produce a joint summary. The project has secured funding for one year and expects additional funding.

CSIS is also conducting an energy and national security project. Its purpose is to analyze the challenges that energy problems emerging over the next decade will pose to U.S. national security, to suggest options for reducing and managing near- and long-term U.S. dependence on energy imports, and to make recommendations about how government, business, and the public can limit or manage dependence on foreign energy sources.

Dr. Charles Ebinger, project director, notes that the study looks at national security in very broad terms. "We do not look at national security, as so many do, strictly in terms of the military. We feel that national economic security is the important point. Economic security means not only protecting the energy viability of our own industries but also being aware of the problems inherent in the international financial area of petrodollar recycling. For example, if a Third World country goes into debt and defaults on its loans because of a staggering rise in energy prices, what happens to the world's financial structures from such a default, what would be the rippling effect, and would the world economy be able to sustain such a default? These are the sort of questions our study is considering."

The first stage of the CSIS project is a book to be published in late 1981 entitled *The Critical Link: Energy and the National Security.* The second phase of the study will result in a series of articles and monographs that will thoroughly discuss specific issues, such as communist bloc energy development, the future of the European oil market, the future of the International Energy Agency, Third World energy problems, the petrodollar recycling crisis, energy-producing versus energy-consuming states, and state and federal jurisdiction in an energy emergency. The last subject is a significant part of the study, and the staff hopes to start a work group on contingency planning. "We plan to bring together industry leaders and staff members from the executive and congressional branches to examine some of the critical issues involved in contingency planning, such as allocation plans and rationing programs," explains Richard Kessler, deputy director of the project.

"Our study also looks closely at how U.S. domestic actions affect the world oil market and the flow of oil to our allies in Europe and Japan. We want to look closely at the domestic component of energy and national security because if we let our domestic energy potential be hindered, for whatever good cause, then this becomes a national security issue as our increased dependency on imported oil would place upward pressure on world oil prices." Kessler points out that the emphasis on domestic energy and its influence on the international market and the importance of contingency planning are two important ways their study differs from previous ones on national security.

Another ongoing project is following up a conference RFF held on the side effects of price decontrol, "High Energy Costs: Assessing the Burden." Hans Landsberg, who organized the conference, explained, "Economists tend to say that price decontrol is a must, but it may have some unfortunate consequences, particularly for the poor." The conference brought together people concerned with welfare and income distribution, experts from universities, representatives from consumer and citizens organizations and regulatory agencies, and government officials.

Landsberg feels that the conference was quite successful because it brought together material that before was quite scattered. "We have completed a brief summary, in which we have used the material we commissioned for the conferences plus what was written as a result of the conference. We also are in the process of preparing a proceedings on the commissioned research papers." The summary will be published later this year; the proceedings will follow.

An interesting aspect of the conference, Landsberg noted, is that some people felt that the effects of price decontrol should not be the concern of energy economists but of a much broader range of economists and social scientists. Decontrol is necessary and the side effects are just grim reality. "But we felt that we could not just leave it there, and so we held the conference to try to sort out some possible remedies," Landsberg stated.

Decontrol is also a topic of interest at the Heritage Foundation. Milton Copulos, energy policy analyst at Heritage, served on the Reagan administration transition team's task force on synthetic fuels and also worked on the energy section of the 20-volume report that the foundation prepared for the transition team. Copulos points out that decontrol was a major aspect of the energy recommendations. "Decontrol of both oil and gas was recommended, as well as the repeal of the Fuel Use Act. We also suggested that the siting and licensing process be expedited and the standards of the Clean Air Act be reviewed, particularly regarding background pollution."

But the original report was merely a starting point, and the studies at the foundation have progressed further. Copulos stated that he is now studying the deregulation of electricity generation and federal land use. Much of the work at Heritage is done through a system of task forces, which are coordinated by the policy analyst dealing with that specific subject. Copulos explains, "A fair amount of my activity is involved in coordinating outside people. I bring in 15–20 people who have expertise in some area, and then I integrate the work of the task force. Most of the task force members are from the private sector and volunteer their time. I think most of them are interested in being involved because they feel they will have direct input into the policy process, because what we publish does get read and used."

Much of the foundation's work centers on removing federal regulations and subsidies. The basic philosophy is that things can be done more efficiently in the private sector. Copulos states, "For example, I see no reason why the federal government should spend money on light water reactors. The commercial technology is there, and the R&D should be performed by the companies that manufacture the reactors. Some federal control may be necessary in reprocessing to limit access to plutonium. But the real issue is that the taxpayer should not be subsidizing something that really belongs in the private sector."

Future Studies

AEI may soon be publishing papers on supply interruptions and federal coal leasing policies. Ed Mitchell, a professor of business economics at the University of Michigan, coordinates the energy studies undertaken at AEI. Much of AEI's research is done by scholars at universities, who write about their research for the institute. In addition, AEI holds conferences on specific energy topics and then publishes a proceedings of the invited papers.

RFF's future projects include a study on the economics of the Natural Gas Policy Act. Joel Darmstadter, senior fellow at RFF, is in the process of locating funds for an energy agenda. "This energy agenda would be an annual volume that would present an interpretive review of significant developments in the energy field, as well as selective essays that would thoroughly explore particular technical and analytic issues. There would also be a section for pertinent facts and figures. The concept of the agenda has generated much enthusiasm from outside sources but as yet we have not been able to find financing for it." Darmstadter also commented that RFF hopes to do some work on community energy systems, particularly emphasizing the role of the electric utilities in innovations like cogeneration and district heating. The study will address the institutional issues of why these technical innovations have not already flourished.

The Washington-based research institutes are sometimes called shadow cabinets because of the influence their studies can have on government policy decisions. This influence is increasing as these organizations study the intricacies of creating a national energy policy. ■

This article was written by Christine Lawrence, Washington Office.

Testing the Hot Waters of Nevada

Binary-cycle research by a group of western utilities is expected to boost hydrothermal prospects.

Development of Nevada's geothermal resources has moved one step closer to reality with preparations to install a hot water power test unit by EPRI and Sierra Pacific Power Co. (Nevada). Participating with Sierra Pacific in geothermal development are the Sacramento Municipal Utility District (California) and three Oregon power companies—Portland General Electric Co., Pacific Power & Light Co., and the Eugene Water & Electric Board.

Sierra Pacific and EPRI are sharing costs in the $108,000 project, which has a goal of measuring and controlling scale formation (mineral deposition) that occurs as geothermal hot water flows through a binary-cycle power plant. The results of a 30-day field test are expected to help the participating utilities define design criteria and operating parameters for a binary-cycle power plant capable of producing 10 MW of electricity. Such a plant is planned for construction in northern Nevada within two years, and the plant site will be selected during the coming year. Hot water resources are estimated to constitute about 10% of the nation's total geothermal base. Development of this hot water energy resource, especially with adequate control of scale formation, could provide a supplemental source of economical electricity for Nevada. In addition, the results of the Nevada testing could lead to further improvements in the binary-cycle process, speeding up the technical feasibility of hydrothermal power in other areas of the nation. ■

Solar Technology Conference

A state-of-the-art overview of solar and wind technologies, with specific emphasis on utility industry requirements and applications, will be featured at EPRI's 1981 Solar Energy Program Review.

The conference, to be held September 30 through October 2 in St. Paul, Minnesota, will include status reports on major solar and wind activities supported by EPRI, DOE, utility organizations, and private industry. Panel discussions involving senior utility management actively engaged in solar energy efforts will be a major element of the program, and a keynote address will be given by Llewellyn King, publisher of the *Energy Daily.* Discussions on effective transfer of EPRI research results to electric utilities are also planned.

Further details on technical content can be obtained from Edgar DeMeo, program chairman, EPRI, (415) 855-2159. Information on conference registration is available from Robert Riordan, meeting coordinator, University of Kansas Center for Research, (913) 864-4078. ■

Line Research Facility Launched

The Electrical Systems Division Committee met recently at a groundbreaking ceremony for the new transmission line mechanical research facility to be built on 250 acres near Haslet, Texas. When finished, the $7 million facility will be used in research to reduce costs and improve reliability of electrical transmission lines and towers.

Utility Support for Research on Cooling

Under the auspices of the Water Quality Control and Heat Rejection Program, several utilities are joining together to participate directly in research projects on advanced dry and wet-dry cooling.

The new organization—Advanced Concepts Test (ACT) Group—hopes to reduce significantly the costs of low-water-use cooling systems. Its first effort will be to examine a new demonstration system in Bakersfield, California. The process being studied is expected to reduce the water used in cooling power plants by 25% at costs from 50 to 65% of those for comparable conventional evaporative cooling systems.

The group consists of Pacific Gas and Electric Co. (ACT host utility), Southern California Edison Co., Los Angeles Department of Water & Power, and Canadian Electrical Association. Additional utility participants are being sought.

The participating utilities will support the projects with engineering input, as well as with financing, according to John Bartz, subprogram manager for heat rejection. "The primary purpose of this group is to gain a utility perspective on the engineering issues," according to Bartz. "This will help us develop a technology that is most practical for the utilities. By getting real-world feedback from utility engineering departments, we expect to get the information needed to make this technology commercially available much sooner." ■

Minac Unit Demonstrated

EPRI's new portable, high-energy linear accelerator, used for nondestructive examination (NDE) of components in nuclear power plants, was demonstrated in the field for the first time this May. This device, known as Minac, was operated continuously for 100 hours during integrity testing of a coolant pump at Rochester Gas & Electric Corp.'s Ginna nuclear power plant. Some 120 radiographs were acquired during the five days of operation.

Minac performed extremely well, according to Project Manager Melvin Lapides, who commented that the coolant pump test was probably as difficult a task as Minac will ever be called on to do. The NDE device is the result of a two-year cooperative effort with RG&E, which supplied the system manipulator and controls, as well as radiographic expertise.

Minac is a major advance in NDE technology. Formerly, radiographic devices used for inspecting heavy-section plant components were so large they could be used only at the manufacturing site. Once in service, detailed radiographic testing was not possible. With Minac, however, a fivefold size reduction has been achieved, in part by increasing the microwave frequencies used in its operation. The radiographic source is now small enough for engineers to get the same quality in service as at the fabrication stage. Minac's radiographic resolution provides better than 1% sensitivity.

Lapides said the Minac equipment and the experience gained from the RG&E test will be made available to utilities through EPRI's NDE Center in Charlotte, North Carolina. Because of the lead time required to plan Minac applications, interested utilities have been asked to identify their needs as quickly as possible. The equipment already has users scheduled through 1983. ■

CALENDAR

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

AUGUST

12–14
Human Factors Enhancement Approaches for Nuclear Control Rooms
Minneapolis, Minnesota
Contact: H. L. Parris (415) 855-2776

26–27
Workshop: Fossil Plant Heat Rate Improvement
Charlotte, North Carolina
Contact: A. F. Armor (415) 855-2961

SEPTEMBER

9–11
Workshop: Modeling of Cooling-Tower Plumes
Chicago, Illinois
Contact: John Bartz (415) 855-2851

17–18
Seminar: Compressed-Air Energy Storage (CAES)
Chicago, Illinois
Contact: Robert Schainker (415) 855-2549

17–18
Symposium: Underground Cable Thermal Backfill
Toronto, Ontario
Contact: T. Rodenbaugh (415) 855-2306
S. Boggs (416) 231-4111

21–25
Workshop: Zero Discharge
Steamboat Springs, Colorado
Contact: Roger Jorden (303) 824-4411
Winston Chow (415) 855-2868

30–October 2
Review and Workshop: 1981 Solar Program
St. Paul, Minnesota
Contact: E. A. DeMeo (415) 855-2159

OCTOBER

2
EPRI Sulfate Regional Experiment: Results and Implications
Dearborn, Michigan
Contact: Monta Zengerle (415) 855-2736

4–8
Environment and Nonnuclear Solid Wastes
Gatlinburg, Tennessee
Contact: Ishwar Murarka (415) 855-2150

14–16
International Symposium: Electrostatic Precipitation
Monterey, California
Contact: Dan Giovanni (415) 855-2442

14–16
Symposium: Power Plant Fans—The State of the Art
Indianapolis, Indiana
Contact: Kathy Davis (415) 854-2186

18–23
Water Chlorination: Environmental Impact and Health Effects
Pacific Grove, California
Contact: R. Kawaratani (415) 855-2969

20–22
Seminar: FGD Systems Data Book and Sludge Disposal Manual
Pittsburgh, Pennsylvania
Contact: Charles Dene (415) 855-2425

26–28
Workshop: Modeling the Performance of Cooling Towers
Chicago, Illinois
Contact: Hugh Reilly (415) 855-2469

NOVEMBER

4–5
Seminar: Prevention of Condenser Failures—The State of the Art
Arlington, Virginia
Contact: B. C. Syrett (415) 855-2956

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Director

METHANOL FROM COAL

Methanol is an alcohol fuel free of nitrogen and sulfur. Its clean-burning characteristics make coal-derived methanol an ideal substitute for all petroleum-derived utility fuels and even for natural gas. (A field test conducted by Southern California Edison Co. and EPRI on a 26-MW combustion turbine has confirmed the excellent clean-burning characteristics of methanol.) Because of the limited availability and high price of methanol, however, its use is not now practical for the utility industry. In the future, its price may be reduced by three factors: successful completion of ongoing work to develop second-generation coal gasification and methanol synthesis processes; efficient plant integration; and economies of scale as a result of larger plants. This report reviews EPRI's efforts in the areas of methanol synthesis process development and overall plant integration.

Liquid-phase methanol synthesis

Methanol is widely used as a petrochemical feedstock. Some 20,000 tons a day are produced in the United States from synthesis gas—a mixture of carbon monoxide (CO) and hydrogen—generated from natural gas or petroleum-derived feedstock; however, methanol can also be produced from coal or biomass. Two low-pressure synthesis processes, the Imperial Chemical Industries (ICI) and Lurgi processes, dominate the methanol industry today. These differ in the reactor system used to control the temperature of the highly exothermic methanol synthesis reaction. The ICI process features an adiabatic reactor with cold gas quench, while the Lurgi process uses an isothermal tubular reactor cooled by boiling water (Figure 1).

EPRI has sponsored an exploratory research project at Chem Systems Inc. to demonstrate the feasibility of a liquid-phase methanol reactor (RP317). In this reactor system, a circulating high-boiling hydrocarbon liquid is used to ebullate the catalyst bed and to remove the heat of reaction

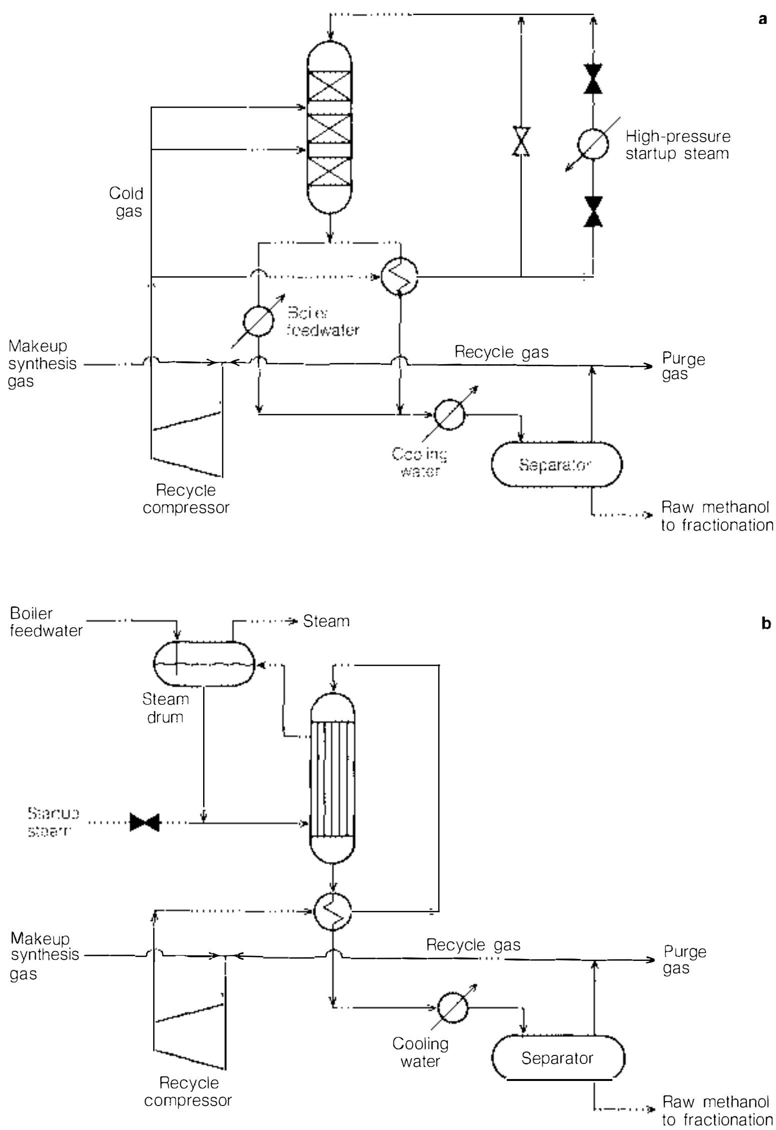


Figure 1 The ICI and Lurgi commercial methanol synthesis processes. These low-pressure processes, which dominate the methanol industry today, differ primarily in the way the reaction temperature is controlled. The ICI process **(a)** uses an adiabatic reactor with cold gas quench. The Lurgi process **(b)** uses an isothermal tubular reactor; water surrounding the reactor tubes is boiled to remove the heat of reaction.

