Building Energy Supplies

ELECTRIC POWER RESEARCH INSTITUTE

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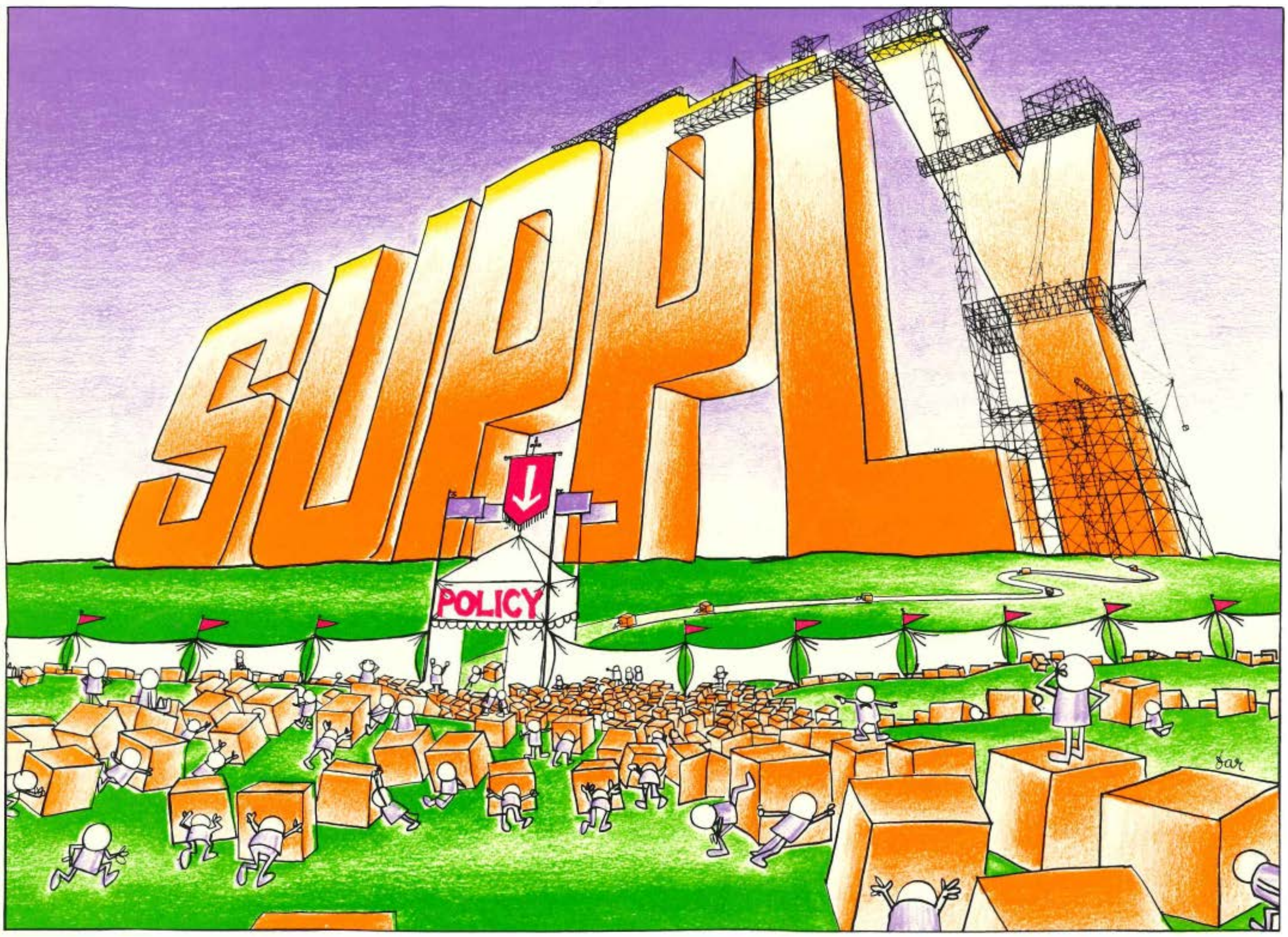

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Cover: Federal and state policies, some still to be determined, are the major constraints to converting domestic energy resources into usable supplies.

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Supply Estimates, Vintage 1977

Prophecies of imminent shortages of critical materials litter the recorded history of civilization. And today, in a period of change and uncertainty in energy policy, such forecasts of dwindling energy supplies again play a dominant role in national plans.

There is no question that any physical resource, be it gold or oil, is a finite commodity. Moreover, as the more readily accessible deposits of such resources are used up, those that are more difficult and costly to develop will have to be used. To some extent, new technologies for extracting and processing a resource can make it possible to exploit less desirable deposits. But in the long run, the limit of a finite supply or the point of unacceptable costs will be reached.

Developing estimates of the extent of energy resources and the cost of processing the resources into fuel supplies is one objective of EPRI's Supply Program. Such estimates are used by EPRI in developing R&D strategies for the utility industry. In this spirit, the Supply Program will produce annually a synthesis of its research and will outline its best guess about the extent of energy resources and the resulting cost of fuels. The first such synthesis, *Supply 77,* has recently been published. It describes the program's evaluation to date. Readers are given a glimpse of the findings in this month's lead article.

Generally, the research of the Supply Program suggests a substantially more hopeful outlook for the physical availability and cost of fuels than do many other similar studies. One primary reason is the greater optimism of the Supply Program's analysts about the extent of energy resources that can be found and developed at today's substantially higher prices. However, the analysts caution that the existence of energy resources and their subsequent conversion into delivered fuels are two different things. Notably, changing national policies on taxation, resource development, environmental protection, and safe working conditions will dramatically affect the cost of fuels and, in part, will determine their availability.

As most readers realize, all forecasts contain a degree of uncertainty. Combining the information at hand with reasonable assumptions, the projections of *Supply 77* provide the best guess of EPRI's Supply Program analysts. The tons of coal mined or the barrels of oil produced and the prices asked for them most likely will be different—higher or lower—than those projected. Prudent national energy policymaking and responsible energy R&D planning should keep this fact firmly in mind. Nevertheless, we need to know today the experts' best guess for the future.

René H. Malès, Director
Energy Analysis and Environment Division

Authors and Articles

This month the *EPRI Journal* turns again toward the future. We opened the year with a look to the past, a retrospective of the shaping forces behind the creation of EPRI and the experience and influence of its president, top management, and senior advisors during the Institute's first five years. In March we placed our focus on the present and devoted an entire issue to the realities of solar R&D and solar technologies today, drawing on the expertise and current activities of a single EPRI program staff.

This month we turn toward tomorrows as close as next month and as distant as the year 2000—to the future in fuel supplies, in nuclear fuel processes, in R&D management style, in electrical materials, and in equipment performance analysis.

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The future of utility fuel for at least the next 22 years is explored by Milton Searl in "Energy Supplies: A Look Ahead" (page 6). Working with the indications of current research, as well as with results from completed projects in his Supply Program, Searl presents an outlook that reflects a needed distinction between economic and physical resource assessments. With a gradually more detailed and consistent fact base as to U.S. energy resource endowment in the ground, Searl and his colleagues are better able to discern availabilities in terms of extraction and use costs, government policies, and economic factors.

Developing this distinction has been a major focus for Searl since 1973, when he joined EPRI to organize energy supply research for the Energy Analysis and Environment Division. But his professional interest extends back over the 30 years in which he has followed, researched, and reported supply economics for oil companies, the Atomic Energy Commission, the White House Office of Science and Technology, and Resources for the Future, Inc.

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An early item on the future agenda of federal and international energy R&D may well be the close evaluation of a new approach to the reprocessing of spent nuclear fuel. Announced by EPRI at the Fifth Energy Technology Conference in Washington, D.C., two months ago, the Civex process was conceived to make plutonium materials theft-proof throughout the course of fabricating or recycling fuel for fast breeder reactors.

"Civex: A Diversion-Proof Plutonium Fuel Cycle" (page 11) was researched and written by John Kenton, the *Journal's* nuclear power specialist, who has observed and chronicled nuclear fuel cycle technology since 1954. The article draws particularly on technical thinking and discussion led by Chauncey Starr and Milton Levenson, director of EPRI's Nuclear Power Division.

The Civex process concept has drawn wide and authoritative attention since its announcement and elaboration by Starr and Walter Marshall, deputy chairman of the United Kingdom Atomic Energy Authority. Responses from the administration and others are noted in this month's Washington Report (page 39).

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A new R&D management style is close at hand for EPRI's many people and their programs on behalf of the electric utility industry. Next month Floyd Culler will succeed Chauncey Starr as president of the Institute, completing a transition that began with his selection last fall and continued with his interim service as executive vice president for the first four months of 1978. "Meeting Floyd Culler" (page 14) is thus a timely article, conceived and written by Nilo Lindgren as counterpoint to his wide-ranging portrayal of "The First Five Years: Chauncey Starr and the Building of EPRI," published in the January-February *Journal.*

Once again, the man's own words and words from those who have observed him over the years are Lindgren's framework. Culler, for example, has a well-honed faculty for sensing the direction in which R&D must go at any time. He has thereby developed a capability, in his own phrase, for "knowing which way to lean" in providing the personal guidance soon to be felt by EPRI staff and programs.

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An intriguing future in electrical materials carries the EPRI-coined name Polysil.* It's a derivative of polymer concrete with obvious applicability as an insulator. But why "Polysil Shows Promise"

*Polysil is an EPRI trademark.

(page 23) is traceable to more than its innovative character. "We do more perfecting than innovating," says John Dougherty, director of EPRI's Electrical Systems Division, and the result is a remarkable combination of properties that may be useful well beyond the traditional province of porcelain.

Journal feature writer Stan Terra traces EPRI's Polysil development with E. Robert Perry, director of the Transmission Department, who originated and managed the R&D. An old hand in product development, Perry himself holds more than 30 patents for electrical apparatus. He is a former director of research for I-T-E Imperial Corp., and he was earlier with Allis-Chalmers Corp. for 15 years, the last 5 as manager of advanced research and development.

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Future experience is the inherent objective of "Predicting Generating Unit Performance" (page 26). Melvin Lapides suggests that new ways of looking at performance data can reveal new ways to determine and even to improve power plant reliability. Lapides has been involved in various aspects of systems analysis since 1952—at General Electric Co., Ford Aerospace & Communications Corp., ITT Corp., as an independent consultant, and as a program engineer for nuclear systems analysis in EPRI's Nuclear Power Division. He holds BS and MS degrees in chemical engineering from Brooklyn Polytechnic Institute, and he has published more than 50 papers on power plant design and performance.

Searl

Lindgren

Lapides

Energy Supplies: A Look Ahead

By Milton Searl

Domestic resource discoveries are building, but policy constraints may inhibit the flow of fresh supplies.

Are the nation's energy resources running out? Some believe rising prices signal serious resource depletion. Others think the supply shortages that have plagued the nation in the past few years are a warning. Yet a recent study summarizing research in the Supply Program of EPRI's Energy Analysis Department points toward a more optimistic conclusion.

Rising fuel prices and spot shortages will most likely persist throughout this century, according to the study, but not primarily because of resource depletion. Nor will the special difficulties of extracting low-grade resources account for any continuing supply squeeze. The main cause will be the policies of our own and other governments—policies that bear on prices, inflation, and the environment. It is policy decisions, or the lack of them, that could form the bottleneck in our energy supply lines between now and the year 2000.