(Figure 2). The system is believed to be more suitable for a coal-derived synthesis gas rich in CO because it is capable of processing an unbalanced feed gas without additional CO shift conversion, provides higher CO conversion per pass with higher methanol concentration in the reactor effluent gas, and affords better temperature control.

On the basis of bench-scale test results, it was concluded that (1) the commercially available copper-based catalyst is active in the methanol synthesis reaction in the presence of a circulating hydrocarbon liquid, (2) in a once-through operating mode, high-CO-containing feed gas performs as well as a more typical methanol synthesis feed gas, and (3) the purity of the product methanol remains consistently high, even at conversion levels over 30% per pass.

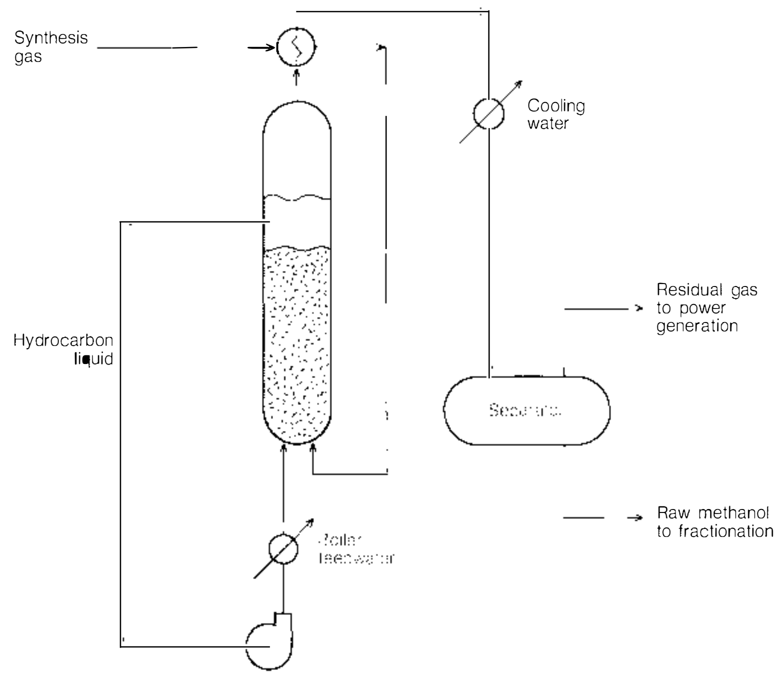
Long-term catalyst activity tests, however, showed steady deactivation at a rate faster than acceptable for a commercial catalyst. Runs in a process development unit also revealed a high catalyst loss from attrition in the liquid-fluidized-bed operating mode. The spent catalyst was found to be enriched in iron and nickel. During these runs the following were also observed.

- The rate of catalyst prereduction affected catalyst activity.
- There was a loss in catalyst activity after a switch to a feed gas having a higher CO content.
- There was a loss in catalyst activity after an increase in the space velocity or an increase in the system pressure.

These experimental results raise some questions concerning the feasibility of the liquid-phase process. The apparent catalyst deactivation is thought to be associated with two phenomena: catalyst attrition and inadequate hydrodynamic conditions in the reactor. Because the liquid phase surrounding the catalyst particles is an added resistance to film heat and mass transfer, the catalyst particles may be exposed to thermal shocks under unfavorable reactor hydrodynamic conditions. Therefore, further demonstration of the basic process concept is required before commercialization can be considered. A follow-on project is being planned in cooperation with DOE; Air Products, Inc.; Fluor Engineers and Constructors, Inc.; and Chem Systems (RP317-3).

A companion project is proceeding at United Catalysts, Inc., to investigate the possibility of improving the mechanical strength of the copper-based catalyst (RP1656). It was found that the weakness of the CuO-based catalysts is related to the void spaces produced by the reduction of CuO. Therefore, it is unlikely that a CuO-based catalyst with good attrition resistance will be produced without some sacrifice in catalyst activity.

Figure 2 Liquid-phase methanol synthesis process under development at Chem Systems Inc. Pressurized synthesis gas is preheated by heat exchange with the hot reactor effluent gas before entering the synthesis reactor. A circulating high-boiling hydrocarbon liquid is used to ebullate the catalyst bed and to remove the heat of reaction by steam generation. After heat exchange with the feed gas, the reactor effluent is further cooled to condense the raw methanol. The unreacted gas is purged from the system and can be used for electric power generation.



Alumina was found to be the best carrier for the CuO-ZnO catalyst for both strength and activity. A high concentration of alumina in tableted CuO-ZnO catalysts improves their resistance to attrition remarkably, although it lowers their activity. It was also found that the mechanical strength of a catalyst formed by extrusion is not always the same as that of the corresponding tablets. Extrudates treated by a new technology developed in this project are denser and stronger and have greater activity and stability than untreated materials.

Two promising catalyst formulations have been selected for future testing at Chem Systems.

Engineering evaluations

The production of methanol from coal involves five major steps: gasification, shift conversion, gas purification, synthesis, and fractionation. Processes for all these steps are commercially available. First-generation coal gasification processes (Winkler, Lurgi, and Koppers-Totzek) were practiced commercially before and during World War II; the remaining four steps involve modern, efficient processes that are widely practiced in the petrochemical industry today. Therefore, large-scale coal-to-methanol plants based on first-generation gasification technology are feasible without undue technical risk. Second-generation gasification technologies now under development (e.g., Texaco, Shell, and British Gas Corp.–Lurgi) could lower the cost of methanol in the future.

In response to a request from a group of

14 northern and midwestern utilities interested in methanol, EPRI joined a cooperative project to investigate whether North Dakota lignite, a major low-cost fossil fuel resource, would be economically attractive as a feedstock for a large methanol plant (TPS77-729). The proposed plant configuration incorporated the Texaco gasification process and a high-pressure methanol synthesis process developed by Wentworth Brothers, Inc., the project contractor. This configuration was found to be inappropriate for the lignite, which has a high equilibrium moisture content, and was burdened by unacceptable technical risks.

To complement that study, EPRI contracted with D M International Inc. for an engineering evaluation of the lignite-to-methanol conversion route based on the commercially proven Winkler gasification and ICI methanol synthesis processes (RP832-3). Several background studies were conducted in support of plant configuration selection, plant integration, and process design.

The raw synthesis gas produced by the Winkler process is a CO-rich, particulate-free gas available at near atmospheric pressure. The preferred processing sequence for this gas was found to be (1) compression to an intermediate pressure, (2) shift conversion and selective Rectisol acid gas removal, and (3) further compression to synthesis loop pressure. Although it was expected that a low-pressure (50-atm; 5-MPa) methanol synthesis process would be best for the Winkler feed gas, a definite advantage resulted in favor of a 100-atm (10-MPa) synthesis loop. Hydrogen recovery from the synthesis loop purge gas was also recommended. A single-column low-pressure distillation system was used to separate the water from the methanol.

Because of the difficulties in achieving very high carbon conversion in fluidized-bed gasifiers, a conservative conversion level of 85% was chosen for the Winkler gasifier. This does not penalize the effectiveness of the overall processing scheme as long as char can be efficiently used for power generation. In the scheme selected for this study, char is mixed with supplemental lignite and used as a fuel in utility boilers to generate electricity and part of the process steam.

The overall thermal efficiency of the selected plant configuration is a relatively low 47%; the specific investment per ton a day of methanol is $129,500 ($42,100 per barrel a day, fuel oil equivalent). The penalties in thermal efficiency are related to the use of a first-generation gasifier operating near atmospheric pressure and to the high moisture content of the lignite.

A separate study was therefore initiated at Fluor to evaluate methanol production from a low-moisture Illinois No. 6 coal by the Texaco gasification process and the ICI methanol synthesis process (RP832-4). The Texaco process is a high-temperature, pressurized, second-generation gasification process that produces a CO-rich synthesis gas with a very low methane content. For such a feed gas, the low-pressure (50-atm; 5-MPa) ICI methanol synthesis loop was recommended, with hydrogen recovery from the synthesis loop purge gas. A two-column distillation system (high and low pressure) was selected for this plant design. The overhead of the high-pressure column supplies the heat required for the low-pressure column, which results in an energy savings. A steam superheater was integrated into the gasifier effluent high-temperature heat recovery train. The overall thermal efficiency of this plant is 57.8%; the specific investment per ton a day of methanol is $132,600 ($42,800 per barrel a day, fuel oil equivalent).

Ongoing economic evaluations indicate that methanol could be produced from coal at a cost that is competitive with the current price of methanol produced from natural gas ($258/ton, or $12/10^6 Btu). For methanol to be economically attractive as a utility fuel, it must become competitive in price with petroleum-derived liquid fuels and natural gas, which are traditionally used for the generation of peaking and intermediate-load power. A factor that may help make coal-derived methanol affordable for utility use is that the price of these traditional fuels is rising faster than that of coal. Methanol may also have to compete with other synthetic liquid fuels (from direct coal liquefaction and shale oil), which, according to EPRI studies, are likely to be lower in cost as well as lower in quality.

An attractive argument for methanol is the possibility of its coproduction with electric power in a gasification–combined-cycle power plant. In the coproduction schemes, the production of methanol would act like a flywheel for the plant, supplying a storable clean liquid for later use as a peaking or intermediate-load fuel. These schemes are being evaluated in EPRI's Engineering and Economic Evaluations Program. *Program Manager: Howard Lebowitz; Project Manager: Nandor H. Hertz*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Director

INTEGRATED FOSSIL PLANT SYSTEMS

Large fossil fuel power plants provide the major portion of electric power generated in this country, and they will continue to do so through the end of this century and perhaps beyond. It is now forecast that almost all new plants to be constructed in the next 10 years will be fossil-fuel-fired, the overwhelming majority being coal- or lignite-fired. A trend creating concern has been the decreasing availability of large power plants over the last 15 years, which is primarily due to the increase in forced outages of major components. The availability of the more than 250 large fossil fuel plants that supply the bulk of U.S. electricity is of particular concern. EPRI's integrated plant subprogram was established to enhance fossil plant performance and reliability through the application of improved plant systems. Current subprogram efforts include diagnostic monitoring, plant instrumentation and performance monitoring, root cause failure analysis, design of advanced low-heat-rate plants, plant operation and control improvement, and preparation of plant design and maintenance guidelines.

Diagnostic monitoring

A preventive maintenance program must address many components. The boiler is clearly the primary contributor to fossil plant downtime. Boiler tube damage is the major area of concern, and because of the large number of tubes involved and the time required for a full inspection, one of the most difficult to monitor and assess. The turbine generator drive train, although typically more reliable than the boiler, is also of vital importance from the standpoint of diagnostic monitoring because of the potentially catastrophic nature of any failure of the rotating system. Turbine shaft, disk, and blade assessment is a critical part of any plant monitoring program. Major generator failures have been responsible for long outages; failure mechanisms include retaining ring bursts, armature bar overheating, and overfluxing of the magnetic stator core. Pumps and fans are of somewhat lower priority because of the practice of installing redundancy in the system, but repeated deratings and partial outages due to the failure of these components can significantly affect utility reserve capacity. Condensers, feedwater heaters, pulverizers, and exhaust gas cleanup systems (precipitators, scrubbers, baghouses) are other components that can shut down or derate a plant.

Nondestructive evaluation (NDE) techniques offer an opportunity to improve plant availability by anticipating component failures. Of particular importance in this respect are new diagnostic methods being developed for the continuous on-line monitoring of operating units. The integrated plant subprogram is investigating several such on-line techniques: vibration signature analysis of rotating machinery (RP1864); acoustic emission monitoring (RP1266-14); nonintrusive methods for turbine blade crack detection (RP1854); laser-Doppler techniques for monitoring torsional vibration in turbine generator shafts (RP1855); eddy-current systems for crack detection (RP1894); and boiler and turbine transient stress analyzers (RP1893). Applications of acoustic emission techniques and laser-Doppler techniques are illustrated in Figures 1 and 2.

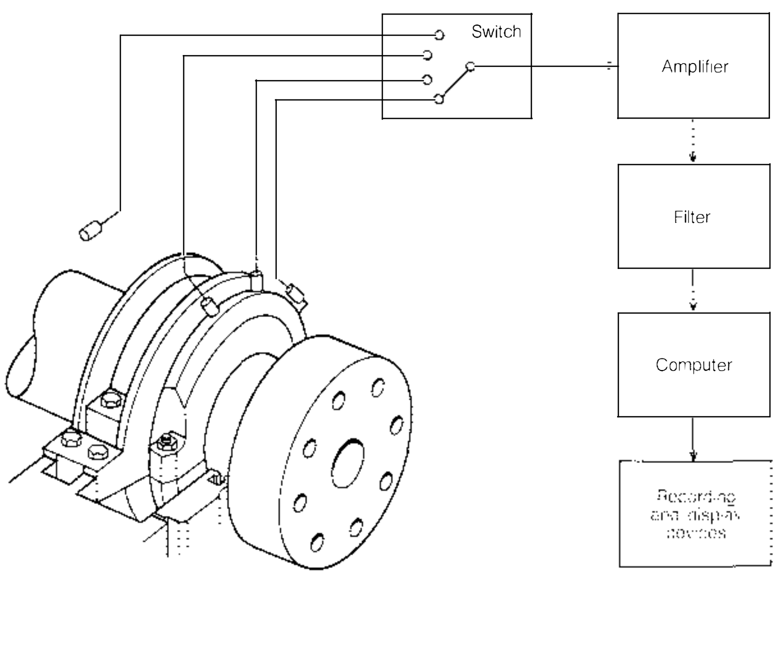
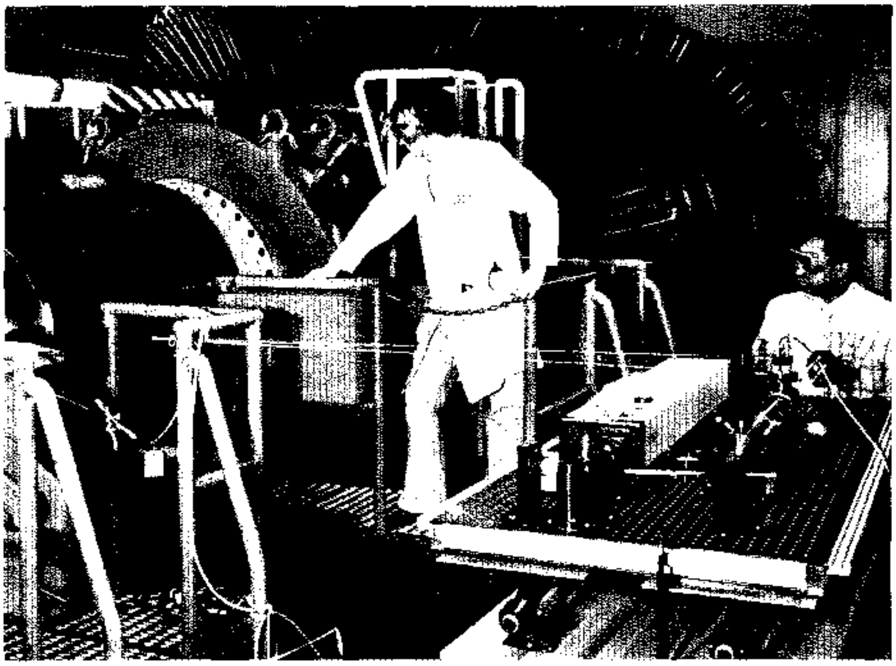


Figure 1 Acoustic emission monitors have been installed on four steam turbines at the Tennessee Valley Authority. Acoustic signals from different locations on the bearing cap are amplified, filtered, and processed by computer to provide a data readout. The monitors will be used to predict such problems as shaft cracking, bearing deterioration, and blade rubbing.

Figure 2 A laser-Doppler technique for measuring torsional vibration in turbine generator shafts. Twin laser beams form interference patterns on the rotor surface. Movement of the rough shaft through these patterns reflects back light, which is correlated to shaft torsional vibration.



Off-line NDE techniques to complement on-line monitoring are also being investigated. The goal is to provide optimal inspection procedures for areas identified by on-line monitors as needing attention. Currently, off-line NDE techniques are being consolidated and developed for boiler tubes (RP1865) and for turbine generator components (RP1266-24, RP1957).

Plant instrumentation and performance monitoring

The improvement of fossil plant performance as measured by plant heat rate is becoming the major effort of many utilities. Fuel cost savings is a primary motivation; another factor is the increasing regulatory pressure to enhance plant efficiency.

Heat rate measurement is not straightforward. Typically, special equipment is required and a specific set of procedures must be followed for the test, which is conducted over several days. Of much more value to utilities would be a continuous description of how plant heat rate is affected by load following, off-design performance, cycling duty, fuel quality, a change in excess air requirements, fouling of heat exchangers, additional flue gas cleanup equipment, and many other operating situations. Achieving this objective requires accurate, calibrated instrumentation, well-defined techniques for fuel assaying and for measuring wet steam enthalpies and other parameters, and suitable computer software for storing and analyzing large quantities of data.