Hidden assumptions

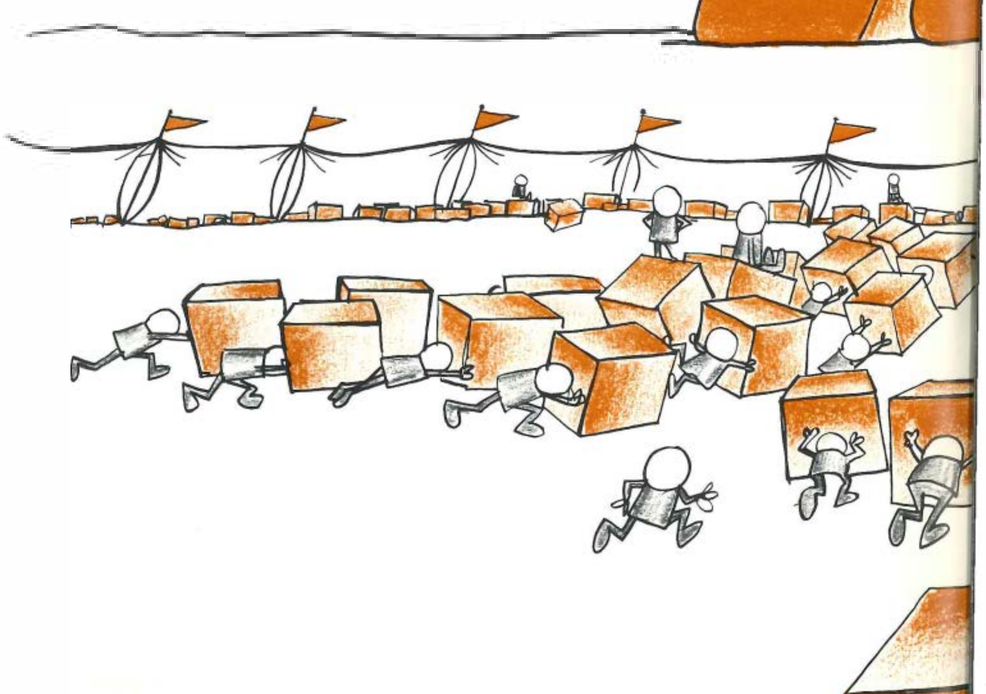
Resource estimates routinely shave the true size of our natural fuel endowment. Almost without exception, existing resource estimates are not estimates of our full resource base but of some lesser amount—an amount usually determined by hidden assumptions about prices, technology, environmental acceptability, government policy, or other constraints. These hidden assumptions about the constraints that can hobble resource development help to account for the tendency toward pessimism that marks many such estimates, as well as the supply forecasts that are based on them.

Some resource discoveries, in fact, may not even be counted. For example, large gas resources in low-permeability formations in the West and in the Devonian shales in the East were ignored for many years, as were large deposits of shallow, viscous oil. It was assumed at the time of discovery that they would never be viable candidates for commercial development. And why not? Because it was assumed that prices would be too low, or the technology inadequate, or the environmental consequences unacceptable. Assumptions of this type often prove false, as they did here. With rising prices, these gas and oil deposits are becoming increasingly commercial.

Bias is inevitable in estimates based on such selective reporting. They project a set of economic, technological, and political constraints that existed at the time of discovery, but may not exist today or in the future. They rule out too many resource deposits on the basis of judgments that are premature.

To clear our resource estimates of this bias, we need to explicitly separate the physical assessment itself from questions of economic, technological, and political feasibility. Only then will we have resource estimates uncolored by hidden assumptions about the constraints on development that may—or may not—come into play.

Sharpening the accuracy of our resource estimates will, in turn, sharpen our supply forecasts. The larger our resource endowment, for example, the longer we are likely to enjoy adequate energy supplies at a reasonable cost. By the same logic, a scanty resource estimate tends to project a pessimistic scenario of rapid resource depletion, serious energy shortfalls, and skyrocketing costs. Knowing how rich our resource base really is can be critical in forecasting our energy future.



Milton Searl is manager of the Supply Program in the Energy Analysis and Environment Division.

Fundamental to the work in the Supply Program is an ongoing effort to build resource estimates that are as complete and unbiased as possible. The further into the future our predictions reach, the more critical this resource factor becomes, particularly in the time frame beyond the year 2000. Once we have a thorough resource estimate to anchor our projections, the constraints can be spelled out and assessed separately. This is the approach that *Supply 77: The EPRI Energy Production Analyses and Forecasts* begins to apply in predicting the pathways of domestic energy supply between now and the century's end.

Supply cornerstone

Primary energy production is the cornerstone of future supply. Crude oil, natural gas, coal, uranium, and hydropower are the primary sources of energy in the United States. These basic forms are generally converted into such higher-utility, higher-value forms as gasoline, heating oil, and electricity before they are passed on to the consumer.

Part of the alarm triggered by the 1973–1974 Arab oil embargo can be traced to the fact that it occurred when our own primary production was sagging. After almost continual growth throughout the nation's history, the output of domestic crude oil and natural gas liquids had

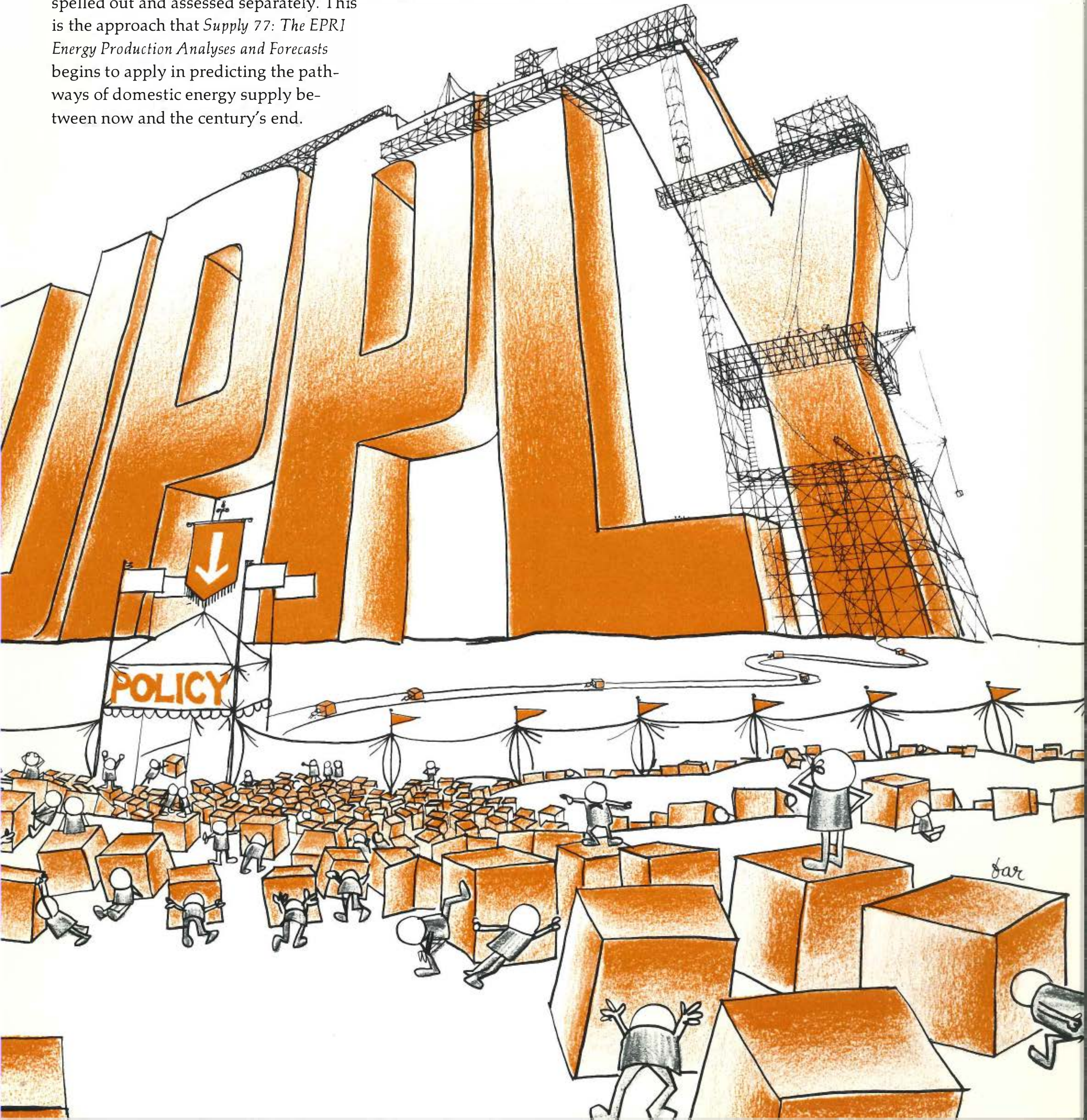


Figure 1 EPRI forecasts a U.S. energy supply of 160 quadrillion Btu per year by 2000, with coal and nuclear assuming an increasing role. Not shown are small amounts of renewable resources that may reduce import requirements.

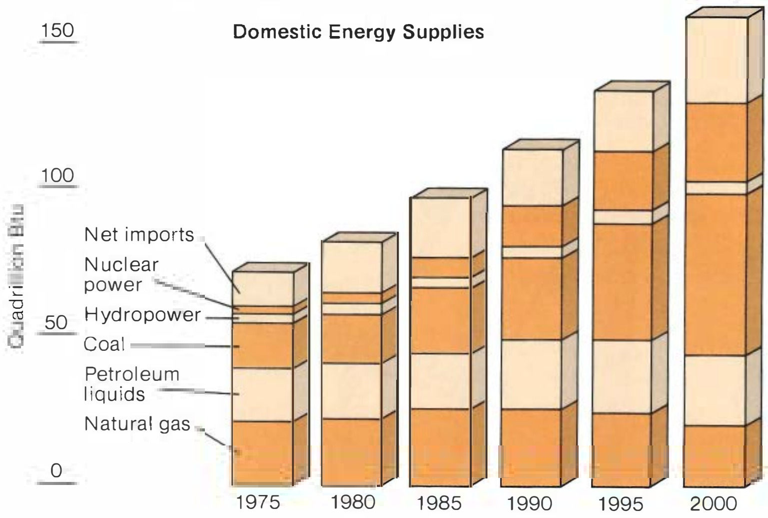
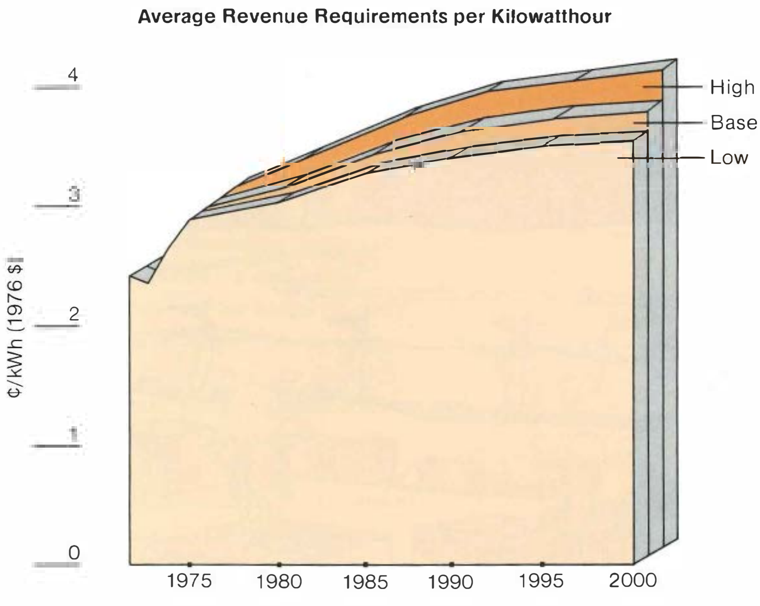


Figure 2 Rate of increase in average revenue requirements per kilowatthour (in constant 1976 dollars) for U.S. electric utilities will be slowing substantially by the mid-1980s. Although the three scenarios—low, base, and high—are not widely divergent, the differences represent many billions of dollars.



begun to decline. Slackening primary production, with consequent shortages, was widely interpreted as a sign of impending resource exhaustion.