A project will be initiated this year to develop an advanced instrumentation system to overcome current measurement limitations (RP1681). The system will be installed at a host utility for long-term operation and monitoring. During this period instruments will be tested and calibrated and procedures refined. The immediate benefit is expected to be the on-line detection of any heat rate deterioration of plant equipment.

Another project is developing methods and computer programs for modeling steady-state and dynamic power plant performance (RP1184-2). In a series of transient disturbance tests at Boston Edison Co.'s Mystic-7 plant, this effort has already proved useful in improving plant performance by optimizing control and monitoring systems. Data from new instrumentation systems will allow computer programs to more closely simulate plant performance.

Root cause failure analysis

There may be a number of "causes" for a perceived equipment failure. In some cases, it will be necessary for two or more incipient defects to be present before the equipment demonstrates the abnormal behavior characterized as a failure. A typical fault tree for a failure of a complex component has many levels of causes. The most elemental level represents the root cause. The definition of this root cause is partly subjective. Probably the ultimate level, the true root cause, lies in human fallibility, whether in component design, manufacture, or operation. For the purposes of EPRI analyses, the root cause of failure is defined as the most elemental level that lends itself to corrective action. The corrective action may require an R&D effort, or it may involve more simply a change in design, manufacturing, or operating practices.

The integrated plant subprogram is currently conducting a series of failure studies to determine the root causes of important generic equipment problems in fossil fuel plants (RP1265). One goal is to define the R&D required to solve these problems so as to improve plant availability. Specific plant components being addressed are pulverizers, turbine generator bearings, boiler controls, boiler draft fans, feedwater heaters, and air preheaters. Problems entailed by coal freezing are also being investigated.

In most of these studies, it is first necessary to accumulate failure information from utilities, manufacturers, insurance companies, and other sources. This information must then be synthesized in such a way that the root cause or causes of the problem can be deduced.

An individual utility may experience a plant problem with no apparent generic cause or no obvious relation to an industry-wide syndrome. The problem may involve equipment failure, maintainability, heat rate deterioration, or any of several other aspects of plant operation. A second effort in the EPRI root cause program is aimed at the development of a methodology utilities can use to identify the cause of such problems and define cost-effective corrective actions (RP1711). Most, if not all, utilities have some informal or formal approach to this kind of situation. The goal of the EPRI work is to define a structured approach incorporating methods that have been shown to be effective for a number of specific utility problems. Equipment reliability concerns at two utilities are currently being studied by means of the EPRI approach.

Advanced low-heat-rate plants

Two independent research teams—each consisting of a turbine generator manufacturer, a boiler manufacturer, an architect-engineer, and a utility—have participated in a project that has clarified the prospects for the next generation of coal-fired power plants (RP1403). The objectives were to identify the limits of current technology, assess the availability record of present-day supercritical plant designs, and develop conceptual designs and cost estimates for an advanced plant. Each team has completed conceptual designs for an advanced plant equipped with all necessary environmental controls and having a nominal operating net heat rate of 8500 Btu/kWh. In addition, the critical technology needs and their development costs have been defined.

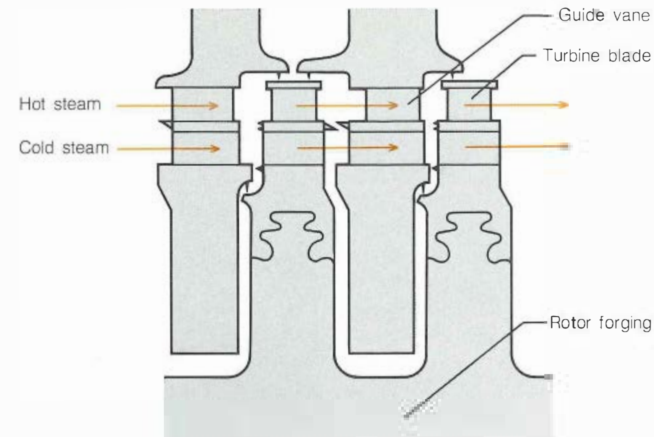
The two studies indicate that these advanced plants, which represent an improvement in heat rate of approximately 10%, could be available for commercial order within five years with a small R&D investment. Additional gains in heat rate are possible, but they will require significant increases in R&D expenditures as well as considerably longer development time.

The advanced plants include the following features.

- Supercritical, double reheat design
- Variable-pressure boiler operation over the load range
- Improved turbine cycle efficiency and innovative cooling schemes for turbine components (Figure 3)
- Improved thermodynamic cycle for the feedwater train
- Improvements in the internal efficiency of equipment
- Innovative back-end designs for waste heat utilization

EPRI and Duke Power Co. will cohost a workshop in Charlotte, North Carolina, in August to present these and other new concepts for improving plant efficiency. Input from utilities and equipment manufacturers will be solicited for this workshop. The advanced-plant design studies are described in detail in the March 1981 issue of the *EPRI Journal* (p. 39), and final project reports are expected to be published shortly.

Figure 3 By supplying a layer of cold steam close to the turbine rotor forging, this advanced cooling scheme allows for higher steam temperatures in most of the flow annulus and permits the use of existing materials for forgings.



Other activities

Also under way in the integrated plant subprogram are projects involving improved plant control (RP1266-15), design guidelines for plant components (e.g., RP1266-18 for pumps), and plant noise control studies (RP1266-23).

The production of guidelines for utilities, whether for equipment design and selection or plant maintenance and operation, is considered an important area of effort within the subprogram. In many cases, individual utilities have developed procedures and techniques over the years that have been effective in enhancing plant performance and reliability. In drafting these methods into formal guidelines, EPRI is transferring timely information to the entire industry. *Project Manager: Anthony Armor*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty Director

POWER SYSTEM PLANNING AND OPERATIONS

Static security analysis

Many utilities are increasing their use of computerized energy control centers to assist the human operator in day-to-day operations and in preserving the power system's security—its freedom from customer interruptions. One such computer application, static security analysis, will allow system operators to study the effects of postdisturbance, steady-state conditions; results from the analysis help the operator keep the power system in a state of normal system operations.

Boeing Computer Services, Inc. is the prime contractor in a 42-month project to advance the state of the art of power system static security analysis (RP1712). BCS will be assisted in this work through subcontracts with ESCA Corp., William F. Tinney, and Brian Stott. The work on this project began in September 1980.

The project has five major objectives that center on three research areas: real-time equivalents, adaptive contingency evaluation, and preventive action.

- Evaluate techniques currently used in the three research areas and determine where weaknesses exist
- Develop an integrated power system static security capability composed of the real-time equivalent, adaptive contingency evaluation, and preventive action components
- Provide this integrated static security capability within suitable time and accuracy constraints
- Develop engineering-grade digital computer programs that are more advanced than currently implemented techniques for the three security analysis components
- Implement, demonstrate, and evaluate the developed static security analysis computer programs in an electric utility dispatch control center

Special emphasis will be placed on a utility demonstration and the benefits of the developed software at the utility site.

Major emphasis in the research project will be placed on analysis methods that can adapt to changing system conditions and methods that can identify modeling and configuration problems. This will provide more flexibility in analyzing system security. Emphasis will also be placed on the efficiency of methods so that system security can be analyzed more fully and the computer resources used more effectively.

In addition to the major project objectives, there are specific aims tied to each of the three major research areas. The real-time equivalents research will seek to improve methods for modeling parts of the system that cannot be observed directly, find ways of making better use of real-time measurements, improve methods for detecting and identifying errors in the external system model, improve models of the interface to the external system, and in particular, improve models of external system voltage control and external reactive generation.

The adaptive contingency evaluation research will seek improvements in the static security evaluation area. The task's major goals will be to provide methods for identifying the contingencies that should be examined on-line, provide contingency severity-ranking information, adaptively adjust the contingency list on-line, develop methods that more intelligently adapt to changing system conditions, and provide more data on violation severity as related to precontingency conditions.

The preventive action research will seek to extend the state of the art in the corrective strategies area. The major goal will be to improve the capability to identify operating strategies for real-time operating conditions and an associated composite set of postulated contingency outage conditions.

To meet the project objectives, the software developed in each of the three research areas must be implemented and demonstrated in an operational mode at a utility control center. *Project Manager: Charles J. Frank*

UNDERGROUND TRANSMISSION

Underground cable oil leak detection

Use of underground transmission systems is often limited to regions where overhead lines are either prohibited or impossible to install, such as areas of dense population. Because the underground environment is anything but favorable to buried cable, reliability is an important consideration. The high-pressure oil-filled (HPOF) pipe-type cable is presently the most reliable and therefore the most popular system used in city areas. With this cable system, three cables (one for each phase) are pulled into a steel pipe, which is then filled and pressurized with a dielectric fluid (oil). However, with the many detrimental conditions that exist under city streets, fluid leaks can occur; these are caused by erosion, corrosion, or puncture of the enclosure pipe. It is both laborious and costly to find and repair these leaks because excavation of city streets is required.

To reduce both the maintenance costs and the time involved in conventional leak detection and location, a research effort was initiated with Power Technologies, Inc., to test and evaluate existing systems and develop novel concepts for finding cable leaks (RP7869). Some of the equipment and concepts analyzed were mass spectrometers, acoustic transducers, infrared detectors, ground-penetrating radar, halogen detectors, short-half-life radioactive isotopes, exotic tracer gases, earth electrical resistivity changes, thermal flow indicators, flow direction indicators, and dogs trained to detect hydrocarbons. Preliminary findings have shown many instruments, even though very sensitive, cannot identify spill areas when the oil is leaking from pipe buried 4–15 ft (1.2–4.5 m) below asphalt or reinforced-concrete streets.

Flow direction indicators have been highly successful in isolating a leak location between two manholes, where access to the pipe is possible. To pinpoint the leak further, the novel approach of using trained dogs and their remarkable sense of smell has been used.

In the animal research, two organizations were employed for the dog-training task: Guardian Training Academy and Southwest Research Institute. Each group trained two dogs to identify Sun No. 4 and Sun No. 6 cable fluids. The training took approximately six weeks, eight hours a day, for each fluid. Demonstrations were then held along actual cable routes in New York City to confirm the dogs' capabilities. Staged leaks under busy city streets were conducted at three locations (Figure 1); the dogs consistently found all the leaks along the cable. Although the results were very good, more work will be needed to improve the dogs' powers of concentration if they are to be used in heavy traffic.

A final report on all equipment and techniques useful for leak detection will be available in September 1981. *Project Manager: Thomas J. Rodenbaugh*

Figure 1 A trained German shepherd named Thor seeks out an underground oil leak from pipe-type cable on Broadway in Manhattan. The success rate for trained dogs detecting and locating oil leaks under 4–15 ft (1.2–4.5 m) of asphalt and concrete streets is encouraging.

Nb_3Ge superconductor development

A research project conducted at the Los Alamos Scientific Laboratory has been successfully concluded with the production of hundreds of meters of high-quality, high-temperature, high-current-density Nb_3Ge superconducting tape (RP7855). The Nb_3Ge tape has been operated at higher temperatures and current densities than any other superconductor. A critical current density of 2.4×10^6 A/cm^2 at 13.8 K was achieved in a 7-m length of tape.

A small prototype superconducting cable with Nb_3Ge tape was built and tested. However, this technology has not yet been transferred to a commercial manufacturer. *Project Manager: Mario Rabinowitz*

TRANSMISSION SUBSTATIONS

Advanced thyristor valve

The advantages of high-voltage direct current (HVDC) power transmission include lower transmission costs, narrower rights-of-way, greater stability, the possibility of linking two ac systems asynchronously, and the ability to extend lines greater distances under either ground or water. Until recently these advantages have been partially offset by the high cost of converter stations. This has generally meant that to be economical, HVDC lines had to be 600 km or longer, except where special conditions warranted their use over shorter distances; examples would be back-to-back asynchronous ties or locations where transmission under ground or water was required.

The first step in lowering converter costs was the use of solid-state converter-inverters, which substituted silicon-controlled rectifiers (thyristors) for the then prevailing mercury arc rectifiers. In a further step, General Electric Co. has been working under EPRI sponsorship to develop an advanced, light-triggered thyristor valve for HVDC transmission systems (RP1291). The project has involved the integration of several components, including a cesium vapor lamp system for triggering photothyristors (RP1291-2), an advanced light-triggered thyristor (RP669-2), and a system for forced-vaporization cooling of HVDC thyristors (RP1207). As these developments are nearing completion, discussions have been opened with a utility to act as host for the advanced valve; if agreement is reached, a valve could be installed as part of an existing converter station by 1983.

The thyristor under development is a 77-mm-diam (3-in) light-fired cell with a nominal 5-kV blocking voltage. Improved heat transfer, both within the thyristor containment package and to the external forced-vaporization-cooled heat sink, adds to the performance of the thyristor during steady-state and transient overload. The thyristor working voltage will be increased by using zinc oxide overvoltage protection across individual thyristors in the valve.

In RP1291-2, now drawing to a close, General Electric has developed a new cesium arc light source capable of triggering several hundred thyristors simultaneously.

The forward voltage drop of a thyristor under load is essentially constant; however, steps being taken in this project to reduce the number of thyristors in series for a given working voltage should both reduce initial equipment cost and significantly reduce the capital cost of losses. The new cesium arc will also lower costs and improve reliability.

Final tasks to be completed before a valve is designed for field trial are the thermohydraulic demonstration of a six-thyristor panel and an investigation of static charge separation effects in the two-phase cooling system. Charge separation is a recently observed phenomenon in which static buildup has been found in circulating Freon or oil coolant systems. The use of two-phase Freon cooling should be advantageous in coping with this problem (which is sensitive to flow rate) because the Freon circulates at only 10% of the rate of a conventional liquid cooling system.

The installation of a demonstration valve, planned for 1983, will not bring valve development to a close. New advances in thyristor protection, thyristor semiconductor processing, and package design aim at even higher safe operating ratings and further lowering of lifetime cost. *Project Manager: Gilbert Addis*

Dc revenue metering

Considering that at one time dc was the predominant form of electric energy, it is a bit surprising that there is no metering device available to utilities for measuring the energy exchange over HVDC transmission lines. Utilities have adapted to technical and commercial realities by measuring the energy transfers in and out on the ac side of the HVDC converters. Although this may be acceptable for point-to-point dc links, it is preferable to also meter on the dc side because there is no good way to accurately measure converter losses. For these reasons, EPRI initiated a project with Washington State University to develop a dc revenue-metering device (RP1510).

A microprocessor-based, digital dc revenue meter has now been built and laboratory-tested at WSU. The device is intended for use with the previously developed dc current transducer described in EPRI report EL-1343. However, it has been built to also handle inputs from less accurate, commonly used current-measuring transductors. This is an attempt to use the processing power of the microprocessor to compensate for the inherent errors of the input sources. This might be an attractive way to improve the accuracy of metering systems in the future.

WSU has developed a simple computer program for calculation of dc power from current and voltage measurements. The calculated power is then integrated over time to produce an accurate estimate of the dc energy. The effect of harmonics, as well as the different operating modes of the dc system, has been carefully analyzed to make sure that this does not introduce unacceptable errors into the revenue-metering device. Portions of the work are based on an earlier completed project to develop a microprocessor-based ac revenue meter (EL-1601).

The prototype dc revenue-metering device (Figure 2) will be installed for field testing at Los Angeles Department of Water & Power's Sylmar converter station, where the previously mentioned dc current transducer is also installed. *Project Manager: Stig Nilsson*

Figure 2 Prototype dc revenue-metering device to be installed for field testing at Los Angeles Department of Water & Power's Sylmar converter station.

HVDC system control

Experience from two completed HVDC projects has shown that if not properly designed, HVDC converter control systems can excite nearby generators in the subsynchronous resonance (SSR) frequency region. This must be avoided, which places yet another constraint on the designers of converter control systems. Therefore in 1978 EPRI initiated a project with General Electric Co. in an attempt to answer some questions concerning HVDC system control of subsynchronous oscillations (RP1425). The purpose of this recently completed project was to discover how HVDC converters can be prevented from exciting subsynchronous oscillations (SSOs) in turbine generators. It was thought that if converter control systems could be designed to avoid this problem, it might also be possible to design them to provide positive damping in the SSO region.

In the beginning of the project the researchers concentrated on development of analysis techniques for the study of the interactions between the machines and the converters. The analytic model was validated by General Electric's HVDC systems simulator. With the help of the model and simulator, an extensive study of the various parameters involved in SSOs was performed to identify which parameters are most significant. With this knowledge, schemes for elimination or control of the interaction mechanics were studied.

Eventually, a subsynchronous damping controller (SSDC) was developed and tested to identify any undesirable side effects resulting from the device. The use of the SSDC concept to control SSOs involving generators and series-compensated transmission lines was also studied. Results from the analytic work were again tested by using the contractor's HVDC system simulator.

One major result from the project is the finding that some negative damping to the oscillatory modes of the turbine generator shaft is inherent in the current control system of an HVDC transmission system. The negative damping will exist within the bandwidth of the current control loop, typically in the range of 10–20 Hz. Torsional vibrations at frequencies higher than the bandwidth of the current control system will experience positive damping.