Fortunately, the truth was not so simple. The dwindling of domestic output in the early 1970s was not due mainly to dwindling resources. It was due to a complex of man-made conditions: competition from low-priced foreign oil; relatively low prices for domestic production; federal delays in leasing attractive offshore oil and gas areas; and environmental concerns that caused increased uncertainties, costs, and delays in completing supply projects. The Alaska crude oil pipeline is an example of a project beset by most of these man-made constraints.

Rising supplies

Following the oil embargo and the near-panic it triggered in many quarters, new incentives emerged for primary energy producers.

Spurred by the prospect of higher prices, domestic suppliers in 1974 reversed a 16-year decline in new drilling for oil and gas. Exploration and development of uranium reserves surged, despite the uncertainties clouding the future of nuclear power. And new coal mining ventures sprang up at a vigorous pace, particularly in the West.

Because it takes time for new programs to get under way, the payoff from all this activity has seemed painfully slow in coming. And some observers have been discouraged by the trend of poor oil and gas yields from the past few years of increased drilling. But current yields are only the beginning. They tend to be low because they come from the development of areas with known low-grade resources that were uneconomic to tap at lower prices.

The real payoff will come from entirely new exploration programs focusing, for example, on deeper drilling and offshore sites. Some of these newly discovered deposits are proving more prolific than might have been expected and are yielding larger amounts of crude oil and natural gas. *Supply 77*'s relatively optimistic forecasts of domestic energy production are based on the expectation that more such discoveries will occur.

Considering the lead times usually required to translate production decisions into new supplies, the response of energy suppliers to postembargo price incentives has been rather rapid. Supplies have already begun to swell. Figure 1 is a breakdown of how domestic energy production is expected to continue expanding between now and the year 2000.

Petroleum liquids

Oil production is expected to bottom out in 1978 (even without considering yields from Alaska's North Slope). Postembargo decisions to launch new exploration and drilling programs will produce results this year, bringing the long decline in domestic oil production to an end. Following the leveling-off this year, the forecast is for gradually increasing production through 1995.

This forecast assumes that crude oil will be priced at the level proposed by President Carter. The president's proposal would allow that portion of domestic output defined as "new" to approach the 1977 price of world oil (about $13.50 a barrel) by 1980. Thereafter, the price would be held constant at that level—allowing, of course, for adjustments required for inflation. Most other vintages and categories of oil production would receive generally lower prices than new oil.

If actual prices turn out to be higher than those assumed, thus providing a further incentive to suppliers, production will probably increase further. The reverse is also true. If prices fall, production will probably sag.

As the century nears an end, oil production will begin to taper off, although higher prices and improved recovery technology could defer this decline for a decade or more. The domestic burden of supplying the nation's needs will have shifted from oil to coal and nuclear power.

Natural gas

Natural gas, like oil, will have supply increases over the near term, with declines later in the century. The increase will run through about 1990. Then, unless prices rise higher than expected, production rates will reverse and fall back to around 1975 levels by the year 2000.

For this analysis, the wellhead price of new gas has been assumed to be $2.00 per thousand cubic feet after 1980. This price was chosen as the likely result of a compromise between the president and Congress, despite the president's initial price recommendation of $1.75. As with oil, older vintages of natural gas would receive lower prices.

Natural gas production, like other forms of primary energy production, is assumed to be responsive to price. In other words, higher prices could reasonably be expected to buoy production to higher levels.

Coal

Increased coal production is a major hope for promoting domestic energy self-sufficiency. *Supply 77* projections indicate coal's share of the domestic energy supply surging from 26% in 1975 to 42% in the year 2000. (This share would be even greater if all coal were used domestically and oil imports were reduced.)

Bringing about the predicted 5.2% annual growth in coal output will require vigorous effort—an effort that will prove easier if the administration continues to stress the development of domestic coal resources. Coal will also have to capture a far wider market to support this level of production. One-half of the nation's total increase in baseload electricity generation will have to be fueled by coal. And coal will have to carve out a strong industrial market as well, in addition to expanding its sales overseas.

Uranium

Installed nuclear capacity is predicted to increase from 43 GW at the end of 1976 to 380 GW by the year 2000. Achieving this jump in capacity will hinge on two important conditions: the rate of orders for new plants must increase, and the time needed to get them on-line must decrease. *Supply 77* predicts that both these changes will occur soon enough to raise capacity to the projected level by the century's end.

So far, nuclear power has been constrained by many factors, holding capacity growth below original expectations. However, an explicit part of *Supply 77*'s output prediction is the judgment that public acceptance of nuclear power will grow as its costs and risks are weighed against its benefits. Uranium supplies from domestic and perhaps foreign sources should be adequate to support nuclear growth, although there may be brief periods of both short and excess supply.

Supply 77 does not specifically estimate the role of new technologies that will draw on virtually inexhaustible power sources such as sunlight, ocean waves, and heavy hydrogen. Whatever contribution these can make during this century will come as a welcome boost to our domestic energy output. But the main weight of meeting the nation's needs between now and the year 2000 will fall on those technologies that already exist to produce and use energy resources. And this means continued use of oil, gas, coal, and uranium.

Fueling electricity growth

What will this fuel supply picture mean for the electric utility industry? Will the fuels necessary to support the projected increase in electric power generation between now and the year 2000 be available? And at a reasonable cost?

Supply 77 projections are again favorable. Fuel will be available and at only gradually increasing costs. Of course, vastly increased fuel consumption will be only a part of the cost of roughly tripling the output of electricity. Also of concern will be the mix of generation, transmission, and distribution technologies to be used in the future. Labor and capital may well be expensive. Furthermore, there may be shortages of capital, water, and environmentally acceptable sites.

The combined effect of the various forces acting on electricity supply expansion are reflected in projections of average revenue per kilowatthour. Figure 2 shows average revenue requirements up to the year 2000 in constant 1976 dollars. (Prices in current dollars depend on the rate of inflation that is assumed; they are not shown here, although they are discussed in *Supply 77*.) These constant-dollar prices were calculated in terms of projected utility costs —a combination of fuel costs, operating and maintenance costs, and capital costs. It was assumed that there will be no changes in regulatory or accounting practices.

As shown, real electricity prices will rise less rapidly in the future than they have in the recent past. The greater part of this increase, furthermore, will occur before 1985. After 1985, if currently planned new capacity is in place and the rate of growth is slowing, the pinch on utilities and consumers alike should begin to ease. Overall, the forecast is for rapid but reasonably orderly expansion of electric power supplies between now and the year 2000.

A word of caution, however: While the electricity price curves projected here are fairly insensitive to the relative proportions of nuclear and coal-fired capacity in the generating mix, they are based on the assumption of a substantial contribution from both nuclear and coal-fired plants. If, in reality, a high-nuclear–low-coal or a low-nuclear–high-coal mix should be the case, increased pressure on costs could result. Balanced development of both nuclear and coal-fired capacity will probably provide the smoothest avenue of growth.

Will it be enough?

Primary energy production will expand vigorously between now and the year 2000. So also, down the line, will the volume of electricity supplied directly to the nation's consumers. But the critical questions remain: Will it be enough? Can it keep up with the anticipated ballooning of energy demand? The sobering answer is: Almost, but not quite.

Domestic energy production is expected to grow at an average annual rate of 3.1% between 1975 and 2000, but this is slightly lower than the 3.2% growth rate in energy consumption assumed in *Supply 77*. As a result, the conclusion is that import needs—primarily our dependence on foreign oil—will continue to grow throughout the century.

This increase will occur both in absolute terms and as a percentage of domestic consumption. With total demand jumping to nearly 160 quadrillion Btu in the year 2000—more than double today's level—imports will also more than double. This translates to yearly imports of nearly 30 quadrillion Btu by the century's end, compared with 12 quadrillion Btu in 1975. In percentages, Americans who relied on foreign supplies to fill 16% of their energy needs in 1975 will depend on imports for 19% of their needs in the year 2000.

Outlook for imports

Even with greatly increased levels of energy production, we seem to be slipping further away from the goal of national self-sufficiency. This is the disquieting side of our supply-demand picture. The encouraging news is that foreign sources on whom we must depend will probably be capable of supplying all the energy we need through 1995 at only moderately increasing real prices, although the outlook beyond 1995 is less clear.

The *Supply 77* study does not deal directly with world energy production and the availability of fuel imports to the United States. However, other EPRI-sponsored research on world energy supply and demand points to plentiful sources of energy, mainly in the form of petroleum, on the world market (EA-745).

The world's undeveloped natural gas resources are also very large. High costs will probably limit development over the next few decades, but large amounts could be available by the year 2000 if we are willing to pay the price. And still other research reveals that prospects for foreign uranium production are also favorable after 1980, raising the prospect of imported fuel for expansion of the nation's nuclear energy supplies (EA-725).

The policy pivot

Are we running out of energy resources? For the time between now and the year 2000, the answer is clearly no. The growth projections for domestic energy production are generally robust, although the failure of supply to keep pace with demand and the increasing reliance on imports could lead to larger problems over the long term.

Prompt launching of a national energy policy to stimulate energy development could yield far more abundant supplies than *Supply 77* now predicts. At the other extreme, supply prospects could shrivel under restrictive policies.

Federal and state policies that continue to restrict the growth of nuclear power, limit coal development, deny leases for development of promising oil and gas areas, delay the siting of power plants and transmission facilities, and prevent energy prices from finding a level in keeping with the costs and uncertainties of investment may be consistent with certain of society's goals. But such policies could result in levels of energy production in the year 2000 that are little higher than those of today and substantially below our future society's level of needs. Over the period between now and the year 2000, the determining factors in energy resource development are more likely to be political than physical.

There is no domestic resource shortage, nor will there be one in this century. The extent to which our resources can be converted into usable energy supplies, though, will largely depend on the policy decisions emanating from our state capitals and from Washington.

Civex: A Diversion-Proof Plutonium Fuel Cycle

A proposed new technique for recovering energy-laden materials from spent nuclear fuel would remove any danger that they might be stolen by terrorists.

Perhaps the public concern most significant in slowing nuclear power development has been the charge that the planned extraction of plutonium from spent nuclear fuel would provide an opportunity for theft of material from which a nuclear bomb could be made by terrorists, international outlaws, or nations suddenly adopting a militaristic policy.

The Civex process is a concept that securely plugs this loophole—and thus completes the decoupling of civilian nuclear power from the military resources of nations—by making it technically impractical as well as economically undesirable to divert plutonium from nuclear power facilities.

Background of diversion issues

There are two fissile materials in use today for power generation: plutonium and uranium. When plutonium is a byproduct of reactor operation, it is a highly efficient fuel but is in a weapons-usable form; uranium is potential weapons material only if it has been concentrated to at least 40% in the fissile isotope. This fissile isotope, ^{235}U, is a rare form, occurring worldwide in the proportion of only 0.7% of refined uranium metal. The remaining 99.3% of the metal is nonfissile ^{238}U.

In an operating reactor core, some of the ^{238}U is transformed under radiation to ^{239}Pu—not because the reactor is designed to do so but by the nature of the process.

The U.S. government has built vast gaseous diffusion plants to concentrate (enrich) uranium in the ^{235}U isotope for the national defense program as well as for civilian power. However, commercial nuclear power plants use uranium that has a concentration of only 2–4% ^{235}U. As a result, separated plutonium requires stricter physical security and accountability controls than does slightly enriched uranium as the two metals progress through the processing steps in the commercial nuclear fuel cycle.

To date, very little commercial fuel has been reprocessed. Originally, it was contemplated that plutonium from spent power reactor fuel would be refabricated into new fuel for use in the existing light-water reactors (LWRs) or in the fast breeder reactors (FBRs) planned for the future. However, the present administration, shortly after it took office, imposed an indefinite moratorium on the reprocessing of spent fuel. The administration acted on the basis of four assumptions.

- Nuclear power outside the United States is growing rapidly.
- Stocks of uranium ore are now ample to feed existing reactors.
- Reprocessing nuclear fuel by the Purex process, which involves separating the plutonium from the unfissioned uranium, has a potential risk of diversion.
- If the United States stopped reprocessing, it would support the argument with other nations that reprocessing is now uneconomic and unnecessary.