It was found that the negative-damping problem can be eliminated by modifying the control system characteristics through the use of an SSDC. The SSDC consists of a wide-bandwidth controller sensitive to the frequency of a signal synthesized from voltage and current measured at the HVDC converter terminal. With such a design, the SSDC can be made to provide a positive-damping contribution over the critical range of subsynchronous torsional frequencies. The dynamic range of the controller can be limited so that there will be no side effects of concern. It should also be possible to design the SSDC to be fail-safe and sufficiently reliable for the application.

The researchers also developed a simple rule that can be used to identify which ac turbine generators might be affected by the HVDC converters. The rule focuses on those machines with strong electrical coupling to the dc converters; units with weak coupling are not significantly affected and therefore do not call for a detailed analysis.

In systems with series-compensated transmission lines, the situation is different; it was found that the addition of an HVDC system to a network containing series-compensated lines has only a minor influence on any preexisting SSR. Although the dc system adds damping, this by itself is not enough to significantly change the SSR situation.

Another finding was that an SSR problem is not transferred through the HVDC system. Thus, a system without series-compensated lines can interconnect via an HVDC link to a system with series-compensated lines without concern for introduction of SSR problems. In some cases, this may favor HVDC linking over ac interconnections. Unfortunately, application of a properly controlled HVDC system to provide a general solution to the SSR problem appears to be extremely difficult, although there may be certain limited situations in which such a control can be designed to result in a system benefit.

To be effective, such a controller must be able to dampen the SSOs appearing after a major fault in the vicinity of the critical machines. This would require a high-gain, high-dynamic-range controller. Such a controller would affect the performance of the normal HVDC control system and therefore require extensive studies before it is used for SSR control. A narrow-bandwidth controller incorporating sharply tuned filters, possibly with adaptive tuning, may be needed. Further work is needed to fully understand the trade-offs and constraints.

The general conclusion of RP1425 is that system planners need not be concerned about subsynchronous interactions between turbine generators and HVDC converters; hence, SSR considerations will not influence where the converters are to be located. System planners may, however, want to take advantage of the damping potential provided by the converters, thereby extending the operating life of turbine generator shafts. Oscillation of these shafts in response to ac system faults and similar transients would normally be damped out much faster if there was a converter station with a properly designed SSDC in the vicinity of the machine. This may permit faster reclosure after a fault or have other similar benefits. Of course, the presence of such an SSDC would not invalidate the need for proper protective relaying at the turbine generator to handle the unlikely event that the controls fail or become ineffective for some unforeseen reason. *Project Manager: Stig Nilsson*

OVERHEAD TRANSMISSION

Transmission line inspection systems

Sophisticated detection devices are presently in use for the inspection of overhead transmission lines. For example, many utilities use infrared equipment to find incipient faults in splices or dead ends. In a recently completed project, Westinghouse Electric Corp. examined other possibilities for applying modern technologies to reduce the cost or improve the quality of line inspection (RP1497-2). The results of this project are included in a final report that will be available shortly.

Initial interviews with several utilities determined that there are 36 items that may require attention in a line inspection. With these in mind, the project investigators then identified the symptoms that would signal a problem on the line and evaluated existing and undeveloped detection techniques that could be employed.

The final report addresses all aspects of transmission line inspection in a practical manner. In addition to evaluation of the various inspection techniques, the report discusses environmental factors imposed on detection devices, the cost-effectiveness of the various options, and the use of unmanned devices that travel along the line carrying instrument packages. The report concludes that robotlike devices could be developed for line inspection, although they are presently not cost-effective.

One area that does have promise for improving the quality of overhead line inspection is the development of improved sensors for use in patrolling the line by helicopter. In particular, an ultraviolet detector has the potential to pinpoint corona sources—often an early indication of a problem condition. This information could be added to what the patrolman sees as he flies the line. *Project Manager: John Dunlap*

DISTRIBUTION

Corrosion detection in underground cables

Research being carried out by the National Bureau of Standards is directed at the development of in situ techniques for measuring and detecting the corrosion of direct-buried copper concentric neutral cables (RP1732). Previous work by NBS for DOE developed this concept; the EPRI-sponsored phase is to prove the concept in the field and develop breadboard instrumentation.

It is expected that an advanced technique for measuring electrochemical polarization with microprocessor instrumentation can be used to indicate a corroding section of cable. Previous polarization measurements have been limited to laboratory investigation, but the availability of microprocessors now allows such measurements to be made in the field. Polarization measurements have already been carried out with limited success on energized cables.

Techniques to detect and measure the voltage and current fluctuations (corrosion noise) caused by the changing characteristics of a corroding neutral conductor are also being investigated under this project. Laboratory tests of the prototype equipment indicate that this noise can be detected on corroding copper under conditions similar to those occurring in the field. However, the practicality of a field measurement instrument based on this technique is still questionable. Field tests of these instruments are planned for the summer of 1981. *Project Manager: T. J. Kendrew*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

TRANSURANICS IN THE ENVIRONMENT AROUND NUCLEAR PLANTS

Nuclear power plants are remarkably efficient in controlling radioactive emissions to the environment; nevertheless, routine operation of these plants may result in some release of radionuclides. EPRI has sponsored a study by Battelle, Pacific Northwest Laboratories to measure the amount of certain radioactive species, especially transuranics, in the environment around nuclear power plants and to ascertain what amounts can be attributed to power plant operation (RP1059). Of the radionuclides, the alpha emitters (e.g., plutonium) are considered the most hazardous to human health. It is known that plutonium occurs in the environment as a result of fallout from weapons testing; however, the relative contributions of transuranics to the environment from fallout and power plant operation are not known. The purpose of RP1059 was to measure these contributions. If the power plant contribution were found to be negligible, there would be little reason for additional controls on plant emissions; if it were found to be significant, additional controls might be warranted. Research began in late 1977 and was completed in late 1980. A final report will be issued shortly.

Procedures

The concentrations of plutonium, americium, and curium isotopes and other long-lived fission and activation products were measured in soil, vegetation, and air at the following nuclear power plants: Rancho Seco (California), Zion (Illinois), Browns Ferry (Alabama), and Quad Cities (Illinois). Two of the criteria for selecting the plants were modern design and operation for at least three years. Also, it was decided to include both PWRs (Rancho Seco and Zion) and BWRs (Browns Ferry and Quad Cities).

Samples of soil, plants, and air were taken at each site. Soil was sampled along the eight compass directions at distances of approximately 0.25, 1, and 3 mi (0.4, 1.6, and 4.8 km) from the reactor building. Also, several background samples were taken 15–30 mi (24–48 km) from the plants. All soil sampling was done by coring to a depth of 2 in (5 cm); duplicate cores were taken at each site. Altogether, about 100 soil samples were collected at each power plant. About 100 vegetation samples (cheat grass) were taken at each plant. The ambient atmosphere was sampled by a filtering device for particle collection; the number of air samples per plant ranged from about 20 to 50.

Because of the extreme importance of establishing a background value for transuranics, additional samples were taken at 10 locations remote from any nuclear plant. These sites were in Idaho, Indiana, Mississippi, Missouri, Montana, North Dakota, Oklahoma, Texas, Washington, and West Virginia.

Samples were analyzed for isotopes of plutonium, americium, and curium, as well as for ^{54}Mn, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{106}Ru, ^{95}Nb, ^{129}I, ^{134}Cs, and ^{137}Cs. Emphasis was on ^{239}Pu and ^{240}Pu because the ratio of the amount of ^{238}Pu to the amount of these two isotopes can be used to distinguish between reactor plutonium and that from fallout: the ^{238}Pu/^{239,240}Pu ratio of nuclear plant emissions is as much as 300 times greater than that of fallout debris. The ^{134}Cs/^{137}Cs ratio from power plants is also higher (about 500 times) than that for fallout. And the presence of ^{242}Cm, ^{243}Cm, or ^{244}Cm in the environment is a good indicator of contamination from a reactor because these isotopes are not now detectable in soil or vegetation in which weapons debris has accumulated.

Results

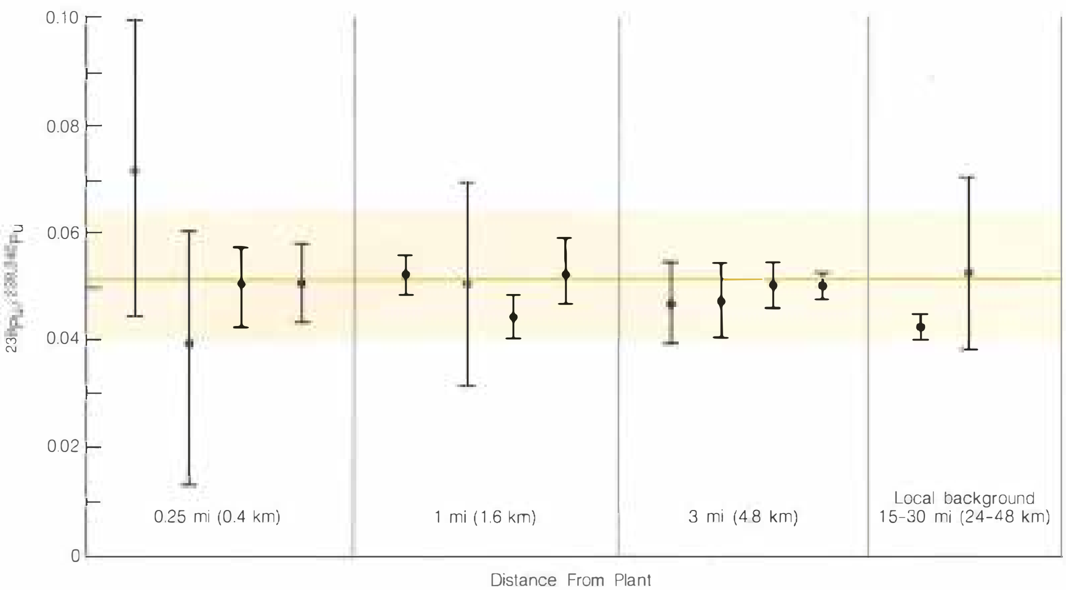
For all practical purposes, the power plant contribution to the environment of the elements tested is negligible. In the case of plutonium, for example, the research found that although the absolute concentration of the element differed widely from plant to plant and even from site to site at a given plant, the ratio ^{238}Pu/^{239,240}Pu was remarkably constant and, with rare exceptions, could not be distinguished from the ratios of background samples.

The results from the Rancho Seco plant indicate the care that must be taken in interpreting absolute concentrations of an element (measured in terms of the number of disintegrations per minute for each kilogram of sample, or dpm/kg), and they also underscore the importance of considering ratios. Upwind of the plant, the ^{239,240}Pu concentration in the soil ranged from about 40 to 120 dpm/kg; downwind it was noticeably higher, ranging from about 80 to 120 dpm/kg. It would be easy to ascribe the higher downwind values to drift from the Rancho Seco plant. The ^{238}Pu/^{239,240}Pu ratio, however, showed no such variation. For all soil samples but one, this ratio could not be distinguished from the 95% confidence-level national background ratio (Figure 1). The sample with the high ratio had one of the lowest plutonium concentrations and the highest uncertainty in its analysis (i.e., in its counting statistics).

On the basis of only the ^{239,240}Pu concentration values, then, it might be assumed that the plant was contaminating the environment. In fact, however, the plant's contribution of plutonium (if there was one) cannot even be recognized. The conclusion that the plant's contribution was negligible is supported by the absence of significant concentrations of other indicator radionuclides in the soils at Rancho Seco. Neither upwind nor downwind samples could be distinguished from samples collected in areas remote from nuclear power plants.

At the Browns Ferry plant, the absolute concentration of plutonium in the soil differed markedly from one sample site to another. The values of the ^{238}Pu/^{239,240}Pu ratio, however, were very consistent, and as at Rancho Seco, they indicate the virtual absence of a power plant contribution. Only two samples had a ratio that fell outside the 95% confidence limits associated with the national background value (Figure 2), and the counting statistics for those two overlapped the confidence limits.

Figure 1 Values for the $^{238}Pu/^{239,240}Pu$ ratio in the top centimeter of soil near the Rancho Seco nuclear plant are compared with the national background ratio, which has been established with a 95% level of confidence (shaded band). Data were taken along compass directions at 0.25, 1, and 3 mi (0.4, 1.6, and 4.8 km) from the plant; local background values were calculated from samples taken 15–30 mi (24–48 km) away.



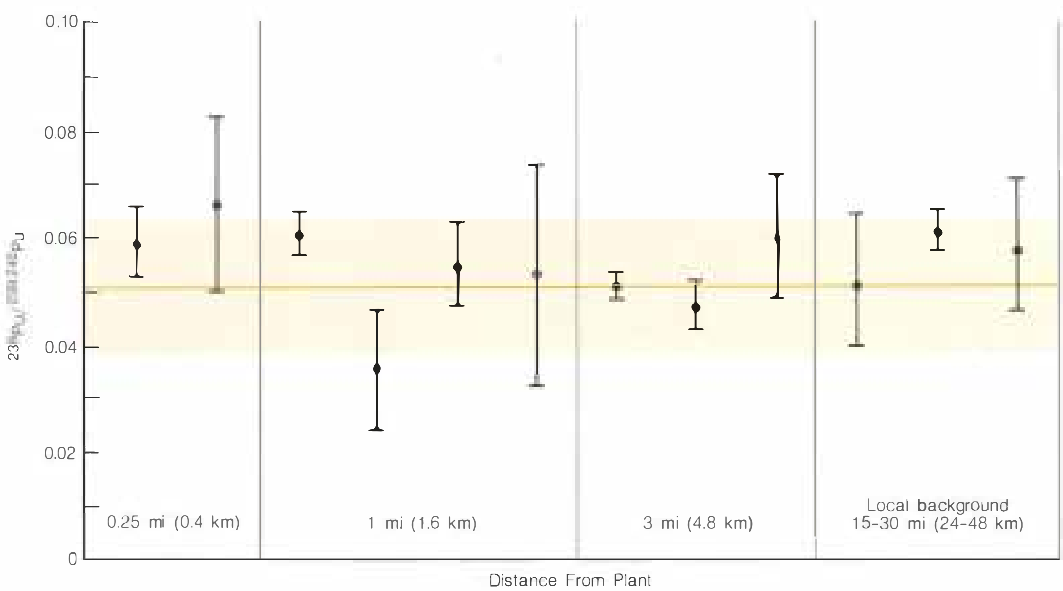


Figure 2 Only two of the samples taken at the Browns Ferry nuclear plant yielded $^{238}Pu/^{239,240}Pu$ ratios outside the national background interval, and even with these two cases, the range of possible values allowed by uncertainty in the counting statistics overlaps the background interval.

Two soil samples at the Zion plant also had $^{238}Pu/^{239,240}Pu$ ratios that fell outside the 95% confidence limits of the national background value. For one sample, no other indicator radionuclides were observed; hence power plant contamination seems improbable. In this case, the anomalous ratio is more likely to be related to soil disturbance and the subsequent accumulation of debris from SNAP-9A, a navigation satellite that disintegrated in 1964. In the other case, however, the anomalous ratio could indicate contamination from the plant because ^{54}Mn, ^{60}Co, and ^{134}Cs were detected in the sample. If such contamination did occur, calculations show that it could be responsible for only about 5% of the plutonium in the soil. Because the absolute plutonium concentration in the sample was one of the lowest in the area, this 5% represents a negligible amount—about 1% of the average plutonium concentration in surrounding soils.

At the Quad Cities plant, only one soil sample had a $^{238}Pu/^{239,240}Pu$ ratio that fell outside the 95% confidence limits of the national background value. Data indicated that about 30% of the plutonium in this sample was of reactor origin; the remaining 70% was from fallout. It should be pointed out that the absolute plutonium concentration in this sample was among the lowest observed in the entire EPRI study—nearly 3000 times lower than the EPA-suggested safe level for soil (26,900 dpm/kg). The 30% power plant contribution of $^{239,240}Pu$ in the sample amounted to 3.1 dpm/kg. This is a trivial amount considering that the other soils at Quad Cities, for which there were no indications of plant contamination, averaged 66.7 dpm/kg of plutonium.

Results on the plutonium concentrations and isotopic ratios of both vegetation and atmospheric particulate matter led to the same conclusions as the soil analyses. The samples typically could not be distinguished from background material. In the rare cases in which a sample had an isotopic ratio different from the background value, an explanation other than reactor release could account for the anomaly.

Analyses of a number of soil samples for various nontransuranic fission and activation products (^{54}Mn, ^{60}Co, ^{90}Sr, ^{106}Ru, ^{134}Cs, ^{95}Nb, and ^{129}I) revealed few indications of power plant contamination. One sample from Rancho Seco was slightly high in ^{54}Mn, but no other indicator radionuclide was present; the high value could fall within the range of natural variation. Two samples at Browns Ferry were also high in ^{54}Mn, but the overall data give no conclusive explanation for the anomaly. At Zion one site showed slightly high values for ^{54}Mn, ^{60}Co, ^{95}Nb, ^{106}Ru, and ^{134}Cs. These may indicate plant contamination, but the $^{238}Pu/^{239,240}Pu$ ratio at the site was similar to that of background material. At Quad Cities somewhat elevated levels of ^{60}Co and ^{134}Cs were noted.