Based on these assumptions, the administration's policy is to discourage reprocessing and to remove access to weapons-usable plutonium by "have-not" countries. Moreover, it sets an example to support the once-through use of nuclear fuel. This would mean no recycling of spent fuel—fuel discharged from power reactors would be treated strictly as waste. This would be done despite the facts that the volume of unreprocessed spent fuel is about 16 times greater than that of reprocessed waste and that vast reserves of potential plutonium fuel, which constitute a national energy resource, would be buried as waste.

A result of this policy was that the fast breeder, which cannot operate without plutonium feed from reprocessed fuel, became a victim of the nonreprocessing policy and the moratorium on reprocessing.

The authors of the nonreprocessing policy hoped that it would buy time, perhaps decades, during which international diplomacy might be used to solve the diversion risk problem.

It was in response to the administration's request for further study of the matter, and against this background, that the Civex process was conceived.

Announcement and support

Civex is a proposal of two leaders in nuclear power development: Dr. Chauncey Starr, president of the Electric Power Research Institute, and Dr. Walter

Marshall, Deputy Chairman of the U.K. Atomic Energy Authority. They coined the name Civex by analogy with the Purex reprocessing technique and to emphasize the former's civilian nature. It was intended that the Civex concept would be of interest to all governments and would result in further investigation and eventually a demonstration plant to prove the Civex process.

In formulating the concept the two men consulted widely with their colleagues in many countries, but they emphasize they are not speaking for their respective organizations or governments. They are supported in their proposal by their colleagues, principally Floyd Culler, Milton Levenson, and Edwin Zebroski of EPRI; R. H. Flowers, K. D. B. Johnson, J. H. Miles, and R. K. Webster of Harwell Laboratories of U.K.A.E.A.

Two days after Civex was announced at a technical conference in Washington, D.C., a subcommittee of the House Science and Technology Committee voted to add $15 million to the DOE budget for FY79 to work on the Civex fuel cycle. The Civex cycle will also be included for study by the 40-nation International Nuclear Fuel Cycle Evaluation (INFCE) study group launched at the suggestion of President Carter.

The Civex process

The basic objective of the Civex process is to close the loophole for plutonium diversion by not separating plutonium in a Civex reprocessing plant. Diversion by altering a plant's mode of operation or by quick modification of its equipment would also be impossible—there would never be the capability for producing pure plutonium or weapons-usable nuclear material anywhere in the system.

In contrast to the Purex flow sheet that produces three product streams—pure plutonium, pure uranium, and all the waste products—the Civex process separates out the bulk of the wastes, leaving a small percentage of the wastes with the uranium and plutonium in such dilute concentration that they are useless for weapons purposes. The reason for leaving some of the waste with the reusable nuclear fuel material is to maintain its radioactivity. This would make it physically unapproachable. Pure plutonium emits only relatively weak alpha rays and can be handled with rubber gloves, but the gamma radiation from the waste left with the fuel in the Civex process is strong enough to be immediately debilitating and lethal in 4–48 hours.

Thus the novelty of the Civex process is that it does not separate out plutonium, makes it impossible to do so, and maintains radioactivity deliberately so that it may be handled safely only by tools remotely operated from behind several feet of concrete shielding and heavy quartz windows. Civex also departs from presently planned practice for nuclear fuel by combining in a single facility the spent fuel reprocessing and the refabrication from recovered material of new fuel, thereby eliminating the transportation of plutonium from reprocessing plant to refabrication plant. It combines the frequently proposed individual concepts of coprocessing, coprecipitation, spiking, and colocation into one physical facility.

This principle was demonstrated in the 1960s in the Fuel Cycle Facility attached to Experimental Breeder Reactor No. 2 (EBR-2) in Idaho. That facility took spent fuel directly from the reactor into concrete process cells, reprocessed it, refabricated new fuel, and returned that new fuel directly to the reactor—entirely by remotely operated machinery and tools. The facility operated for five years and made five complete cores for EBR-2. During that time, no one entered the process cells. The facility also contained remotely operated maintenance equipment and tools for repairing the automated machinery or the tools themselves.

Reopening the breeder option

While in principle the Civex process can be designed either for the LWR or the FBR fuel cycle, the concept is better suited for the FBR cycle because one of the basic elements of Civex is keeping a few percent of radioactive waste (fission products) together with the reclaimed uranium and plutonium from which new fuel is fabricated for return to the reactor. The physics of the two types of reactors is such that FBRs are quite insensitive to the presence of fission products, whereas LWRs are not so tolerant. In addition, the radioactivity level of spent FBR fuel is much higher than that of LWR fuel.

Proponents see Civex primarily as a link in a new, diversion-proof cycle in which Civex reprocessing plants would take spent fuel from LWRs and FBRs and produce new fuel for FBRs. Thus Civex could be a key to bringing about the acceptance of FBRs. It would thereby ensure a large future supply of electric energy, using a fast-reactor technology that has already been demonstrated in the United States and abroad.

The incentive for developing the breeder is to extend uranium supplies. For example, an existing 1000-MW LWR operating at 75% capacity factor requires the mining of about 630 kg (1400 lb) of uranium for each day of normal operation if the spent fuel is not reprocessed and recycled, and only about 400 kg (880 lb) if the fuel is reprocessed and the uranium and plutonium recycled in LWRs. However, if that same spent fuel is reprocessed for use in a 1000-MW breeder, that breeder requires no new uranium if both the uranium and plutonium in the spent fuel are used. This shows how much stored energy is contained in the spent fuel and how much more energy—about 60 times more, compared with uranium recycle in LWRs—can be extracted from a given quantity of natural uranium if it is recycled through an FBR.

Thus Civex would have a beneficial effect on world energy supply by removing the threat of plutonium diversion from the fast breeder fuel cycle and extending the energy content of our uranium supplies by 60 times. This is why the FBR is a top priority in France, the U.K., West Germany, the USSR, and Japan.

Timetable

As all the component stages of the Civex process have already been proved in laboratories or pilot-plant operations here and abroad, it is estimated that it would take about 10 years to carry out the necessary preliminary studies and design, build, and operate a demonstration Civex plant. This is no more than the time it would take to bring on-line a demonstration utility-scale FBR. Thus the two demonstration projects could be carried out in parallel, and a complete system might be ready for deployment in 10 years.

To electric utilities, the credibility of the long-term expansion of nuclear power depends on a program that reduces the uncertainty of uranium ore availability and enrichment capacity. The indefinite deferment of the FBR was a consequence of the hoped-for deferment of worldwide fuel reprocessing. But that has not happened and it is clear that it is not likely to happen. Most industrialized nations see nuclear power, reprocessing, and the breeder as essential to their future.

By 1985 some 500 nuclear power plants are expected to be in operation worldwide, only one-fourth of them in the United States (although until last year the United States had more power reactors in operation than all the rest of the world combined). No doubt the use of nuclear power will continue to grow as each nation moves toward low-cost-energy independence.

Recommended policy

It is now in the best interest of the United States, both domestically and for its foreign relationships, Starr states, to lift restrictions on reprocessing and breeder development and to encourage the development of a fully integrated system, combining LWRs, Civex reprocessing, and FBRs. Such a program could diversion-proof civilian nuclear power, thus assisting in the international prevention of weapons proliferation. It would restimulate U.S. utility industry confidence in nuclear power.

During the two or three decades of transition until a Civex-FBR system is fully in place, the "have" nations would guarantee to supply nuclear fuel to the "have-not" nations and would take back the spent fuel they had supplied. This could either be reprocessed or stored until the demand for FBR fuel increases. The return to the United States of spent fuel would increase the need for long-term storage capacity or for plutonium separation, presumably in existing chemical facilities. Such separated plutonium might be stored for future breeder fuel inventory or recycled in LWRs if the economics justified. The safeguards required for such separated plutonium are relatively easy—as 33 years of incident-free history attests.

Should the moratorium on reprocessing continue, plutonium would be the longest-lived component of the spent nuclear fuel to require storage. With plutonium removed from the radioactive fission products, they would decay in about 600 years to a point where the total radioactivity would be less than that of the uranium ore originally mined. As the nuclear industry has often suggested, the safest way to dispose of plutonium is to "incinerate" it in a reactor to produce electricity.

Meeting Floyd Culler

by Nilo Lindgren

On May 4, at the annual meeting of the Board of Directors, Floyd L. Culler, Jr., formally takes office as the president of the Electric Power Research Institute. He succeeds Chauncey Starr, who becomes full-time vice chairman of the Board.

When Floyd Culler's appointment as the next president of EPRI was announced last September, there was a surge of speculation about the man who was known to have had a very distinguished career at the Oak Ridge National Laboratory but who, despite deep involvements in the nuclear energy field, was not well known in the utility industry.

There were immediate questions about the man and his work and why he had been selected to lead EPRI in its next phase of development. What perceptions and strengths would he bring to the technical and other issues facing the utility industry?

There was also frank curiosity about the fact that Floyd Culler had spent 33 years in one place—Oak Ridge—a remarkable phenomenon in an era when job hopping and professional career jockeying are the norm, especially in high-technology fields.

That fact suggested to some that Culler was an "inside man," one who concentrated on inward-looking management. This led to the view that Culler would take a vigorous role in consolidating the EPRI organization. The assertion by Frank Warren, chairman of the Board, that "Floyd Culler is going to run the shop" appeared to confirm that view. It was in accordance with the Board's understanding of Culler's responsibility, and it reinforced the stated distribution of respon-

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sibility—that Chauncey Starr would deal more and more with national and international energy issues. Thus, Culler and Starr might be perceived as having naturally complementary roles in the years just ahead in grappling with the varied and changing problems now facing the utility industry.

The problems, as Frank Warren points out, "go far beyond just the national problems in the United States. The technical matters of nuclear power, waste processing, breeder reactors, and the driving forces that emerged from the Middle East oil embargo are problems international in scope." What the utility industry hopes the new president will bring to the solution of these problems could be an indication of its perception of the future and how EPRI's role in nondomestic issues should be shaped.

An initial sense of Floyd Culler in the larger arena comes through in his testimony before the U.S. House of Representatives' Committee on Science and Technology last June. Speaking on the objectives of U.S. energy policy, Culler says of President Carter's concern with nuclear weapons proliferation: "We applaud his willingness to propose actions that are based on moral principles rather than expediency. We are coming to expect it of him and we admire him for it. The president has signaled that the time has come for the nations of the world to decide how to use nuclear energy for production of power when confronted with its potential for destruction. This is the great confrontation that we have put off since the good and evil faces of nuclear energy became apparent in the 1940s."

Although it surely was not a primary criterion for the selection of a new EPRI president, Culler's background and widely acknowledged expertise in nuclear reactors, fuel cycles, and waste management is hardly a handicap. At Oak Ridge he was responsible for R&D in most parts of the fuel cycle and recycle. He has managed huge projects—through design, development, and construction—and is acquainted with all phases of reactor technology, such as burners, advanced converters, and breeders. And, as one talks with him, it is soon apparent that his range of scientific knowledge and interests is far wider than his curriculum vitae might imply.

His connections with official Washington and his major awards and memberships also clearly attest to his accomplishments. He is a member of the Scientific Advisory Committee to the International Atomic Energy Agency and a member of the National Academy of Engineering; he has served on advisory councils to the U.S. Environmental Protection Agency and the U.S. Department of Health, Education and Welfare, among others. Last year he served as a member of ERDA's Liquid Metal Breeder Reactor Program Review Committee, requested by President Carter and Dr. Arthur Schlesinger, and according to a number of accounts, took a leading role in its work.

If anything, Culler's reputation as being deeply identified with the nuclear field, and his known pro-breeder position, may, in the view of some former Washington officials, make it "a little tough going" for Culler. And others—who see him coming from what they describe as a "kneejerk-reaction nuclear community"—could be concerned, for instance, with his views on solar and other renewable energy resources. To the contrary, his support of work in these areas is unequivocal (page 20).

There is another side to Culler's reputation that also accompanies his record of technical accomplishments: all those who have known him and have worked with him testify to his warmth, his availability and human concern, his honesty, and his deep integrity as a person. What one hears is that he is not only deeply respected but also loved by his colleagues.

The selection process

The selection process, Shearon Harris, former chairman of the EPRI Board, tells us, was long and thorough. All candidates were carefully evaluated according to their strengths in various categories. "Floyd Culler," says Harris, "was one of those we felt had the highest qualifications in all categories being judged . . . and eventually, after some extended personal interviews, it evolved into a clear-cut decision."

Some of the categories of qualifications included scientific education, the perception of the individual in the scientific and educational communities, experience in congressional testimonies and public presentations, reputation in the international community, and the degree of exposure to actual management of R&D activities. "We could find, for example," says Harris, "a great scientific-and-engineering–trained university president who had vast experience at administration but who had never managed an R&D project!" And, he concludes, in response to the question of whether or not someone was wanted who could hold a tight management rein, "I would say at this point in EPRI's relationship with its constituents, *management capability* was the top qualification."

Chauncey Starr's own summary of the qualifications is much more brief. "I had one general criterion," he says with a burst of laughter. "He could do everything I could do, only better!"

In a more serious vein, Starr has said of Floyd Culler, "He is one of the outstanding R&D administrators in the United States. I think he'll be a tremendous asset to EPRI and add a very considerable strength to our growing operation. His technical leadership at Oak Ridge has probably made it one of the very significant contributors to the development of nuclear power."

Why EPRI?

One of the many questions one asks Floyd Culler is why, after his many years at Oak Ridge—during which time he helped build one of the largest and most diversified national laboratory facilities in the country, and also received numerous offers to take positions elsewhere—did he decide to leave and to accept the presidency of EPRI. Why, unlike most professionals, did he stay so long in one place and then decide to leave after such a career investment?

"I will tell you why," he asserts with conviction, "I love Oak Ridge, and I love the people there. I know that now, and have for a long time. But I decided a few years ago that it would be fun to try something totally unfettered by a direct association with the federal government, something where the restraints and controls are different from those encountered in connection with government agencies.

"Not that I've had trouble with AEC, ERDA, DOE, or other agencies," he is quick to add, "but in management of government-sponsored work, you can become too far removed from the scientific and technical content of the R&D program. To avoid such dissociation, I have declined opportunities to take management positions in Washington. I think that's the wrong direction to go, for me. It is the right direction for power, perhaps, but the wrong direction for increasing knowledge and understanding.

"The most compelling reason for staying at Oak Ridge for so long is that I find that I enjoy being close to the working phase of development," Culler explains. "I need to be associated with a broadly informed, expert group to be effective, and personally comfortable, in managing R&D. In my opinion, there is no laboratory in the world with the scope and depth of R&D that exists at Oak Ridge."

So, over the years, Culler did not really think seriously about leaving Oak Ridge to take any of those jobs in Washington or elsewhere. But EPRI was another matter. "It is too marvelous an opportunity," he says, "to work with essentially the same kind of people, the same spread of thought, with about the same scope of R&D, and to do something very important in the energy business that the government cannot do!"

Taking the initiative

Culler's view is that government, because of its conflicting roles as R&D sponsor and regulator, cannot take the initiative in the energy field as easily as the private sector can, despite the impediments and difficulties facing it. "The government cannot become the strong advocate of a particular technology, much less a particular process."

Defining what initiatives need to be taken by the private sector is part of what Culler sees as an important function of EPRI in the next decade "in order to make sure the country doesn't go bankrupt because of energy." Thus, improving the understanding of the relationship between energy and the economy, nationally and internationally, is an important background, in Culler's view, for making the wisest choices for energy supply, conservation, and environmental protection.

In talking about that initiative, Culler describes how it is the essential ingredient for guiding and managing research. "No one ever *gives* initiative," he says; "the research manager must find where it should be *taken.* Many people don't like to take initiative because by so doing they are exposed . . . and they don't like being vulnerable. So anybody, and any R&D organization, who does take the initiative, after an intelligent review of options, . . . will succeed. The initiative must be taken by actively blunting or working around institutional impediments, if they threaten to stop the action, and the action must be taken without unsettling the society."

What must be done, Culler seems to argue, is to find the right balance between public and private interests, to moderate the necessary changes ("so that utilities don't lose money or vex customers while keeping the grid reliably supplied"), and to define the new initiatives. What he argues for is the preservation of the "good of the older structure, while blunting those forces that could prevent a new solution—*the* solution—from having a reasonable chance for success."

And then, in a statement that reveals part of his style of doing things, Floyd Culler says, "I prefer not to battle for the initiative . . . at least not by a confrontation . . . but rather, I would let it emerge slowly as a white hope." It is at once a statement of belief and strategy.

"Choosing what to do in R&D and how is always an uncertain business," Culler points out. "There are usually no evident paths to successful choices, no master plan for selecting either the problems that may return the greatest benefit if solved or those that are likely to yield to solution. In managing R&D it is important to sense the general direction in which development must go and to favor that direction," Culler says.

"After years in R&D, I usually know the way to lean," he asserts emphatically, leaning his entire body as though pushing a great weight that must be moved. "I know the way to lean! Directing R&D requires leaning toward a solution, but not an irrevocable commitment; this is particularly true in research. At the edge of understanding, when you don't know what's there on the other side of ignorance, you acquire knowledge slowly and see little beyond what is reported each morning. There is a very sharp dividing line between knowledge and conjecture. Being led by the information, leaning, is the essence of management."

Culler goes on, "I have grown accustomed to being close to the edge most of the time. I can't know beyond the boundary of knowledge, but I do usually have a sense about the direction I want to lean in, and how to take advantage of the things that have already been developed . . . as a foundation for learning." His description evokes a sense of titanic but zestful struggle.

"This obviously means that I have in mind no detailed master plan for solving the important problems on which we are and will be engaged," Culler cautions. "But I do know what solutions are required and what resources are available for use in their solution. And I know that it is essential to have a set of principles to guide the directions one chooses and the excellence one hopes to attain. These principles perhaps may never be explicitly stated, but they underlie—like simple questions of right and wrong, of equality and fairness—one's vision of the future, and what may be needed in the future. This vision is as important as the awareness of what is currently happening, of current research results: it, along with current observation of results, establishes for me the direction for leaning.

"A master plan for R&D only charts the means of executing work after the overall directions are established. To establish directions within an organization, a structure of thought, evolving with input from many, has to be maintained. From this substantive knowledge, the directions in which to send new probes can be chosen, knowing that not all of them will pan out.

"Some people think R&D moves us from one equilibrium state to another, but equilibria do not exist in the real world; there is constant change. So we need a lodestar, a vision of the future, to set directions; and a constant awareness of which way the wind is blowing or the tides are running, or how the motors are behaving, to constantly correct our course.

"Institutions such as Oak Ridge and EPRI are necessary to help form the visions and to provide the active sense of direction needed, through R&D initiatives. It is necessary to have tentacles out . . . to sense what changes are occurring, so that you know the way you want to lean, and the direction you want to go."

On managing research

Given the vision, how does the manager keep the immediate objectives clearly in the foreground in a practical, moment-by-moment way, without getting his own identity as a manager involved in the work? That is, how does he *manage?* Culler's answer is that "a manager should always be part of the thinking process in R&D but should take care to define objectives only when there is reasonable agreement among informed researchers that the objectives are correct. During the debate that leads to decision," he says, "the manager should act as just one other participant. In that role, when you are winging it with everyone else, being educated by the flow of ideas, you experience the very real joy of planning and synthesis, of corporate thought. But at the end of discussion, when the time comes to choose, the manager must make clear choices from among the options that have been offered."

However, there are times, Culler concedes, when the path to be taken is quite clear and the steps to workable solutions are evident. Then he sees the manager's role as one of "gently steering" and struc-

One of the most striking features about Floyd Culler is his capacity for expanding into your space and feeling what you feel. He acknowledges that he works out of such an awareness. "When I am talking with people," he says, "I think I know when I am communicating well, because I can *feel* the other person's response. I can feel their presence and, as it were, a return set of thoughts." As a consequence, Culler goes on, the kind of management he likes best "is a very personal one, . . . based on a mutual bond of personal respect, in which we know one another's strengths and weaknesses and can relate without being critical of one another, only of the things with which we are dealing. This way, hopefully, it is possible to work objectively on technical issues—even to disagree violently—without wounding one another or losing a jot of mutual respect."

turing the discussion.

After directions are established and the plans are made, Culler continues, the manager must make sure that support is obtained and that the work is "carefully monitored so that people know approximately what they are expected to do and when. They must be made aware of whether they are doing reasonably well or poorly." But, Culler stresses, if it is poorly, "in a way that is not injurious to confidence and personal esteem."

Like most professional managers, Culler wants people around him who know much more than he does. "When a person is working in an area of technical specialty," he states, "I expect him to know much more than I do, and to cover the span from reasonable fundamentals to very practical knowledge."

Personal growth

The theme of knowledge and continued learning reappears in many forms as one talks with Floyd Culler. One of the attractions that held him for so long in Oak Ridge is the breadth of the sciences and technologies represented there, a fact that may surprise those who associate its work only with nuclear energy. "Over a period of time," says Culler, "both through advancing responsibility and just out of plain curiosity, I was exposed to much of what was going on in science at Oak Ridge."

During the World War II years, with a background in chemical engineering (he earned his BS at Johns Hopkins in 1943), Culler became deeply involved in nuclear fuel reprocessing and waste disposal—a field in which he is acknowledged as one of the leading experts. By the time he was 23, he was already involved in building chemical plants and uranium mills and in heavy engineering. "We learned fast," he says, "and had a chance to do things while young that most people will never get to do."

In 1947, after what in Oak Ridge are called the "Y-12 years" (named after the great section of valley where the first huge electromagnetic separation plants were built and operated), Culler moved to the Oak Ridge National Laboratory (ORNL) as a design engineer. At ORNL, a federal installation that is professionally managed for the government by the Union Carbide Corp., he was one of the few people who was given the opportunity to move for a year throughout the labs, working where he wished, and attending lectures by many of the outstanding people then in Oak Ridge, such as physicist Alvin Weinberg, director of the laboratory, and by Dr. Eugene Wigner, former director of ORNL and Nobel-prize physicist who is now at Princeton, and others. His own responsibilities grew as he was advanced to section chief, then director of the Chemical Technology Division, before being named Assistant Laboratory Director in 1965 and deputy director in 1970. During 1973, Culler was acting director of ORNL.

Generally, after the war effort, ORNL concentrated its energies on different kinds of reactors and on improved fuel cycles, waste disposal, and the basic sciences. By the mid-1950s ORNL began expanding its interests, and Culler's interests grew apace. A major thrust in the biological sciences grew out of concerns with radiation effects on living systems. A kind of landmark came in the late 1950s when ORNL began working for other agencies, and it started evolving into a "truly national laboratory." In the late 1960s, with the groundswell of environmental concerns in the country, ORNL became involved broadly in environmental work and had one of the largest groups of ecologists in the world, working on projects for the National Science Foundation, EPA, AEC, and others. The 1970s marked another stage, with work in end uses, improved energy systems, and conservation for NSF, HUD, FEO (which later became FEA), and ERDA. Work on coal liquefaction was also started. Later, work was begun in geothermal, solar, and other aspects of conservation R&D. These activities for outside agencies now constitute perhaps 10 to 15% of ORNL's total R&D budget.