Vegetation and air were also sampled for these fission and activation products, but the material sampled was greatly affected by fallout from Chinese weapons testing in 1977 and 1978. No samples were found that could be distinguished from background material.

Conclusions

On the basis of the extensive sampling done in this study and the very high-quality data obtained, it is apparent that the power plant contribution to transuranics in the environment is, at most, trivial. In only two or three samples out of many hundreds was there any indication of plutonium contamination from a power plant. And in these cases, the plant contribution was low and the amount of plutonium was well below an average background value and very much below a so-called safe limit being considered by EPA. With a few exceptions, environmental samples around power plants could not be distinguished from background samples in terms of transuranic content. Similar findings were obtained for other fission and activation radionuclides. Thus the control of transuranic emissions from nuclear power plants appears to be sufficiently thorough, and plant operation has little or no effect on the distribution of those elements in the environment. *Project Manager: Ralph M. Perhac*

INTEGRATED FORECASTING MODEL

*Under RP1108 EPRI has sponsored the development of a comprehensive energy model for internal planning and assessments of markets for new technologies (*EPRI Journal, *November 1978, p. 52). Work on the model, called the integrated forecasting model (IFM), has been conducted by Decision Focus, Inc. After several years of development and testing, in 1980 the IFM was used in a demonstration study of the impacts of synthetic fuels on the electric power industry. An EPRI working group was formed to direct and evaluate the study and in the process to become familiar with the model.*

The IFM is a comprehensive energy system model capable of simulating energy activities in five-year increments through the year 2025. It is a direct descendant of the Gulf-SRI methodology developed in the early 1970s to study the Nixon administration's decision to accelerate the development of a synthetic fuels industry.

The model is potentially valuable for a number of EPRI planning functions. Because it is process-oriented and can represent diverse technologies in a detailed way within the context of the total energy system, it is an ideal tool for assessing the markets for a new technology. Thus it will be useful in evaluating EPRI's diverse R&D activities. The IFM also has potential as a forecasting tool. It is comprehensive yet has a capacity to represent structural detail where needed. Thus it can complement and enhance other forecasting models currently used in preparing EPRI's five-year R&D program plan. In particular, it can provide more detail about the electric utility industry.

Model characteristics

The IFM is designed as a long-term market model of the complete U.S. energy sector. It represents the sector as a network and links together distinct energy activities from resource extraction through final demand. In general, the model assumes disaggregated decision making; that is, each activity is designed to maximize its own profit, subject to pricing information it receives from other activities that affect it. Activities are modeled as engineering processes, and explicit detail on age and replacement of capital equipment is recorded.

Resource activities represented in the IFM include both oil and gas extraction (by broad technology category), oil and gas importing, coal mining (by region), and uranium mining. Conversion activities include synthetic fuel operations (coal-based, oil shale, and biomass), refinery operations, and very detailed electric power operations. Energy demand activities are separated into demands for various energy services (e.g., space heating and transportation) and into various types of equipment used to satisfy such services (e.g., heat pumps, electric resistance heaters, gas furnaces, and solar-assisted heating systems). This structure allows many types of conservation activity to be represented explicitly.

Recent development work has resulted in several improvements in the electric power sector of the model. It is now capable of representing load shapes by end use, incorporating time-of-use rates, simulating both accounting cost and marginal cost pricing, and representing a large number of technologies by fuel and operating characteristics.

Although the IFM is a large, relatively detailed model, its modular, user-oriented structure minimizes operating and maintenance problems. The model software is designed to facilitate user access, and the system possesses a flexible logic structure. The model is designed to be easily refocused to emphasize specific sectors or details important to the problem at hand.

Demonstration study

By January 1980 IFM development had progressed to the point that the model was considered ready for introduction to potential EPRI users. Thus a study was launched to demonstrate the model by examining the future of a synthetic fuels industry and its impact on the electric power industry.

This topic was selected because of both its timeliness and the analytic challenge it would present to the model. The future of synthetic fuels is of great interest both inside and outside the Institute. EPRI funds substantial research on synthetic fuel technologies including coal-based liquefaction and gasification, as well as on generation technologies for using such fuels. Because the existence of a mature synthetic fuels industry will have widespread effects on energy supply, demand, and conversion activities, this topic represents an excellent test for an energy system model like the IFM.

The study was directed by a working group of EPRI planners and synthetic fuel experts drawn from the Policy Planning Division, the R&D Planning and Evaluation Staff, and three technical divisions: Advanced Power Systems, Energy Analysis and Environment, and Energy Management and Utilization. While sometimes causing difficult coordination and reconciliation problems, the working-group approach had two important advantages: The study benefited from a wide range of experience and perspectives; insights, data, and criticism from working-group members greatly enriched the study findings. This approach enabled potential IFM users throughout EPRI to learn about the strengths and weaknesses of the model by working with it directly. Thus, the study provided an ideal transfer vehicle for the model.

To introduce the study and explain its objectives and ground rules, a meeting of the entire working group was held. This was followed by a lengthy series of smaller meetings with various individuals and subgroups. At these meetings, opinions were exchanged on the most important questions to be addressed by the study; the model's structure and representation of energy markets were discussed in detail, along with many of its significant algorithms; and the most important data inputs were evaluated, including technology process parameters, primary resource estimates, and levels of energy demand.

The modelers incorporated information from these meetings into the study design and the model calibration process. A model run was then performed, and the results were interpreted and presented to the working group at a second general meeting. The group criticized the results and made suggestions for further refinements, which the modelers undertook to implement in a second round of small-group meetings. Through a series of these runs and critiques, the study focus was sharpened and the model and data base were solidified.

After the calibration process was completed and the significant driving variables of the analysis were identified, a series of sensitivity cases was designed and run. The working group was then briefed one last time, and agreement was reached on a set of preliminary study results, which are summarized below.

Preliminary results

A number of significant uncertainties affecting the future of a synthetic fuels industry were identified in the study. The ones considered most important and examined through sensitivity analysis were the actual production costs of new synthetic fuel technologies; institutional factors, such as environmental, licensing, and siting constraints and pressures on labor and equipment markets; and the actual size of the world oil and gas resource base and the consequent prices of natural oil and gas in future world markets. One important uncertainty that was held constant throughout the analysis and not explicitly studied was the rate of economic growth, which is an important determinant of the growth of energy demand.

The study found that if a significant synthetic fuels industry does develop in the United States, it will have several effects on the electric power industry. The continued availability of both oils and gases at stable, although high, prices will create competition for electricity in important end-use markets, including the residential and commercial space-conditioning markets, some industrial process heat markets, and the automobile transportation market. Electricity growth will be slowed in these areas and will be more narrowly confined to such traditional markets as lighting, appliances, and electromechanical power. Electric system load factors may be improved because of the relatively slow growth of electric space conditioning, which has a low load factor. This, in turn, may reduce the need for additional peaking and cycling technologies in the future.

Unless there are severe constraints on coal and nuclear baseload capacity, synthetic fuels as an electric power feedstock will affect only the peaking and cycling markets. In general, synthetic fuels will be too expensive to compete as baseload feedstocks, even under very optimistic cost and availability assumptions. The notable exception to this finding is the gasification–combined-cycle baseload technology, which will compete favorably.

The emergence of a synthetic fuels industry will put significant pressure on the coal supply industry. The consensus of the working group is that although enormous coal resources exist, labor problems, environmental constraints, and other institutional factors may create supply bottlenecks.

The working group generally agreed that a significant synthetic fuels industry will probably not develop by the year 2000 or even by 2010. This is attributed less to higher-than-expected process costs for synthetic fuel technologies than to significant institutional constraints. Possible constraints include factor market limitations (e.g., short-term shortages of chemical engineers, pipefitters, pressure vessels, or chromium); siting and licensing delays as a result of local opposition to development; the imposition of local taxes to provide auxiliary services for boomtowns; short-term capacity constraints in the coal supply or railroad industries; and environmental or occupational legislation mandating special handling conditions for synthetic fuels.

The results of the synthetic fuel study are currently being compiled, finalized, and reviewed. An EPRI report is expected to be published this fall. As a result of this successful demonstration study, EPRI planners are considering a variety of future model applications. *Project Manager: Lewis J. Rubin*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Director

LOW-ENERGETICS LMFBR CORE

A significant improvement has been made in cores for large liquid metal fast breeder reactors (LMFBRs). Analyses have shown the feasibility of a core design that reduces by approximately two-thirds the positive reactivity effect of coolant (sodium) voiding. Thus, in a hypothetical core-disruptive accident (a scenario considered for licensing), energy would be released at a greatly reduced rate and the force on the reactor vessel cover of a slug of liquid sodium propelled from the core would not be great. The design for this low-energetics core has been developed under RP620.

LMFBR plants can generate electricity, replenish their own fissile material (plutonium), and produce excess fuel that can be used as the initial loading for additional breeders. These plants will make the owners independent of outside fuel suppliers. Depleted uranium left over from the enrichment process can be used as the feedstock for the fuel cycle, and the United States has enough of this uranium in storage to last for many centuries.

LMFBRs are not pressurized; the primary coolant is at atmospheric pressure and is subcooled more than 720°F (400°C). This essentially eliminates many of the safety problems with which LWRs have to cope. For conventional cores in large LMFBRs, however, the void coefficient of reactivity (a measure of how fast power could increase in the event of coolant voiding) is positive. This means that in a hypothetical case where the coolant boils, the power would increase—an undesirable situation. There are compensating factors that would come into play, the principal one being the Doppler effect: as the temperature increases, there is an increase in the resonance capture of neutrons, a negative reactivity effect. The Doppler effect is strong, but it would not be sufficient to overcome the positive reactivity effect of total voiding of coolant from the cooling channels of the fuel and the upper axial blanket.

In conventional large LMFBR cores, the fuel assemblies are arranged in a cluster that measures about 12 ft (3.7 m) in diameter and is surrounded by a radial blanket. The blanket assemblies contain fertile ^{238}U, which is supplied from the nation's vast stock of depleted uranium. The fuel assemblies typically contain approximately 18% plutonium oxide and 82% uranium oxide, which means that there is an appreciable amount of fertile material (^{238}U) in the fuel pins as well as in the radial blanket. For LMFBRs, this conventional design is called a homogeneous core. The newly developed design for a low-energetics core has blanket assemblies located at strategic positions within the core as well as in concentric rings around the core. This arrangement is called a heterogeneous core.

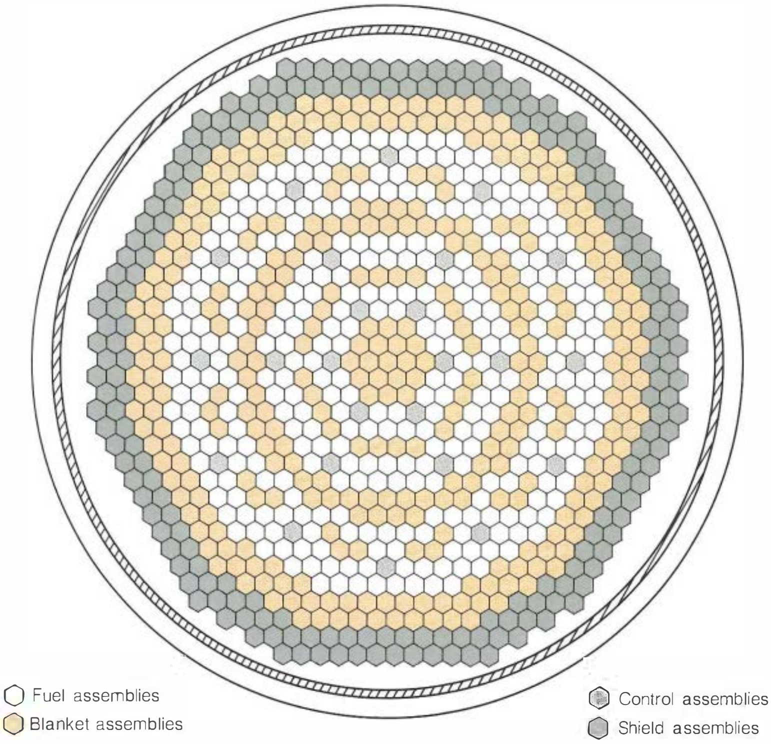
In a postulated core-disruptive accident involving sodium boiling in a fuel assembly in either type of core, the atom density of the sodium decreases; this causes the parasitic capture of neutrons in the sodium to decrease—a positive reactivity effect. Also, when the atom density of the sodium in the fuel coolant channels decreases, neutron leakage from the individual fuel assemblies increases. In the homogeneous core, which is made up entirely of fuel assemblies and control rods, the leakage is primarily from one fuel assembly to another. The fuel assemblies just exchange neutrons, and the increased leakage has no negative reactivity effect except at the edges of the core, next to the radial and axial blankets. In the heterogeneous core, however, the internal blanket assemblies—those located among the fuel assemblies—intercept some of the leaking neutrons; this is a negative reactivity effect.

There are many parameters that affect LMFBR core behavior. Fuel pin diameter, height of the active core, thickness of the axial and radial blankets, and arrangement of the internal blanket assemblies and control rods were the main parameters studied in two EPRI projects, reported in NP-1000 and NP-1616. It was found that a compromise between tightly coupled and weakly coupled fuel zones works best. *Weakly coupled* refers to an arrangement that uses a large number of internal blanket assemblies to surround local zones of fuel. Such an arrangement is very effective in reducing the positive reactivity effect of sodium boiling in the fuel, but it tends to isolate the fuel regions to the extent that they act almost like separate reactors; this is not desirable from the standpoint of control. *Tightly coupled* refers to an arrangement in which very few internal blanket assemblies are placed among the fuel assemblies. The neutronic behavior of this design is almost the same as that of a homogeneous core, and the positive reactivity effect of sodium boiling is not lowered to an acceptable level.

Figure 1 illustrates the preferred arrangement indicated by the studies. Assuming a total loss of sodium from the coolant channels of the fuel and the upper axial blanket, the positive reactivity effect in this core is only one-third of that in a homogeneous core of equivalent power.

There was some concern about the shift in power production among the individual fuel and blanket assemblies in the heterogeneous core. As plutonium grows in the blanket areas during an operating cycle, the percent of total power produced by the fuel decreases. Of course, this shift also occurs

Figure 1 The newly developed design for a low-energetics LMFBR core has blanket assemblies strategically placed among the fuel assemblies, which decreases the coolant-void coefficient of reactivity by a factor of three.



in the homogeneous core (at the interface of the fuel and the radial blanket), but more sites are affected in the heterogeneous arrangement. Neutronic and thermal-hydraulic analyses were performed to identify an arrangement that would minimize this power shift. The arrangement shown in Figure 1 was found to be fairly effective.

Three sets of criteria for sizing the fixed orifices that supply coolant to the fuel and blanket assemblies were studied. The best yielded tolerable changes in outlet temperature as the operating cycles progressed and held maximum fuel and blanket cladding temperatures to a reasonable level.

Additional work was performed to explore hardware concepts that would be consistent with the numerical analyses of the heterogeneous core (NP-1617). Dimensional drawings of fuel, blanket, control rod, and reflector-shield assemblies were made, and an arrangement for the lower support grids was devised.

A preliminary study of the bowing and seismic behavior of a large core was also conducted (NP-1615). The results indicate that it is feasible to operate a large heterogeneous core. However, the development of a final core design for fabrication and use will require a careful experimental program and extensive refinement of details. For example, the stiffness-in-bending of the various assemblies must be measured, and modifications must be made to optimize the core system as a whole in terms of bowing behavior and response to seismic forces.

The Clinch River breeder reactor project has changed from a homogeneous core to a heterogeneous arrangement quite similar to the one illustrated here but smaller. DOE is interested in heterogeneous cores for future large LMFBRs, and EPRI intends to explore the possibility of a joint program with the agency to develop this very promising breeder assembly. *Program Manager: R. K. Winkleblack*

PWR RELIEF VALVE TESTS

In the aftermath of the Three Mile Island accident, NRC required all nuclear plant licensees to test safety and relief valves under actual and anticipated operating conditions. Subsequently, EPRI was directed by the TMI Ad Hoc Oversight Committee to plan and implement a valve testing program that would meet the needs of utilities operating or constructing PWR units. (BWR operating characteristics were considered sufficiently different to require a separate program, which is only informally associated with the EPRI effort.) Testing of power-operated relief valves (PORVs) under steam conditions has been completed in the first phase of this program (RPV102-15).