Thus, through the years, one engineer-

From his years of experience with government-sponsored and -managed energy R&D, Culler is convinced that the government does "a rather good job, probably far better than most people give it credit for in research and development." But, he argues, "the government cannot easily take the initiative in the energy problem, because to do so it would have to be both advocate and regulator in the long run, a dual role that cannot be played. Thus, although advocates and leaders can develop within the government, their initiative tends to be constrained by the regulatory process."

ing and scientific field led Culler to another. Work with uranium led to his interest in geology, concerns with radiation effects led to biology, interests in fusion led to high-energy physics, and so on. For the past two years Culler has been working on broad energy-option questions in connection with CONAES (the Committee on Nuclear and Alternative Energy Systems, cosponsored by the National Academy of Sciences, the National Research Council, and the National Academy of Engineering). And CONAES, he says, has brought him in touch with other fields in which he had not yet gained experience, such as petroleum and geothermal energy.

In retrospect, now that he has become president of EPRI, Culler seems to see his involvement in CONAES as a very fortuitous preparation for an even broader perspective on energy technologies.

But CONAES was only the cap on 30 years of continual expansion, about which Culler remembers best the "marvelous support" of others, and of working in a location where he could reach experts in almost any field in a matter of minutes.

"I am comfortable," he says, "working in a place like ORNL—and like I think EPRI is—where there are enough people around to talk with, where we can decide together what is important and what is not. We can jointly plan and decide how to implement development, while making sure that the management structure is clearly established and working well. I think that I would be lost without a big collective intelligence—a corporate brain—surrounding me."

How Oak Ridgers see Floyd Culler

As a young chemical engineer, Culler participated in the gradual diversification of ORNL, and as his responsibilities grew, he was seen more and more as an initiator and pusher of further diversification.

Of this role, Joseph Lenhard, director of the Research and Technical Support Division in the DOE Oak Ridge operations office, serving as the contract officer between ORNL and its customers (such as DOE), says incisively: "Floyd has an image as the idea man. Everyone thinks of him as Mr. Fuel Cycle and Mr. Nuclear, but we don't have in Oak Ridge a man who is better acquainted with the total energy picture than Floyd. He is an idea man not only in nuclear but across the board."

Don E. Ferguson, a chemical process engineer who succeeded Culler as Director of the Chemical Technology Division and who has worked closely with him for 25 years, confirmed this view. "Floyd has always been a very good person to work for. He has lots of ideas, and it takes a small army to follow Floyd around just picking up the ideas and converting them into useful activity. He makes for a busy life."

Culler's role as a real pusher for new directions and new opportunities is associated in part with the global viewpoint he has acquired. "Floyd's way," says Dr. Herman Postma, now director of ORNL, "is to see a need and a problem area and then to ask 'what can my institution do to solve this problem, or how can we play a role in bringing about a solution?' He can put it together and see whether the R&D program makes sense or not."

One incident cited by Postma occurred 13 years ago when, as head of the Chemical Technology Division, Culler began exploring the possibilities of using process heat from nuclear energy as a way of converting coal from liquid to gas, and saving energy in the process. That was during the early euphoric period of nuclear energy, suggests Postma, with a perspective now invested with ironic amusement, when it was imagined that "nuclear energy could do everything."

Though that particular project was not to succeed, Culler did succeed in pushing the laboratory into a coal program long before ERDA got into it, through a "strange back door." It related, says Lenhard, to a demand for pollution controls on a coal-fired electric plant "before the technology was here." Culler jumped on the problem with the help of Don Ferguson and a few other key people, got their lab up to speed, made an in-depth analysis of the various options, and provided them to AEC for consideration. As a result, notes Lenhard, ORNL was in a position to compete for Office of Coal Research work at an early period before ERDA was formed.

His friends cite other examples of Culler's leadership and success, and his admirable qualities. Dr. Alvin Weinberg, who selected Culler to become the deputy of ORNL, says of him, "Floyd is above all a man of excellent character, so wonderfully open, so enthusiastic, and basically so totally honest. There's no sham about him whatsoever. And then, as you come to know him, you realize he's a man of extraordinary intellect and capable of keeping in mind a fantastic wealth of detail. Finally, he is a person of extraordinary practical sensibilities and sensitivities. This comes from his having been personally involved in engineering projects—huge ones—that were successful."

But Culler's friends and colleagues are also amused by his foibles and mistakes and do not wish to make him seem cut completely out of heroic cloth. "He talks a lot," says one; "he can talk your ears off." It may be that he is a step ahead of others in meetings, and sometimes he takes off and elaborates for an hour if no one interrupts. "It may seem to outsiders like an ego trip, and they may get irritated because he seems to be dominating a meeting, but it's just that he gets so enthusiastic and involved." Weinberg, too, mentions Floyd's talkativeness, "but unlike a lot of other people, you realize he knows what he's talking about . . . he never talks nonsense."

"If you stick your neck out that many times," remarks Lenhard, "you are going to make a mistake once in a while, and Floyd makes occasional mistakes."

"The favorite mistake," says Ferguson, "is mercury seals. Floyd always has a flair for anything he designs, and he wants to make it just a bit better than an ordinary person would. Once he wanted to build a pool of mercury under a wall so you could push something down into the

The World at Oak Ridge

Floyd Culler's views of R&D management should probably be set against the background of his work at Oak Ridge. Today, when there is such widespread public concern about the presence of nuclear energy, it is perhaps difficult to appreciate what the scientists and engineers must have experienced while spending years wrestling with this particularly formidable force, trying to channel it for peaceful uses. The very name Oak Ridge came to symbolize to the outside world as much as anything the excitement and struggle of creating and shaping a major industry. Equally, on the darker side, it represented the conflicts, turmoils, and doubts that some of the leading scientists of the atom have expressed. Nuclear power stands at the apex of the awesome proofs of man's science and technology, and there is little doubt that the people of Oak Ridge—in a town created in the thinly populated valleys miles from Knoxville—felt they lived and worked in a special world in itself. There is little doubt that the scientists and engineers there grew accustomed to living and working at the leading edge—of science, of secrecy, of exacting requirements for engineering reliability, of massive technology transfer, of the potential biological and social impact of their work, of public reaction, and finally, for some, of the most profound human and moral issues of our time.

Even town planning became an issue in Oak Ridge, and Floyd Culler was the first chairman of the city's planning commission who pushed for a rational plan in the original law that made Oak Ridge a "civilian town" after its special wartime role in the development of the atom bomb.

Commentary on Floyd Culler

The problems that EPRI and the electric utility industry will face in the next 5 to 10 years will surely be different from the problems of the immediate past. The pressing business 5 years ago was to build a viable R&D organization and a sensible program plan that could address major technical questions troubling a diverse and widely separated constituency.

A major challenge ahead will be to prove conclusively,

"As I see it, the utility industry faces tough, generic problems, and a balance of good technological options will be needed from which the utility decision makers can pick and choose. From my experience in working with Floyd Culler at Oak Ridge and in Washington, I believe he will push at EPRI to develop a range of technological options—options that are economically sound and that meet performance specifications. The mandate at Oak Ridge was to search constantly for how to do things differently and, at the same time, to achieve a high degree of performance and safety. These kinds of standards and requirements are now instilled in Culler. I'm sure he will build on this experience to work toward a strong arsenal of technological options to offer the utilities."

Frank Baranowski
Vice President
Advanced Programs
Washington Office
Mechanical Technology, Inc.

"Floyd is a very energetic, outgoing individual who has untold interests . . . in everything he sees and hears. And he has a remarkable memory. He can take a comprehensive, complex report, memorize all of its important facets, and just play it back like a tape recorder.

"Besides his keen interest in people and ideas, he loves engineering . . . designing something that is actually going to be built. In a design working session, he guides the group through the pertinent and important aspects of the design and gets input from anyone who has any ideas or suggestions. Finally, he is very good at delegating tasks to his subordinates for getting the job done."

Don E. Ferguson
Director
Chemical Technology Division
ORNL

"I guess you can recognize a strong manager by the way the organization rallies behind him. Floyd Culler can make just an offhand suggestion and somebody is going to pick it up, follow through on it, and come back to Floyd with an answer. He has an image as an idea man, and he comes up with many good ideas."

Joseph Lenhard
Director
Research and Technical Support Division
U.S. Department of Energy
Oak Ridge Operations Office

Experience and Personal Qualities

to the utility constituency and to the country, that the R&D coming from this organization, and its mode of operating, can lead to a range of credible and useful analyses, devices, products, and systems that represent cost-effective solutions to real-world requirements.

Associates and friends of Floyd Culler speak here about some of the qualities, skills, and experience that he might bring to bear in his new role as president of EPRI.

"One measure of the success of R&D is how much of it gets transferred to industry. In that respect, Floyd was very instrumental in setting up a large plant. A small-scale pilot plant was developed here at Oak Ridge, then scaled up and moved to Idaho. Floyd was responsible for the whole design, construction, and transfer process, and it was very successful."

Dr. Herman Postma
Director
ORNL

"Floyd Culler comes to EPRI at an opportune time. The thrusts that Chauncey Starr brought in the nuclear field were primarily reactor-oriented and breeder technology–oriented. Culler can bring to bear judgments on the immediate problem of waste management and, I hope, bring an understanding to the utility industry of the waste management field so as to develop their support for a viable waste management operation. This is an area in which we should look to EPRI for leadership.

"Management, compaction techniques, better measurement techniques need to be understood so as to instill in both the utilities and the public the confidence that they are being properly handled. In this area, I can foresee more mutual programs going on between EPRI and DOE."

Robert Thorne
Acting Assistant Secretary for Energy Technology
U.S. Department of Energy

"One of the fundamental questions that confronts the utility industry is still the problem of the acceptability of nuclear energy. As EPRI tries to assist in a solution of this very difficult problem, Floyd Culler's total grasp of the field should be very helpful."

Dr. Alvin Weinberg
Director
Institute for Energy Analysis
Oak Ridge

Floyd Culler Speaks Out

On Managing Research

"From a management point of view, research and development starts from an ability to state problems with reasonable clarity, to synthesize different possible solutions, and to dig at problem solutions with a relentless energy. It's a bit different than managing sales or construction or production. An essential element is being able to recognize the people who can synthesize ideas, and who, every now and then, can really create."

On Recognizing Good Researchers

"I'm not really sure how to recognize them, but almost always I have noted something special on a first interview with those who turn out to be good. There is a certain set of qualities: humility in the face of ideas, a kind of restless curiosity, a balance of information and revolving ideas, and the willingness, urge, or steadfastness to work at something until it's finished. You almost can see the excitement that comes through. The good ones are usually recognizable from the start. I can remember the interviews with them, years later, almost word for word."

On Working With Chauncey Starr

"We haven't spent a long time with one another, but we have worked together in what I would call practical pressure cookers. Under pressure, we seem usually to share a common solution and complement each other. . . . Chauncey will think of something, I'll think of something, and so on . . . our minds travel along, building one on the other. For the kind of thinking on very major issues, where thoughts are planted and grow more organically, we need, and take, much time to reach mutually agreeable conclusions."

On Maintaining Your Constituency

"We have to make sure that there are recognizable contributions to the operating effectiveness of the utilities—things that *they* recognize as being helpful . . . they have a hand on the stopcock that controls the cash flow."

On The Advisory Committee Structure

"The Advisory Committee structure is a marvelous setup. There isn't anything like it elsewhere for feeding information and insight into EPRI. But whether that same structure can effectively move results out from EPRI to the managers and executives in the utilities, I don't know. Generically, it doesn't seem to me that things work that way . . . that those who advise are also those who hear. The process of collecting advice is basically different from the delivery of results."

On Solar Development

"Probably more than with any other source, solar energy brings along the question of the morality of the use of power. When people say 'solar' they are often really saying 'for humanity's future, for the future of all living systems, we should use solar and nothing else that pollutes, no matter what it costs.' But the gap in its application is primarily economic. The reason that solar costs more lies not in the generation or harvesting of its heat but in its storage. The solar business most certainly should be pursued, but it is most unlikely to compete economically with other sources in the near future."

mercury on one side and have it pop up on the other. So we refer to mercury seals as one of Floyd's designs. Of course," concludes Ferguson, speaking as a serious engineer, "mercury is about the last thing you want to get into a chemical processing plant! We bring him back to earth with that." Ferguson chuckles, "Floyd really enjoys kidding, and being kidded."