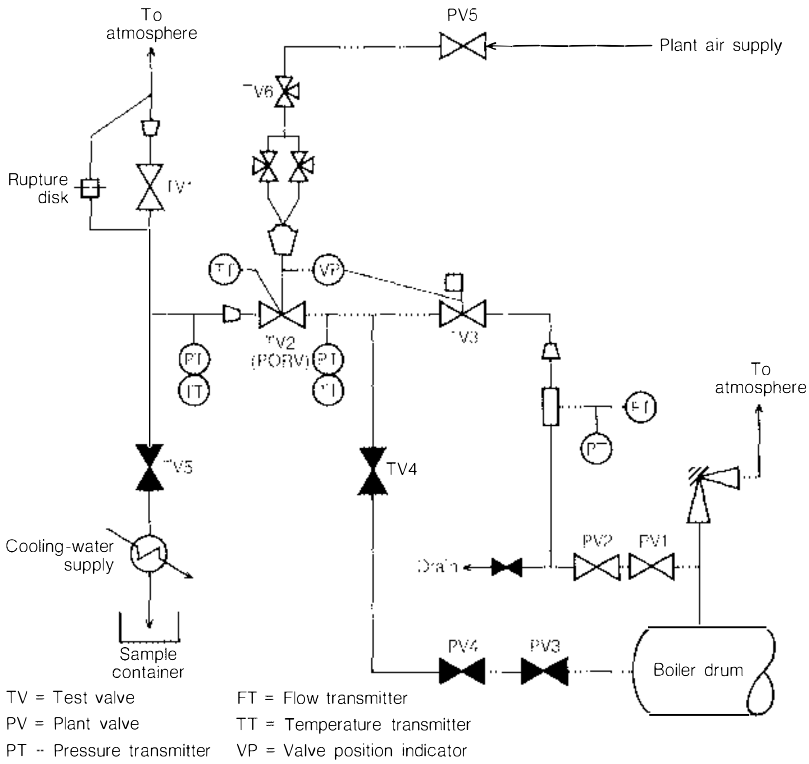
Major stipulations for the test program were that a plan had to be developed and submitted to NRC by January 1, 1980; all valves used in overpressurization protection of the reactor coolant system had to be tested (either directly or by representative sample); and the tests had to be completed by July 1, 1981. The valves were to be tested under three kinds of fluid conditions: steam, liquid, and transition (steam to liquid or liquid to steam).

It was quickly determined that there were no existing facilities capable of producing the conditions necessary to test the full spectrum of valves, and only limited options were available. After a detailed evaluation process, Combustion Engineering, Inc., was selected as the primary program contractor and the host for all safety valve tests. Wyle Laboratories and Duke Power Co. were also selected to participate in the program; PORVs were to be tested under liquid and transition conditions at Wyle and under steam conditions at Duke Power's Marshall station. The Marshall tests are described below.

Test loop

The Marshall test loop (Figure 2) was constructed by Duke Power before the TMI accident to investigate problems with power-operated relief and block valves that had failed to meet performance criteria during hot functional testing at its McGuire nuclear plant. Saturated steam at pressures up to 2450 psig (16.9 MPa) is the only fluid condition available at Marshall. Thus PORVs could

Figure 2 Elevation schematic of the PWR relief valve test loop at Duke Power Co.'s Marshall steam station. This configuration was used to test PORVs from nine manufacturers for flow rate, actuation time, and seat leakage.



be tested under design conditions at the facility but not in all the fluid regimes postulated for transient and accident modes of operation. Modifications to the test loop were required to accommodate vertically mounted valves, redirect and muffle the discharge, and provide additional piping supports (necessary because of the dynamic forces associated with the quick-opening PORVs). Modification work began in May 1980, and the first PORV test was conducted in August 1980.

All performance signals were transmitted to a data acquisition and control room located on the turbine deck some 80 ft (24 m) below the test loop. The principal parameters monitored during the tests were flow, actuation time, and seat leakage. Data from valve and test loop sensors were recorded on strip charts for real-time visualization and also on magnetic tape for analytic flexibility.

Test procedures

Valves from nine manufacturers were tested. These are considered to be fully representative of the valves in operating PWRs and those to be used in PWRs now under construction. Upon receipt, each PORV was inspected and disassembled. To maximize installation efficiency, the length of each test valve assembly was standardized by varying the dimensions of pipe stubs and flanges to compensate for differences in valve body length. Welding was done in accordance with industry standards for high-pressure systems, and each juncture was radiographed to ensure there were no defects. In most cases a series of valve actuations preceded the official testing. This provided an opportunity to observe system response and to check out instrumentation.

The EPRI test plan called for 10 valve actuations against full steam flow. In practice no PORV experienced fewer than twice that number, and some were subjected to nearly 100 actuations while mounted in the test loop. The first and last operation in any given test sequence was a seat leakage test, which was accomplished by closing TV1, TV2, TV4, PV3, PV4, and PV5 and opening TV3, TV5, PV1, and PV2 (Figure 2). Steam leaking through the PORV (TV2) was directed to a small (maximum 3 gal/min; 0.7 m^3/h) heat exchanger and condensed. After a delay to allow the system to stabilize, the condensate was collected in a graduated cylinder. Several samples were taken for specified time periods and the results averaged to determine the seat leakage value.

The second operation in the test sequence was a sustained actuation (approximately 1 min) to determine valve capacity. An orifice plate was located in the test loop in the riser portion immediately following the main isolation valves (PV1 and PV2). The pressure and the differential pressure at this plate were measured during the actuation, and a computer code (FLOWMAN) was used to calculate flow. Four actuations of approximately 15 s each completed the first half of the test sequence. During these cycles particular attention was paid to valve opening and closing times and overall system behavior.

Another seat leakage test was performed at this point. Immediately thereafter, the rupture disk located in the TV1 bypass line was removed to effectively decrease the system back pressure on the test valve. This provided a measure of certainty that the flow rates were valid, as well as additional assurance that test valve performance did not vary because of a difference in downstream pressure. As in the first half of the test sequence, the second part consisted of one sustained and four shorter actuations. After the last low-back-pressure cycle, the rupture disk was replaced and a final seat leakage test performed. Valve manufacturer representatives were present for each test series.

Test results

In general, the results of the PORV testing at Marshall were excellent (Table 1). With only isolated exceptions, flow rates were as predicted, actuation times were within specified values, and seat leakages were acceptable. In two cases there was evidence of significant galling of internal parts, and although the valves never failed to open or close, leakage was considered excessive at times. This, plus the potential for seizing or improper operation, needs further evaluation.

In the air-operated globe-type valves, there tended to be washing of the gaskets that provide the seal between the body and the cage. In the pilot-type valves, the bellows in the pilot section failed to maintain a seal function on two occasions. Overall valve performance was only slightly degraded, if at all, as a result of these anomalies.

Details of the PORV testing at Marshall have been communicated to the participating utilities, and a final report will be published in the near future. *Project Manager: J. D. E. Jeffries*

Table 1
NOMINAL RESULTS OF PORV TESTING AT MARSHALL STATION

Valve Manufacturer	Model	Flow (lb/h)	Actuation Times (opening, closing) (s)	Seat Leakage (gal/min)
AiResearch	3 × 6-in straight	296,549	0.210, 1.8	0.008
Control Components International	3-in, self-drag	227,735	1.4, 1.0	0.026
Copes Vulcan*	3-in, 1500 lb	223,689	1.3, 1.8	0.457
Copes Vulcan†	3-in, 1500 lb	236,179	1.6, 1.6	0.178
Crosby	HPV-SN	169,872	0.350, 0.150	0.042
Dresser	31533VX-30	156,396	0.185, 0.307	0.006
Fisher	SS-103-SS-95	180,790	2.3, 1.0	0.151
Masoneilan	20,000 series	196,150	1.8, 1.6	0.036
Muesco	70-18-9DRTX	97,934	2.0, 1.6	0.241
Target Rock	80X-006	170,950	0.587, 0.194	0.0

*Internals of 17-4PH
†Type-316 stellated plug, 17-4PH cage

RELIABILITY OF STEAM TURBINE ROTORS AND DISKS

EPRI has committed almost $15 million for studies directly involving steam turbine technology. Nearly 40% of this amount is allocated to two reliability projects—one on rotors (RP502) and one on disks (RP1398). Background information on these projects has been given in previous EPRI Journal *reports (April 1978, p. 52, and April 1979, p. 38).*

Rotor reliability

Under RP502, a set of computer programs for predicting rotor lifetime has been developed. Taken together, the programs are called the steam turbine rotor analysis program (STRAP). STRAP allows the user to evaluate the remaining service life of a rotor by combining results from ultrasonic bore examinations, calculations of the rotor stress, characterizations of material properties, and data from a linear elastic fracture mechanics model that predicts the growth of any detected flaws. STRAP software and documentation are available through a licensing agreement with the Electric Power Software Center.

STRAP uses the commercially available finite element program ANSYS to perform the rotor stress analysis. A separate version of STRAP, called SAFER, has been developed by American Electric Power Service Corp.; SAFER differs from STRAP only in that it has its own stress analysis program. Through an agreement with AEP, SAFER will also be available soon from the center.

As a result of RP502, the turbine rotor examination and evaluation system (TREES), a computerized, focused-shear-beam ultrasonic rotor bore examination system, was developed. This system, developed by Southwest Research Institute and funded primarily by AEP, is compatible with both STRAP and SAFER. AEP has used TREES and SAFER to estimate the remaining life of turbine rotors.

In addition to TREES, a state-of-the-art system that uses only off-the-shelf components was designed and developed by Battelle, Columbus Laboratories under EPRI funding. This system is called the bore ultrasonic characterization system (BUCS). BUCS is now at EPRI's Nondestructive Evaluation Center, where it will be used for training and evaluation. The technology for both TREES and BUCS is available through licensing agreements with EPRI.

Information on the capabilities and availability of STRAP, SAFER, TREES, and BUCS is presented in Table 2. A seminar on RP502 was held in June 1981, and final reports on the various contracts under the project should be available in the fourth quarter of 1981.

Table 2
CAPABILITIES OF ROTOR AND DISK RELIABILITY PROGRAMS

	Rotor Stress Analysis	Bore Sonic Inspection	Fracture Mechanics Analysis	Lifetime Prediction	Availability
STRAP	X		X	X	Electric Power Software Center
SAFER	X		X	X	Electric Power Software Center
TREES		X			EPRI Project Manager
BUCS		X			EPRI Project Manager
BIGIF			X	X	Electric Power Software Center

Disk reliability

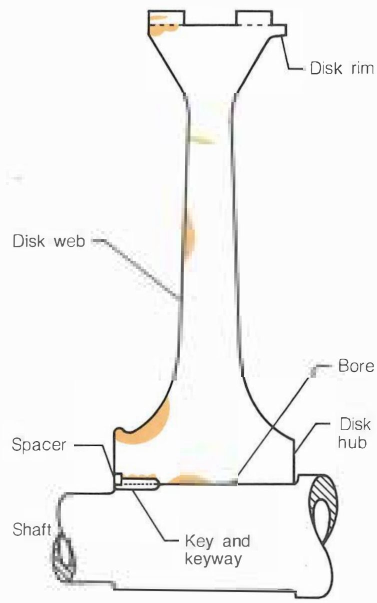
RP1398 is concerned with cracking of low-pressure steam turbine disks (Figure 3). Results from a project survey of field experience on disk cracking show that stress level, width of crevice between key and keyway, steam condensation, and oxygen level in the steam correlate strongly with keyway crack initiation. Keyway crack growth rate correlates strongly with temperature, and indirect evidence suggests that disk yield strength also influences crack growth rate.

Laboratory tests in sodium hydroxide and in sodium hydroxide–sodium chloride mixtures produced cracks in disk steel that look like cracks observed in the field; however, laboratory crack growth rates in these environments appear to be much higher than growth rates observed in the field.

A seminar on turbine disk cracking was held in April 1981. A report on the failure analysis of a cracked disk has been issued (NP-1532), and a report on the field survey of disk-cracking problems is expected to be available in the third quarter of 1981. Current work under RP1398 is addressing disk stress analysis, residual stresses, an on-line conductivity monitor, and the feasibility of developing a method for disk lifetime prediction.

In related work, a computer program called BIGIF, which was developed under RP700, has been modified to permit calculation of crack growth in regions of contained plasticity (for example, near keyways or in blade attachments). This program, also listed in Table 2, is available from the Electric Power Software Center. Associated projects in the Nuclear Power Division are investigating improved nondestructive evaluation methods for disks (RP1803) and improved disk materials (RP1929).

Figure 3 Cracking has been observed on the rim, web, keyway, and bore of shrunk-on low-pressure steam turbine disks.



Water erosion (or possibly erosion-corrosion) has been noted recently in keyways of certain types of turbines used in U.S. nuclear plants. RP1398 will address this problem only if it becomes sufficiently widespread. *Project Manager: M. J. Kolar*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Advanced Power Systems				
RP1319-9	Advanced Cooling, Turbine Structural Design	3 years	65.7	Nielsen Engineering & Research Inc. *A. Cohn*
RP1527-1	Light-Ion System Analysis and Design	22 months	340.0	Bechtel National, Inc. *K. Billman*
RP1527-3	Light-Ion System Analysis and Design Review	9 months	13.0	Physics Applications, Inc. *K. Billman*
RP1607-1	Photovoltaic Field Test Performance	8 months	112.3	Boeing Computer Services, Inc. *R. Taylor*
RP1974-1	Fusion-Fission Hybrid Rod Survey	2 months	34.3	W. J. Schafer Associates, Inc. *N. Amherd*
RP1975-1	Photovoltaic Status and Prospects Assessment: Cells and Modules	7 months	75.5	Research Triangle Institute *R. Taylor*
RP1975-2	Photovoltaic Status and Prospects Assessment: Balance of System	7 months	52.2	Bechtel National, Inc. *R. Taylor*
RP1975-3	Photovoltaic Status and Prospects Assessment: Economics	7 months	30.4	Science Applications, Inc. *R. Taylor*
Coal Combustion Systems				
RP559-4	Diagnosing Grain Boundary Embrittlement in Rotor Steels	3 years	90.0	Stanford University *R. Viswanathan*
RP637-2	Detection of Water Induction	25 months	620.3	Westinghouse Electric Corp. *J. Parkes*
RP979-12	Evaluation of Gas Turbine Material Response, Grimethorpe Pressurized Fluidized-Bed System	28 months	291.5	General Electric Co. *J. Stringer*
RP1260-23	Capacitive Cooling System for the Advanced Concepts Test Facility	4 months	37.5	Chicago Bridge and Iron Co. *J. Bartz*
RP1265-11	Corrosion-Related Failures in Power Plant Feedwater Heaters	6 months	48.8	Battelle Memorial Institute *B. Syrett*
RP1266-24	Assessment of NDE Methods for Turbine Blades	1 year	66.0	Reinhart and Associates, Inc. *A. Armor*
Electrical Systems				
RP1352-2	Probability-Based Design of Wood Transmission Structures	2 years	462.3	Research Institute of Colorado *P. Landers*
RP1834-1	Capacitor Case Rupture Prevention	21 months	390.1	Westinghouse Electric Corp. *R. Tackaberry*
RP1980-1	Plan for Lightning Research	6 months	90.9	Ebasco Services, Inc. *H. Songster*
RP2028-1	Removal of PCBs From Transformer Oil	10 months	604.2	General Electric Co. *Dr. G. Addis*
Energy Analysis and Environment				
RP1109-14	Neutralization of Acid Conditions	9 months	35.3	International Research and Technology Corp. *R. Brocksen*
RP1216-06	Commercial End-Use Forecasting Model for Utilities	20 months	319.0	Georgia Tech Research Institute *J. Wharton*
RP1630-11	Western Regional Air Quality Studies: Visibility and Air Quality Measurements	39 months	3560.2	Aerovironment, Inc. *G. Hilst*
RP1630-12	Development of a Method to Measure Hydrogen Peroxide in Air, Clouds and Rain	1 year	99.3	National Center for Atmospheric Research *J. Jansen*
RP1639-3	Trace Element Interactions in Metal Carcinogenesis	4 months	77.6	Lawrence Berkeley Laboratory *W. Weyzen*
Energy Management and Utilization				
RP1198-13	Development of Carbon (Graphite) Electrode Materials for Zinc-Chlorine Batteries	1 year	76.2	Stonehart Associates, Inc. *D. Douglas*
RP1201-16	Dispersed Logic and Communication Load Management System	14 months	25.3	City of Philippi, West Virginia *T. Lechner*
RP1275-5	Industry Analysis	9 months	50.0	Science Management Corp. *I. Harry*
RP1495-2	Technology Status and Research Needs in Unitary and Single-Zone Heat Pumps	7 months	92.9	Science Applications, Inc. *A. Lannus*
RP1569-1	Feasibility of Electric Vehicle Development by the Utility Industry	7 months	57.1	O. M. Bevilacqua and Associates *J. Mader*
RP1699-2	Thermal Ratcheting and Autoclave Tests on Advanced Conversion and Storage Materials	11 months	100.0	Battelle, Pacific Northwest Laboratories *R. Schainker*
Nuclear Power				
RP1572-2	Value Characterization Under Two-Phase Flow Conditions	7 months	96.3	Science Applications, Inc. *S. Kalra*
RP1582-1	PWR Power Shape Monitoring System: Status Review	3 months	34.4	Science Applications, Inc. *A. Long*
RP1709-3	PDQ-7 Pseudax, Stage II Modifications	9 months	50.1	G.R.P. Consulting, Inc. *W. Eich*
RP1755-2	Advanced Recycle Methodology Program: Isotopics Benchmarking for High-Burnup PWR Fuel	20 months	32.2	S. Levy, Inc. *W. Eich*
RP1803-1	Improving Inspection Technology for Steam Turbine Rotors and Disks	5 months	5.3	J. A. Jones Applied Research Co. *S. Liu*

New Technical Reports

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

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

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ADVANCED POWER SYSTEMS

Market Potential for Small Advanced-Thermomechanical-Cycle Combustion Turbine Generators