As for the future and how his experiences may serve him at EPRI, two former associates of Culler offer some predictions. Frank Baranowski, former Director of Nuclear Fuel Cycle and Production for ERDA and former Director of Production for AEC, concludes that Culler will work to develop a strong range of technological options to offer utilities. Robert Thorne, now the Acting Assistant Secretary for Energy Technology in DOE, foresees that Culler will build bridges between EPRI, DOE, and the utilities in support of viable nuclear waste management.

What of the future?

"Many people have asked what plans I have for EPRI," Culler said, as he turned his own thoughts to the years ahead. "This broad subject has been on my mind constantly as I meet the people with whom I will be working and as I learn more about EPRI.

"The elements that can produce necessary excellent R&D in the energy field have been established for EPRI by Chauncey Starr and the EPRI staff. They have had remarkable support from the sponsoring utilities. EPRI's broadly stated purpose is surely appropriate: to provide the technology for the reliable production of electricity, in quantity as needed, at the lowest cost, and with minimum risk to the environment and public health.

"EPRI's reputation for excellence and objectivity is well established. These attributes are its greatest asset. Excellent research and development, and a very real objectivity, must be the sine qua non for our staff. And for those of us who manage, maintaining a staff of exceptional quality must therefore be a primary objective.

"Good people must be allowed as much freedom of choice and direction as possible for good development, and for good development to be converted to effective use. I hope, along with everyone else who manages, to keep from smothering our development efforts with forms and procedures. But there must be systems by which we can hold ourselves accountable. Others, too, must be able to judge the wisdom of our choices and the effectiveness of our stewardship.

"EPRI is now five years old. The R&D initiated three or four years ago is now reaching a stage where it can, or should, be useful—and if not useful now, to be reevaluated for its future potential. We must now convert our technology to practical use and our processes to production. Our important job will be to translate from bench to pilot plant and, more importantly, from pilot plant to production scale. We must get on with the industrialization of the technology that offers the means to use energy resources other than oil and gas, to reduce costs, to increase reliability, to conserve energy, and to reduce the environmental and health risks attendant with electric energy production and use.

"During the next few years, the big question will be how and when to fund the large pioneer, or demonstration, production-scale plants. This must be worked out between private and government sources.

"We must soon get on with demonstrating the new technology for converting energy sources such as fossil, nuclear, solar, and geothermal—and conservation techniques—to reliable production.

"Our development must be responsive to the public interest in protecting the environment and public health. At present, the questions that have their basis in public acceptability of both old and new technology are at the root of the uncertainty about energy policy. The resolution of this uncertainty is as important as technology and an intelligent conservation ethic in working toward a robust energy supply."

Polysil Shows Promise

A new synthetic developed under EPRI contract appears superior to porcelain as an insulation material and offers promise of many other uses for utilities.

When a new material appears on the scene that does more, does it better, and costs less than existing materials, it can truly be called a breakthrough. Such is the case with Polysil,* a new synthetic developed under EPRI contract, which holds promise of a variety of uses for the utility industry.

Polysil's most promising immediate use is as an insulation material, since in many ways it is superior to porcelain, now the most widely used substance for insulators. According to Robert Perry, director of EPRI's Transmission Department and initiator of the Polysil project, "This is the first successful new material developed in over 30 years for general indoor and outdoor electric power insulation."

Perry explains that Polysil, a polymer-silica compound, has several characteristics that make it superior to porcelain: it has twice the dielectric strength (electrical resistance); it has just half the dielectric constant, resulting in lower power losses; its design flexibility allows it to be cast in many shapes and enables it to encapsulate metal; and it is far simpler to produce than porcelain, costing about half as much. It is also highly resistant to impact.

What it is

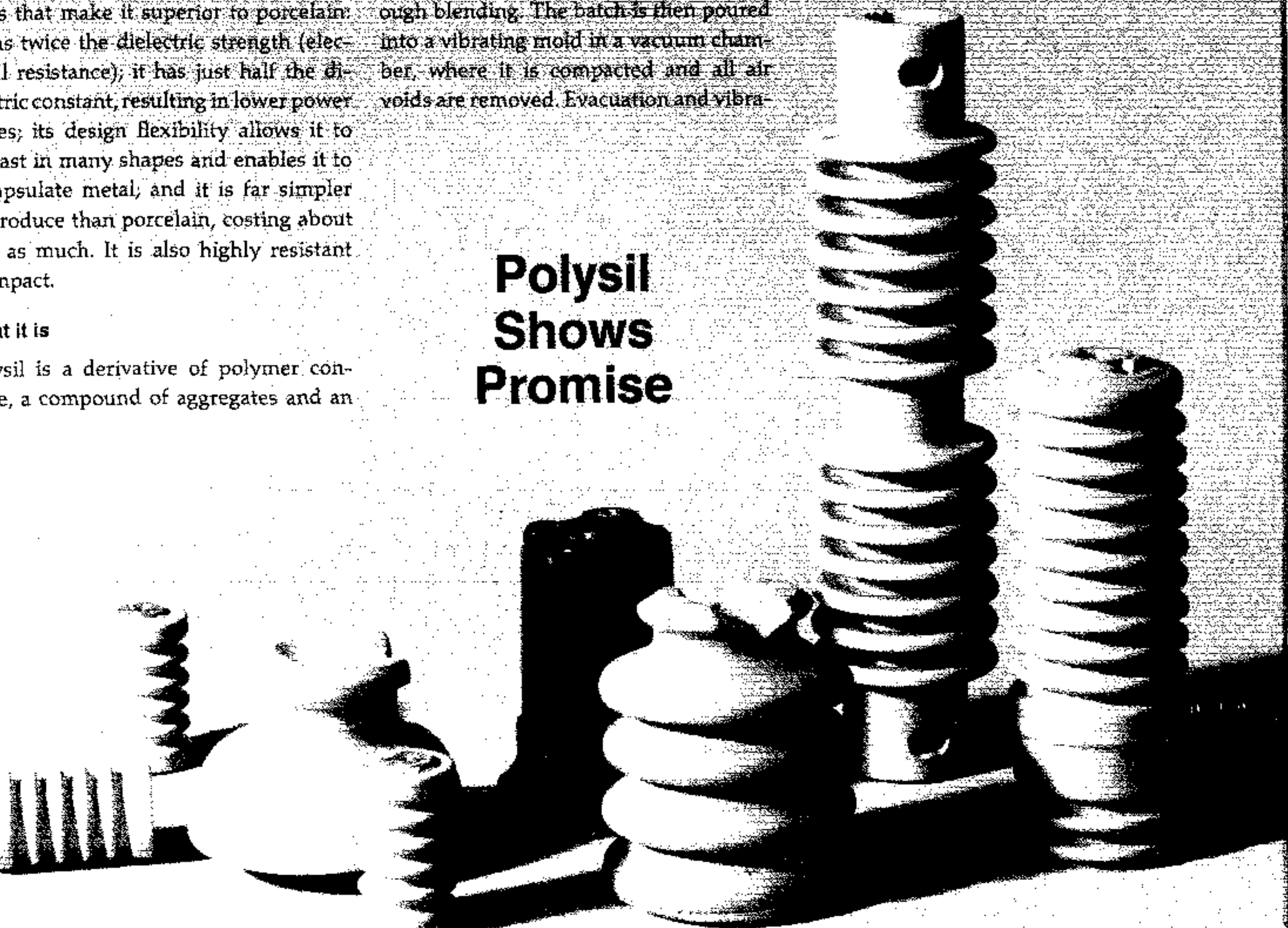
Polysil is a derivative of polymer concrete, a compound of aggregates and an organic binder. Polymer concrete was developed by Brookhaven National Laboratory in the mid-1960s at the request of the U.S. Bureau of Reclamation. It has six to eight times the compression strength of conventional concrete, and has proved successful in resisting erosion in dam spillways. Its possible electrical application was recognized by EPRI, which funded an 18-month, $275,000 investigation of this potential by Westinghouse Electric Corp. in 1975. The result was development of a new derivative of polymer concrete, given the trade name Polysil, that has superior electrical and mechanical properties.

Polysil is made by combining silica or ground rock (90%), an organic binder, and reinforcing fibers (10%). The components are mixed in a vibrating mixer for thorough blending. The batch is then poured into a vibrating mold in a vacuum chamber, where it is compacted and all air voids are removed. Evacuation and vibration are stopped after about 3 minutes, and the Polysil is allowed to gel and cure for about an hour.

It is estimated that Polysil can be produced for less than half of porcelain's manufacturing cost of about 80¢/kg (40¢/lb). Perry calculates that as much as $7.5 million a year could be saved by the utility industry if only 5% of the insulators purchased were made of Polysil.

Production and design flexibility

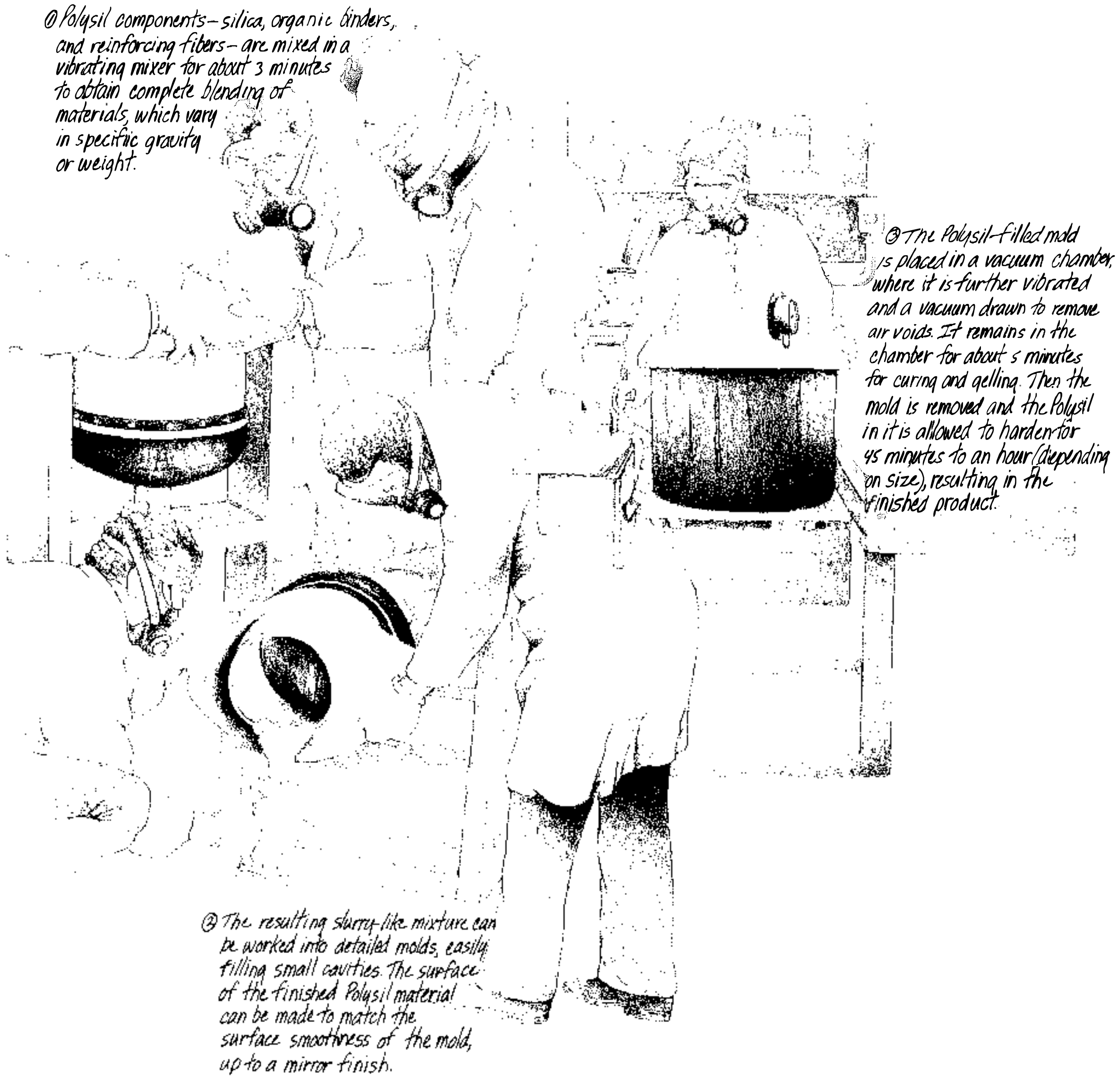
Flexibility in production and in design are among Polysil's chief advantages. As



*Polysil is an EPRI trademark.