AP-1778 Final Report (TPS79-770); $11.00

A survey of small U.S. electric utilities was conducted to determine their interest in acquiring small, fuel-flexible combustion turbine power plants with cogeneration and combined-cycle potential. Three design concepts were evaluated by 53 utilities. The survey found that interest centers on coal-fired advanced cycles around 10 MW (e) that offer high efficiency and reliability. The contractor is A. C. Kirkwood & Associates. *EPRI Project Manager: Henry Schreiber*

Antisolvent-Induced Agglomeration of Mineral Matter in Coal-Derived Liquids

AP-1779 Final Report (RP774-1); $14.00

This report discusses the problem of separating mineral matter and unconverted coal from liquefaction products and examines sedimentation promoted by antisolvent liquids as a solution. Among the topics covered are the relationship of antisolvent properties to initial settling rate, the relationship of coal liquid properties to sedimentation rate, the interaction of pressurizing gases with antisolvents, and the applicability of inclined sedimentation. The contractor is West Virginia University. *EPRI Project Manager: Norman Stewart*

Accidental Criticality of Fusion-Fission Hybrid Blanket Designs

AP-1790 Topical Report (RP236-2); $11.00

The potential of a fusion-fission hybrid blanket to achieve a critical configuration was investigated. This report presents the results, as well as reviews of several recent fusion-fission hybrid studies and an analysis of accidental criticality. The general trend of all blanket reconfigurations involved significant increases in neutron multiplication; however, low blanket residence times and low fissile inventories prevented criticality. The contractor is the University of California at Los Angeles. *EPRI Project Manager: N. A. Amherd*

Evaluation of a Short-Residence-Time Two-Stage SRC Process

AP-1827 Final Report (RP779-21); $11.00

A laboratory study using small-batch equipment was conducted to investigate the effectiveness of sulfur scavengers during the two-stage liquefaction of Indiana V coal. The study evaluated the capability of the process to produce low-sulfur solvent-refined coal (SRC) that could meet EPA emission standards. This report discusses the coal-processing configuration, short-residence-time liquefaction to improve hydrogen utilization, and the impact of higher-molecular-weight solvents on the liquefaction process. Comparative reaction study results are included. The contractor is Auburn University. *EPRI Project Manager: C. J. Kulik*

Workshop Proceedings: Combustion Turbine Residual Oil

WS-80-132 Proceedings; $23.00

EPRI sponsored a workshop in Atlanta in July 1980 on the use of residual oil fuels in combustion turbines. Necessary modifications and procedures for residual fuel operation were discussed, as well as the experience of utilities that have used residual fuel. The contractor is Coecorp. *EPRI Project Manager: R. L. Duncan*

COAL COMBUSTION SYSTEMS

Western Subbituminous Coals and Lignites

CS-1768 Final Report (RP1030-11); $17.00

This report describes subbituminous coal and lignite resources and characteristics and examines the potential for upgrading low-rank western coals by such methods as coal drying, physical cleaning, sodium reduction, and fine-coal agglomeration. Current R&D efforts are reviewed, and recommendations for future work are made. The contractor is Bechtel National, Inc. *EPRI Project Manager: R. S. Sehgal*

Leaching of Asbestos-Cement Cooling-Tower Fill

CS-1777 Final Report (RP1260-8); $12.50

The leaching of cooling-tower fill made of asbestos cement was investigated. This report assesses the extent and severity of the problem, examines its causes, and recommends corrective measures in the design and operation of future plants. It also summarizes previous studies of asbestos-cement water pipe and cooling-tower fill. The contractor is Brown & Caldwell. *EPRI Project Manager: Winston Chow*

Biofouling Control Practice and Assessment

CS-1796 Final Report (RP1132-1); $17.00

This report examines the practice of chlorination for controlling condenser tube microfouling in once-through cooling systems. It presents a data base compiled from questionnaires, existing data bases, and interviews at 29 plants exhibiting a range of biofouling parameters. It also describes performance tests conducted on the main condenser at an operating plant to determine the effect of chlorine addition. A bibliography of current and recent research on biofouling control and related topics is included. The contractor is NUS Corporation. *EPRI Project Manager: Winston Chow*

Failure-Cause Analysis: Turbine Bearing Systems

CS-1801-SY Summary Report (RP1265-3); $6.50

A three-phase project is under way to determine the root causes of generic problems leading to the failure of turbine generator bearing systems. This report summarizes the first phase, which involved the development of a comprehensive plan for collecting data on bearing system failures. The report also reviews the background and objectives of the study. The contractor is Franklin Research Center. *EPRI Project Managers: J. B. Parkes and T. H. McCloskey*

Laboratory Evaluation of the Impact of Drying and Screening on Refuse-Derived-Fuel Quality

CS-1802 Final Report (RP1180-6); $8.00

Samples of refuse-derived fuel (RDF) were analyzed to determine the impact of thermal drying and screening on fuel quality. Sample collection procedures and analyses are described. Parameters studied include distribution according to seven size classes; RDF composition in terms of paper, plastic, wood, nonferrous metals, glass, and fines; moisture, ash, volatile solids, and fixed carbon content (determined by proximate analysis); and heating value and combustible chlorides. Chemical analysis of the ash was also performed. The contractor is Cal Recovery Systems, Inc. *EPRI Project Manager: C. R. McGowin*

Evaluation of 10-MW Shawnee Cocurrent Scrubber

CS-1806 Final Report (RP1033-1); $24.50

This report summarizes the results of prototype-scale testing of a 10-MW cocurrent SO_2 scrubber at Tennessee Valley Authority's coal-fired Shawnee steam plant. It includes a description of the facility; results of sodium carbonate, lime, and limestone tests; results of special air-water tests; and a discussion of the mechanical performance of key system components. The cocurrent scrubber was shown to be a versatile, effective gas-liquid contactor for use as an SO_2 control device. The contractor is Radian Corp. *EPRI Project Managers: T. M. Morasky and C. E. Dene*

High-Strength Austenitic Alloys for Generator Retaining Rings

CS-1808 Interim Report (RP636-2, RP1266-12); $9.50

This report describes research to produce a new high-strength austenitic alloy suitable for use in generator retaining rings. A heat-treatable, nonmagnetic alloy capable of achieving yield strengths in excess of 200 ksi and fracture toughness in excess of 100 ksi $\sqrt{in}$ has been developed. The contractors are the University of California and DOE. *EPRI Project Manager: Ramaswamy Viswanathan*

Corrosion Problems in Coal-Fired Boiler Superheater and Reheater Tubes: Steam-Side Oxidation and Exfoliation—Review and Results of Laboratory Tests

CS-1811 Final Report (RP644-1); $14.00

This report presents (1) a review of literature on steam-side scale exfoliation in superheater and reheater tubes and (2) the results of a laboratory test program that investigated the causes and controlling parameters of scale exfoliation. The relationship of scale exfoliation to operating temperature cycles is examined, and effective means of eliminating exfoliation are summarized. The contractor is Foster Wheeler Development Corp. *EPRI Project Manager: John Stringer*

Corrosion Problems in Coal-Fired Boiler Superheater and Reheater Tubes: Steam-Side Oxidation and Exfoliation—Development of a Chromate Conversion Treatment

CS-1812 Final Report (RP644-1); $9.50

This report describes a chromate conversion treatment for preventing steam-side scale exfoliation in superheater and reheater tubes. The performance of scaled tubes that were first chemically cleaned by three techniques and then chromate-treated and tested in steam is evaluated. Test results on oxide growth rate reduction, improved scale stability, reduction of exfoliated scale, and compatibility of dissimilar metal welds are presented, and recommendations for further work are made. The contractor is Foster Wheeler Development Corp. *EPRI Project Manager: John Stringer*

Exhaust-Fired Fluid-Bed Combined Cycle for Power Generation: Preliminary Feasibility Study

CS-1818 Final Report (RP582-2); $12.50

This report discusses technical investigations into several novel 300-MW combined cycles based on the marriage of an atmospheric fluid-bed boiler with an air heater to two hot-air expansion turbines. In the growth versions of the proposed cycles, various supplemental liquid fuels would be burned in order to raise the gas temperature to the turbines and hence improve cycle efficiency. The contractors are Westinghouse Electric Corp. and Babcock & Wilcox Co. *EPRI Project Manager: S. G. Drenker*

Feasibility Study for a Forest-Residue-Fueled Electric Generating Plant

CS-1819 Final Report (TPS79-742); $18.50

This report describes the procedures and results of a study to determine the feasibility of constructing small electric power generation plants fired solely with forest residue. Intended to serve as a guide for other potential users of a similar resource, the report discusses environmental constraints and presents a conceptual design resulting from an evaluation of several power plant design options. Details on a physical survey of national forests in the Eugene, Oregon, area and selected candidate sites are also given. The contractor is Nor'west-Pacific Corp. *EPRI Project Manager: R. K. Manfred*

ELECTRICAL SYSTEMS

Transient Stability Margin as a Tool for Dynamic Security Assessment

EL-1755 Final Report (RP1355-3); $15.50

The results published in this report form the basis for further development of the energy function method, a direct method for determining the transient stability of a multimachine power system. The report covers issues related to the region of stability, the modes of system instability for a particular disturbance, and the components of the transient energy responsible for instability. An extensive series of computer simulation studies supporting this work is also outlined. The contractor is Iowa State University. *EPRI Project Manager: J. V. Mitsche*

Substation Control and Protection Project: System Requirements Specification

EL-1813 Interim Report (RP1359-1); $12.50

This Phase 1 report documents the requirements for a substation control and protection system. It covers the areas of installation, environment, operating personnel, maintenance and testing, expansion and modifications, design, documentation, and reliability. It also lists 26 specific system functions and provides a description, an input-output list, and a set of requirements for each. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: S. L. Nilsson*

Metallic Return Transfer Breaker Development

EL-1816 Final Report (RP667); $11.00

This report describes development work on a metallic return transfer breaker (MRTB) for HVDC systems. The breaker incorporates a novel current interrupter developed by the contractor (the crossed-field tube), a mechanical in-line switch, and a zinc-oxide nonlinear resistor. Successful 300- and 600-A (dc) current transfer tests with the MRTB at Bonneville Power Administration's Celilo converter station are detailed, as well as the failure of the 1200-A transfer; causes of the failure are examined. The contractor is Hughes Research Laboratories. *EPRI Project Manager: N. G. Hingorani*

Model Study of HVDC Electric Field Effects

EL-1817 Final Report (RP1097); $17.00

Energized scale models of a 400-kV HVDC test line and a ±250-kV converter station were designed and built to compare the electric field distribution of the full-scale facilities with that of the models. The report discusses instrumentation, modeling and scaling problems and their solutions, calibration and verification tests, and the accuracy of the model measurements. Comparison of corresponding ground-level electric field strength test ranges showed that the agreement between full-scale and model measurements is good. The contractor is Ohio State University. *EPRI Project Manager: S. L. Nilsson*

Three-Phase UHV AC Transmission Research, 1977–1979

EL-1820 Final Report (RP68-3); $26.00

This report presents the results of work performed at EPRI's Project UHV from October 1976 to December 1979. A three-phase ac test line with different bundles and line configurations was energized to obtain design data on audible noise, radio noise, corona loss, and television interference for line voltages between 1000 and 1500 kV. In addition, basic research on audible noise produced by bundle conductors, flashover tests on line insulation with switching impulses, and flashover tests on contaminated insulators under steady-state and transient overvoltages were performed. The contractor is General Electric Co. *EPRI Project Manager: R. E. Kennon*

Crystallized Fly Ash Feasibility Study

EL-1836 Final Report (RP1210-1); $9.50

This report describes a study that evaluated crystallized fly ash as a material for satisfying structural and insulating requirements for overhead distribution line components. The process necessary for developing crystallized fly ash in a controlled manner was investigated, and samples were prepared from both as-received fly ash and beneficiated fly ash. Analyses of fly ash, fluxing agents, and nucleating agents were performed, and the physical, mechanical, and electrical characteristics of crystallized fly ash were measured. The contractor is ECP Inc. *EPRI Project Manager: R. S. Tackaberry*

ENERGY ANALYSIS AND ENVIRONMENT

Industry and Economic Impacts of Restrictions on the Growth of Generating Capacity

EA-1775 Interim Report (RP1152); $15.50

Issues concerning the interaction of the energy sector and the economy were studied through computer models. The Hudson-Jorgenson long-term interindustry transactions model was linked to the Baughman-Joskow regionalized electricity model, and the combined model system was used to examine the implications on the national economy of energy sector uncertainties affecting the utility industry until 2000. Two sets of issues were analyzed, and eight cases consisting of different combinations of uncertain events were examined for each issue. Detailed quantitative results are included. The contractor is Dale W. Jorgenson Associates. *EPRI Project Managers: H. P. Chao and E. V. Niemeyer*

Preliminary Results From the EPRI Plume Model Validation Project: Plains Site

EA-1788 Interim Project (RP1616); $12.50

This report presents interim results from the EPRI plume model validation project, which is designed to validate by statistically rigorous procedures the atmospheric dispersion models applied to electric generating facilities employing tall stacks. Project objectives are outlined, and the operational performance of four Gaussian models in predicting short-term air quality impacts is evaluated. The field measurements program and the model validation methodology are also summarized. The contractor is TRC Environmental Consultants, Inc. *EPRI Project Manager: G. R. Hilst*

Effects of High-Voltage Transmission Lines on Honeybees
EA-1809 Interim Report (RP934-1); $8.00

Results from a study of the activities of honeybees hived in an electric field beneath a 765-kV transmission line are presented. The effects of zero-, intermediate-, and high-dosage exposures on five parameters—worker capped brood count, net hive weight, worker dry weight, honey moisture content, and amount of propolis in the hive entrance—are summarized. Hive reactions to a reversal of treatment at midseason are also described. The contractor is Bioconcern. *EPRI Project Manager: Robert Kavet*

Potential for Load Management in Selected Industries: Summary
EA-1821-SY Final Report (RP1212-3); $8.00

This report is a condensation of a previously published report (EA-1573) that examined the potential response of U.S. industrial customers to time-of-day pricing of electricity. The methodology of the study, key results, and implications of the conclusions are examined. The contractor is Chem Systems Inc. *EPRI Project Manager: S. D. Braithwait*

Integrated Lake-Watershed Acidification Study: Contributions to the International Conference on the Ecological Impact of Acid Precipitation
EA-1825 Interim Report (RP1109-5); $12.00

This report presents seven papers given by members of EPRI's integrated lake-watershed acidification study at the International Conference on the Ecological Impact of Acid Precipitation, which was held in Sandefjord, Norway, in March 1980. The papers describe the study's progress and examine the quantitative relationship between atmospheric acid deposition and surface water acidity as shown by three forested watersheds in New York's Adirondack area. Details on the chemical dynamics of the lakes and the ecological effects of acid deposition are also presented. The contractor is Tetra Tech, Inc. *EPRI Project Manager: R. A. Goldstein*

Aircraft Measurements of Pollutants and Meteorological Parameters During the Sulfate Regional Experiment (SURE) Program
EA-1912 Final Report (RP862-4); $15.50

This report describes flights performed during SURE to monitor pollutant levels and meteorological conditions. It presents flight summaries and describes the aircraft, the instrumentation system used, and operational procedures. It also presents conclusions drawn from a preliminary analysis of the data collected. The contractor is Research Triangle Institute, Inc. *EPRI Project Manager: G. R. Hilst*

Emissions Inventory for the SURE Region
EA-1913 Final Report (RP862-5); $23.00

This report describes an emissions inventory developed for the Sulfate Regional Experiment to represent anthropogenic sources extant in 1977. Emission rates are given for eight pollutant species (SO_2; $SO_4^=$; NO; NO_2; high-, moderate-, and low-reactivity HC; and total emitted particulates) in each of five source classifications (electric utility, industrial, commercial, residential, and transportation). External factors that influence emission rates are investigated for the different source types. The contractor is GCA Corp. *EPRI Project Manager: G. R. Hilst*

ENERGY MANAGEMENT AND UTILIZATION

Economic Assessment and Comparison of Alternative Beta Alumina Electrolytes
EM-1799 Final Report (RP109-6); $12.50

Manufacturing costs of two types of ceramic electrolytes used in the sodium-sulfur battery were analyzed. Costs of batteries using the alternative beta alumina electrolytes were also calculated and compared. The study found that the electrolytes are a very high cost element of the sodium-sulfur battery, and ways to reduce their cost were explored. The contractor is Compagnie Générale d'Electricité. *EPRI Project Manager: J. R. Birk*

O_2 Reduction on Platinum Catalysts in H_3PO_4
EM-1814 Final Report (RP634-1-2); $12.50

A study was conducted to examine the optimization of the performance of platinum electrocatalysts for the reduction of oxygen in fuel cells using phosphoric acid as the electrolyte. This report discusses the mechanism and kinetics of oxygen reduction on platinum electrocatalysts, platinum dissolution, acid reduction by hydrogen, and the effects of impurities on the reaction. Recommendations based on the present research are included. The contractor is Case Western Reserve University. *EPRI Project Manager: A. J. Appleby*

Evaluation of Alloys for Fuel Cell Heat Exchangers
EM-1815 Final Report (RP1041-3); $11.00

This report presents the results of an investigation of the behavior of commercial stainless steels, superalloys, and aluminide coatings in both clean (sulfur-free) gas and raw (1% H_2S) gas representative of the product gas of a Texaco gasifier at temperatures of 1400-1800°F. The objective was to determine which, if any, of these materials is suitable for use in a high-temperature heat exchanger operating in intermediate-Btu coal gasification atmospheres. The contractor is Lockheed Missiles & Space Co., Inc. *EPRI Project Manager: John Stringer*

NUCLEAR POWER

Evaluation of PWR Radiation Fields and Out-of-Core Surface Activities
NP-858 Interim Report (RP825-2); $11.00

Radiation-field data from 13 Westinghouse PWRs were evaluated to define radiation-field buildup trends and to determine factors influencing those trends. A standard radiation-monitoring program identifying measurement techniques and locations was developed to enable interplant comparisons of radiation-field data. The use of a collimated GeLi detector for isotopic surface activities on steam generator manway cover inserts and coolant loop piping is also described. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: R. A. Shaw*

Core Design and Operating Data for Cycle 3 of Peach Bottom-2
NP-971 Final Report (RP1020-2); $9.50

This report contains data needed to define fuel characteristics and reactor operation for cycle 3 of the Peach Bottom-2 BWR. Reference-quality data for use in the qualification of reactor core analysis methods are provided and serve as the basis for the assessment of the irradiation environment during cycle 3. Design data include fuel assembly descriptions, core component arrangements, control rod descriptions, and core loading patterns peculiar to cycle 3 operation. The contractor is General Electric Co. *EPRI Project Manager: R. N. Whitesel*

Low-Flow Stability Tests at Peach Bottom Atomic Power Station, Unit 2, During Cycle 3
NP-972 Final Report (RP1020-2); $17.00

This report presents results from low-flow stability tests conducted at the Peach Bottom-2 BWR during cycle 3 as part of a larger project to gather data from operating power plants for the improvement of operating flexibility. Details of stability measurements of a large BWR core at operating conditions in which the system is less stable are provided as reference data for the qualification of advanced BWR stability predictive computer codes. The contractor is General Electric Co. *EPRI Project Manager: R. N. Whitesel*

BWR Refill-Reflood Program: Single-Heated-Bundle Experimental Task Plan
NP-1524 Interim Report, Vols. 1 and 2 (RP1377-1); $14.00

This report describes tests to be performed in an atmospheric pressure, single-heated-bundle facility both for model development and for qualification of an adiabatic steam injection technique that will be used in a large-scale 30°-sector test facility. A description of the experimental facilities, a specification of the test matrices, and a plan for using the data obtained are also included. The contractor is General Electric Co. *EPRI Project Manager: Mati Merilo*

BWR Refill-Reflood Program: Core Spray Distribution Final Report
NP-1580 Interim Report (RP1377-1); $8.00

This report presents the results of the refill-reflood test effort to assess core spray distribution in a steam environment for a full-scale 30° sector of the BWR-4, -5 (218) design. It includes descriptions of the test facilities and the core spray hardware. Results are also given for individual spray nozzles and nozzle-to-nozzle interaction tests. The contractor is General Electric Co. *EPRI Project Manager: Mati Merilo*

NSSS Transient Tests at ANO-2
NP-1708 Final Report (RP1385-1); $18.50

This report presents experimental data from a series of four nuclear steam supply system transient tests performed at Arkansas Nuclear One, Unit 2. Procedures and results are detailed for the following tests: complete loss of forced primary coolant flow, full-length control element assembly (CEA) drop, part-length CEA drop, and turbine trip. The tests establish a more comprehensive data base than previously available for PWR simulation code qualification. The contractor is Combustion Engineering, Inc. *EPRI Project Managers: J. A. Naser and R. N. Whitesel*

Test of Isothermal Soaking Procedures for Limiting Tube Denting in Nuclear Steam Generators

NP-1761 Interim Report (RP623-2); $23.00

The effectiveness of hydrazine-treated water and alkaline phosphate solutions in arresting steam generator corrosion and tube denting was evaluated under isothermal and heat transfer conditions. This report describes the test equipment (capsules and pot boilers), procedures, conditions, and results. None of the tested isothermal soak procedures was able to completely halt active denting in pot boiler testing; the maximum reduction in denting rate was 70%. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: R. G. Varsanik*

Simplified Models for Transient Analysis of Nuclear Steam Generators

NP-1772 Interim Report (RP684-1); $5.75

A linear modeling technique and its use in analyzing integral-economizer once-through steam generators are summarized. A brief description of a nonlinear moveable boundary model is included, as well as preliminary results obtained with the model. Results from the linearized model compare quite favorably with the experimental data from a 19-tube-bundle test facility. The contractor is the University of Michigan. *EPRI Project Manager: S. P. Kalra*

Steam Generator Mock-up Facilities

NP-1785 Final Report (RPS126, RPS1172); $6.50

This report describes the design and construction of three fixed-site and one air-transportable steam generator mock-ups configured to inspect tubing degradation in PWR steam generators. The mock-ups are designed to accommodate a large number of tubes containing simulated defects associated with PWR steam generators. The report provides general descriptions of tubing defects and standard evaluation procedures, including data collection and interpretation methods. The contractor is Battelle, Columbus Laboratories. *EPRI Project Managers: G. W. DeYoung and G. J. Dau*

Steam Generator Chemical Cleaning Demonstration Test No. 1 in a Pot Boiler

NP-1789 Topical Report (RPS128); $17.00

This report summarizes a demonstration test to chemically remove corrosion products from the secondary side of PWR steam generators. It presents secondary-water-chemistry specifications, visual observations, nondestructive and destructive metallographic examination results, and conclusions. The results indicate that it is feasible to remove corrosion products generated under prototypical conditions. The contractor is Combustion Engineering, Inc. *EPRI Project Manager: C. S. Welty, Jr.*

Full-Scale Controlled Transient Heat Transfer Tests: Analysis Using the FAST Prediction Method

NP-1792 Final Report (RP815); $12.50

The FAST computer code model is a recently developed numerical model for predicting one-dimensional, transient, thermal nonequilibrium two-phase flows. This report presents FAST predictions and compares them with measurements obtained from the Westinghouse J-loop. The performance of several correlations used to predict critical heat flux is evaluated. The contractor is the University of Waterloo. *EPRI Project Manager: Mati Merilo*

Full-Scale Controlled Transient Heat Transfer Tests: Facility Description

NP-1793 Final Report (RP494-1); $14.00

This report describes the Westinghouse J-loop, a well-instrumented, high-pressure steam-water test facility designed for controlled transient thermal-hydraulic experiments under conditions like those calculated to occur during a loss-of-coolant accident. Pretest and posttest procedures and the facility's data acquisition system are also detailed. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Mati Merilo*

Evaluation of Steam Generator Tube 85-127 From Oconee 1B

NP-1794 Final Report (RPS136-1); $12.50

A destructive examination of an alloy-600 tubing sample from a steam generator at Duke Power Co.'s Oconee station was conducted to determine the cause of corrosion damage. The methods used to assess the relative responsibility of chemical and mechanical effects for the damage are described, and the results of surface chemistry and mechanical effects analyses are detailed. Conclusions and recommendations are included. The contractor is Babcock & Wilcox Co. *EPRI Project Managers: G. W. DeYoung and J. P. N. Paine*

Brunswick-2 Water Chemistry

NP-1795 Interim Report (RP819); $15.50

This report presents definitive information on chemical conditions in the condensate-feedwater system and the reactor water cleanup system of a large BWR designed with forward pumping of heater drains. Data on dissolved oxygen, specific conductance, and pH levels at 12 sample points were obtained by continuous monitoring equipment and data acquisition computers. This data base provides insight into such transient conditions as startup and shutdown and the rare occurrence of resin intrusion. The contractor is General Electric Co. *EPRI Project Manager: M. D. Naughton*

Separated Two-Phase Flow Model: Application to Critical Two-Phase Flow

NP-1800 Topical Report (RP443-2); $11.00

This report describes the application of a newly developed separated two-phase flow model for predicting thermal-hydraulic responses in LWRs. The separated flow model, developed to allow the calculation of critical flow rates for steam-water mixtures, is able to consider hydrodynamic as well as thermal nonequilibrium effects and thus incorporates the interphase interaction terms for momentum, energy, and mass. The report includes a comparison of model predictions with results from critical two-phase flow experiments. The contractor is Dartmouth College. *EPRI Project Manager: K. H. Sun*

German Risk Study: Main Report

NP-1804-SR Special Report; $26.00

A translation of Phase A of the *Deutsche Risikostudie Kernkraftwerke*, this report assesses the risks due to accidents caused by the operation of nuclear power plants in the Federal Republic of Germany. In Phase A the probabilistic risk assessment methodology used in the American *Reactor Safety Study* (WASH-1400) is applied to the system technology and siting conditions particular to the German situation. *EPRI Project Manager: I. B. Wall*

Flow Regime Characterization With a Multielement Conductance Gauge

NP-1805 Final Report (RP1019); $9.50

An instrument that permits flow regime identification in two-phase air-water flow was evaluated. The measurement system employs a multielectrode sensor spool piece that is nonintrusive and hence causes no additional pressure drop. A rotating sequential switching technique was used to make conductivity measurements between all electrode pairs. Testing was conducted over a full range of void fractions in both horizontal and vertical attitudes. Analysis involved calculation of parameters related to flow symmetry, void fraction, and void fraction fluctuation. The contractor is Auburn International, Inc. *EPRI Project Managers: D. G. Cain and Mati Merilo*

Full-Scale Controlled Transient Heat Transfer Tests: Data Report

NP-1810 Final Report (RP494-1); Vol. 1, $15.50; Vol. 2, $32.00

Volume 1 summarizes the results of transient critical heat flux (CHF) behavior studies under conditions like those postulated to occur after a design basis accident. It covers the test procedures (including CHF time and distribution), error analysis, preliminary interpretations, and qualitative conclusions. Volume 2 presents detailed data on the test runs, including CHF time and temperature summaries and plots of flows, pressures, densities, and heat transfer coefficients. The contractor is Westinghouse Electric Corp. *EPRI Project Manager: Mati Merilo*

Basic Studies on the Variabilities of Fabrication-Related Sensitization Phenomena in Stainless Steels

NP-1823 Final Report (RP1072-1); $14.00

This report presents a study of intergranular stress corrosion cracking of type-304 stainless steel (SS) pipe welds in BWRs. It discusses low-temperature sensitization, the influence of thermal-strain history on type-304 SS sensitization, and the chemistry and geometries of crevices, common sites for accelerated corrosion in passive material such as SS. A weld-simulation apparatus constructed to study sensitization as a result of thermal and thermomechanical cycling is also described. The contractor is General Electric Co. *EPRI Project Manager: M. J. Fox*

BWR Oxygen Control Demonstration Program

NP-1835 Interim Report (RP706-1); $8.00

This report describes operational procedures used to control dissolved oxygen and hydrogen peroxide concentrations during BWR startups. It includes the results of BWR oxygen control demonstrations and an analytic review of the impacts of major system varibles on oxygen transients. The contractor is NWT Corp. *EPRI Project Managers: M. J. Fox and R. E. Smith*

Patents

Each issue of the *Journal* includes a list of newly filed patent applications. The EPRI identification number, title, and abstract filed with the application are reprinted below. Information on obtaining a license under EPRI patent or patent application can be obtained from the Manager, Patents and Licensing, P.O. Box 10412, Palo Alto, California 94303; (415) 855-2866.

Information on other licensable inventions, as well as computer codes available from EPRI, is published quarterly in the *EPRI Guide*. This publication can be obtained from Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081.

Fluid-cooled blade or vane and method of manufacture
ED0234-77-02

A fluid-cooled blade or vane for use in a gas turbine or like apparatus is disclosed herein. The blade or vane includes an elongated open-ended skin of predetermined cross-sectional configuration; a number of spaced cooling tubes located within and extending in the elongated direction of the open-ended skin; a reinforcement spar disposed within the skin along with tubes; and solid material, preferably copper, filling the elongated skin around the tubes and spar. A specific method of making the blade or vane just described is also disclosed and includes initially providing the elongated skin as a preform. The cooling tubes and spar are disposed within the preform in their intended positions. Thereafter, the filling material, while being maintained in a molten liquid state, is caused to flow into the remaining space within the preform around the tubes and reinforcement spar. At the same time, this molten material is prevented from entering the tubes. Thereafter, the molten material solidifies within the preform so as to hold the cooling tubes and reinforcement spar in place.

Improved photovoltaic cell
ED1085-80-33

A photovoltaic cell in which a plurality of semiconductor bodies are provided on a conductive layer on a major surface of a substrate. Each body includes a core and an outer layer of different conductivity types. A transparent conductive layer interconnects the semiconductor bodies. In one embodiment, a single conductive layer is formed on the substrate, and a voltage differential is generated between the single conductive layer and the transparent conductive layer. Alternatively, two conductive layers can be provided on the substrate, and the voltage differential is generated between the two conductive layers.

Techniques for making amorphous metal material and superconductors therefrom
ED1290-79-30

A technique for making superconductive wire, tape, or the like by initially forming this material in an amorphous state is disclosed herein, along with specific ways of initially providing the amorphous material. Each wire, tape, or the like is formed by means of a rapid quench process in which at least one but preferably two rotating disks are used in order to rapidly quench opposite sides of a continuous supply of molten metal. If the ultimately formed amorphous material is to be a superconductor, it is thereafter annealed in a prescribed way to enhance its superconductive characteristics, preferably after being formed into its intended shape. A nonsuperconductor may be formed simultaneously with and connected to the superconductor.

Method and means for measuring particulate matter on a filter
ED1336-80-20

The amount of particulate matter deposited on a fabric filter during operating conditions is determined by capacitive measurements. The fabric filter material is mounted on a first perforated electrode, and a second electrode is spaced from the first electrode and capacitively associated therewith. Capacitance between the electrodes varies with the amount of particulate matter on the filter. Bridge circuitry is employed to determine the capacitance between the electrodes.

Apparatus and method for ultrasonic detection of flaws in power plant piping systems
ED1448-79-07

A method of in-service ultrasonic detection of intergranular stress corrosion cracking conditions in pipe sections of nuclear power plants. A plurality of ultrasonic return signal features and an associated general form of algorithmic combination are selected on the basis of ultrasonic pipe studies to use in distinguishing return signals from cracking conditions and geometric reflectors. A calibration pipe sample having a prearranged configuration with geometric reflectors substantially corresponding to the unknown pipe section and at least one known cracking condition is provided. Sequential ultrasonic examinations are performed, using the calibration pipe sample, first to enable tuning of the algorithmic combination to optimize the ability to distinguish return signals from geometric reflectors and known cracking conditions, followed by an ultrasonic examination of the pipe section, using the same selected return signal features and the selected algorithmic combination of the values to ascertain presence or absence of a cracking condition. A kit of parts, including a crack detection instrument and a variety of calibration pipe samples corresponding to the various pipe section configurations in a nuclear power plant, is also disclosed.

Underground cable-installing apparatus and method utilizing a multipositionable plow blade
KD1518-01-02

An underground cable-installing apparatus is disclosed herein, along with its method of operation. The apparatus utilizes a power-driven land vehicle and an elongated cable-laying plow blade supported by and for movement with the vehicle in a way which places a lowermost end portion of the blade in the ground with its cutting edge disposed in the direction of vehicular movement. As the blade moves through the ground, it lays cable in its path from a cooperating cable-feeding mechanism. In accordance with one operational feature of the apparatus disclosed herein, its plow blade is supported for movement relative to its vehicle between a number of different operating positions, including positions in front of and behind the vehicle as well as various positions on either side thereof. In accordance with another feature, the cable itself is fed from a supply wound about a drum or reel which is supported in an adjustable fashion on the vehicle.

Undergound cable-installing apparatus and method utilizing a fluid-jet-assisted, vibrating blade arrangement
KD1518-01-04

An underground cable-installing apparatus is disclosed herein, along with its method of operation. The apparatus utilizes a power-driven land vehicle and an elongated cable-laying plow blade supported by and for movement with the vehicle in a way which places a lowermost end portion of the blade in the ground with its cutting edge disposed in the direction of movement of the vehicle. In accordance with one operational feature of the apparatus disclosed herein, a plurality of high-impact fluid jets are used to aid the cable-laying plow blade in cutting through the earth. In accordance with another feature, the blade is also subjected to vibration, preferably by placing a vibratory member on the in-ground portion of the blade.

Apparatus for and method of installing underground cable having aboveground terminals
KD158-01-05

An apparatus for installing cable underground is disclosed herein, along with its method of operation. The apparatus utilizes a power-driven land vehicle and a cable-laying plow blade supported by and for movement with the vehicle in a way which places a bottom end portion of the blade in the ground so as to plow through the soil. A supply of cable is also supported on and movable with the vehicle along with a cable feed arrangement cooperating with the blade for laying a continuous length of the cable from its supply into the ground at a fixed depth relative to and along the path of the plow blade. The feed arrangement itself includes a feed shoe which makes it easy to bring up to ground level intermittent sections of the cable as the latter is installed and without withdrawing the plow blade. These spaced aboveground cable sections serve as terminals for ready access to the buried cable.

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