Perry points out, "While porcelain insulator production calls for a large plant, vast capitalization, and high energy, Polysil insulators can be made with a simple mixer, molds, and vacuum pump in small, low-cost facilities. And since production can be decentralized, substantial savings in transportation costs and time should be achieved." Unlike porcelain, Polysil does not require kiln-firing, so it also saves considerable energy in the production process.

Metal inserts can be cast in Polysil insulators in the casting process, thus eliminating the need for attaching conventional end caps that account for about two-thirds of the cost of low-voltage insulators. And contamination effects often experienced in high-voltage porcelain insulators can be reduced with Polysil, Perry notes, because metal capacitor plates can be embedded in Polysil insulators during casting, giving a more even distribution of voltages across the sur-



face of the insulator. On the conductor end of the insulator, the maximum stress can be reduced by as much as 80%.

Since building and equipping plants to manufacture Polysil insulators would require relatively little capital, the plants could be located near utilities and could produce insulators to meet local requirements. A utility on the Gulf Coast, for example, may need a salt-resistant, capacity-graded insulator, while a power company in dry, relatively contaminant-free Arizona could do with a simpler design.

Extensive laboratory tests have demonstrated Polysil's electrical and mechanical characteristics, and field tests are now under way to determine performance. In one outdoor test at the Westinghouse Research and Development Center in Pittsburgh, Polysil insulators subjected to 0.063kV/mm (1.6kV/in) across the surface for nearly a year had no tracking. "This was surprising to insulation people but not to us," Perry says. "The silicon particles that make up 90% of Polysil act to break up the track, preventing it from moving progressively across the surface of the insulating material."

Field tests

For the field tests, racks of 16 Polysil insulators—each insulator of a different design—are being placed in substations of several utilities in the United States and Mexico in a variety of environments: desert, seashore, urban, rural, clean, contaminated. The racks are instrumented to measure such factors as humidity, leakage currents, and oscillations of the corona. And each insulator will be photographed monthly to determine what the visible effects are. Data recorded by the instruments will be collected each month and correlated for the test as a whole.

The field tests are designed to continue for several years, but it is expected that enough data will be available after the first year to indicate which designs work best, where, and under what conditions. This information will be made available to the utility industry and to potential manufacturers of Polysil.

Perry points out that the name Polysil is an EPRI trademark and that the Institute will allow manufacturers the use of that trademark providing they meet the strict specifications for producing Polysil and are able to maintain quality control. Utilities that purchase Polysil insulators would thereby be assured of their reliability.

Variety of uses

Many potential applications are seen for Polysil. The nonconducting parts of hook disconnect switches could be cast as one piece, for instance, simplifying their design and improving their appearance. Perry explains that normally these switches are made by bolting two 15-kV insulators to a metal base and attaching a cap on the top, to which the electrical parts are bolted. The result is a number of parts and a rather unesthetic piece of hardware, commonly used in residential locations, where appearance is a consideration. The only metal parts in a single-casting, V-shaped Polysil version would be the parts of the switch's hook and blade and the connectors to the distribution lines. And because of Polysil's high mechanical strength, there would be no need to add strain insulators when attaching a hook-switch of this kind to a utility pole. Perry estimates that the Polysil switch could save utilities as much as 30% in cost compared with the conventional type. It is foreseen that a Polysil uniform-field EHV switch could be designed that would be safer, smaller, and cheaper than existing switches.

It is also believed that Polysil could lead to the elimination of insulators in substations. By substituting Polysil for concrete as a construction material, the Polysil support structures themselves would serve as insulators. And since there would be no need to mount insulators on top of concrete structures, as is now done, substations could be designed with a lower, more appealing silhouette—and at lower cost.

Other applications of Polysil being investigated include its use as a material to encase underground transmission conductors, in the production of circuit breakers and transformers, and as footings for transmission towers. By using an existing centrifugal casting process, it appears possible to cast utility poles from Polysil. The result would be a lightweight, thin-walled pole six to eight times stronger than concrete and perhaps even less expensive than wood poles. Perry comments, "We are seeing just the tip of the iceberg at this stage as far as Polysil applications are concerned." He predicts that utilities will be installing Polysil insulators by 1979.

The main drawback of Polysil is the question of its longevity or durability. With such a new material there simply has not been enough time to demonstrate its in-service life, although tests thus far indicate a good probability of long life. An impressive record as a construction material has been achieved by polymer concrete over the past 10 years. It has been widely used with success for many years as a construction material in the Soviet Union, Japan, Germany, Italy, and South Africa.

Cautious optimism

Utility industry reaction to Polysil so far has been one of wait and see. Always concerned about reliability, utilities want more proof of Polysil's performance and longevity. "At the same time," Perry notes, "they can see the cost savings and versatility that Polysil would give them, and they are enthusiastic about that." All utilities, large and small, he adds, have insulation problems, and a new development such as Polysil could be of universal benefit.

John Dougherty, director of EPRI's Electrical Systems Division and a veteran of some 25 years in the utility industry, views Polysil with cautious optimism. "EPRI needs to guard against trumpeting Polysil's merits before proof is demonstrated," he cautions. Dougherty's concern is that "we may oversell Polysil before proving its capabilities. We don't have all the answers on performance yet, but," he adds, "it does look promising."

Predicting Generating Unit Performance

by Melvin Lapides

Analysis of power plant operating histories shows that estimating future performance is not a straightforward process, but useful lessons can be learned to improve availability and reliability.

Estimating the future performance of new electric generating units is not a straightforward process. This fact is demonstrated by the many performance studies conducted to aid in energy policy deliberations. Comparatively few of these studies agree with one another—often they even disagree with historical data. Each points to a different technical or nontechnical parameter as the key to good performance, and none can explain exactly why two otherwise identical units on the same system have different track records.

Viewing these studies and thinking about the hundreds of items that can differentiate one unit from another (or that can invalidate the use of historical data) suggests that each generating unit has an original personality that requires individual study. While this is a valid perception, it doesn't negate the interest in using past operating experience as a performance guide. Modeling an electric generating unit for what it is—namely, a maintained system wherein problems occur and responses are made in accord with economic pressures and system constraints—permits surprisingly good replication of the past, as well as useful insights for future application.

Melvin Lapides is Program Engineer, Nuclear Systems Analysis, in EPRI's Nuclear Division.

Aerospace experience

The analytic reliability methods emphasized in the aerospace and electronics technologies to predict equipment lifetimes offer a useful starting point for assessing generating equipment performance. A basis for this work is the classic "bathtub" curve (Figure 1), which appears in virtually every text on reliability. It gives a generic representation of a tangible product's performance in terms of the experience accumulated with it. The bathtub curve consists of three sections. In the debugging section, oversights in design that contribute to poor performance are corrected. The random-failure section accounts for the small residual probability that some kind of malfunction will occur no matter how well the product is designed and tested. The wear-out section reflects the change in performance that results from deterioration of the product under prolonged use.

Building an electronic subsystem for a spacecraft involves subjecting hundreds of microelectronic parts to screening and wear-in tests to ensure that the test survivors fall into the random-failure portion of the curve. The subsystem assembled from these survivors is tested under conditions that simulate the actual environment to be encountered in service. Accelerated-life-testing to simulate the total service period is also quite common. Finally, the completed subsystem is subjected to overstress during qualification testing. If the final product survives these tests, it's a reasonably good bet that it is operating in the random-failure section of the bathtub curve. Powerful, statistics-based reliability prediction techniques can be applied to components from this part of the curve, and this is indeed where they are most likely to be correct. Such techniques are useful not only to estimate performance but also to establish the initial design criteria. Nevertheless, applying reliability prediction techniques to spacecraft subsystems contrasts sharply with what is required for most large electric generating equipment.

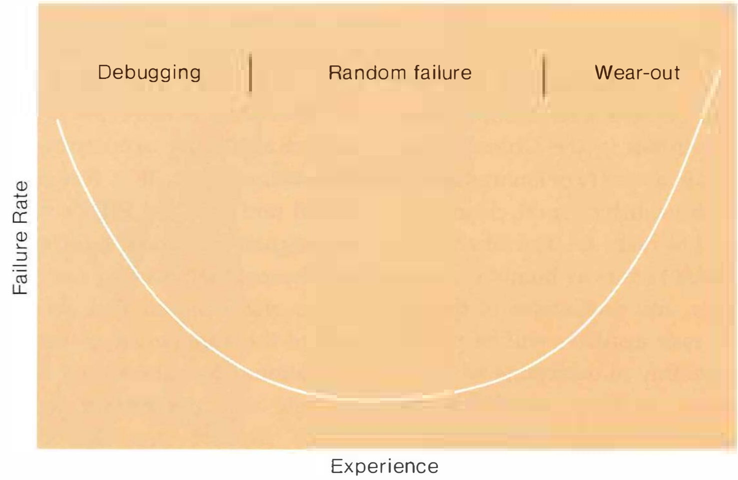


Figure 1 Testing a large number of parts under specified service conditions usually results in the classic "bathtub" curve. Failures in the early parts tested lead to changes, a gradually the quality is improved. As these improved parts near the end of their useful life, the failure rate goes up.

Planning power plant maintenance

Electric generating units are likely to include components and subsystems that operate in each of the three sections of the bathtub curve at any given time. The reasons for this are both technical and economic. For example, a baseload unit with an intended service life of 30–40 years contains many elements that will wear out long before that time. It is usually poor economics to increase the design lifetime of these elements, and in many cases, it is technically infeasible. A better plan is to arrange for periodic replacement of individual elements. Indeed, much of the design phase for electric generating equipment is concerned with developing and accommodating a periodic maintenance and replacement schedule. When examining the performance experience of electric generating equipment, one is largely measuring the success of the maintenance plan. A malfunction may not be a random failure; it may be the result of a faulty perception of maintenance requirements. The bathtub curves for these circumstances probably resemble those in Figure 2.

The first several years of a new unit's operation are expected to be a learning period, wherein operators can study their original maintenance planning and make necessary corrections. After this startup period, one can reasonably expect performance to approach long-term performance goals. Year-by-year, unit-by-unit studies of all the equipment in a particular class partially confirms these observations. What usually appears is an initial, low-performance learning period followed by relative stability. The length of the learning period for the first-of-a-kind unit is generally more extensive than for the tenth or twentieth unit, since some benefit is usually gained from experience with the earlier units. However, just as important as this correlation is the fact that the pattern is irregular.

Electric generating equipment is, by and large, high-reliability equipment, which means that it doesn't really malfunction that often. Furthermore, most of the malfunctions—about 80%—encountered within a subsystem are not of a serious nature. On an average, for example, a large steam turbine will malfunction two or three times a year, with most malfunctions being resolved in a comparatively short time by such actions as adjusting the control system or fixing oil leaks. But very infrequently something serious may happen, such as a turbine-blading failure, which will cause the unit to be down for hundreds of hours. These infrequent events are a prime reason for the irregularities found in performance trend analyses. Their effect is compounded because new generating equipment usually isn't bought very frequently.

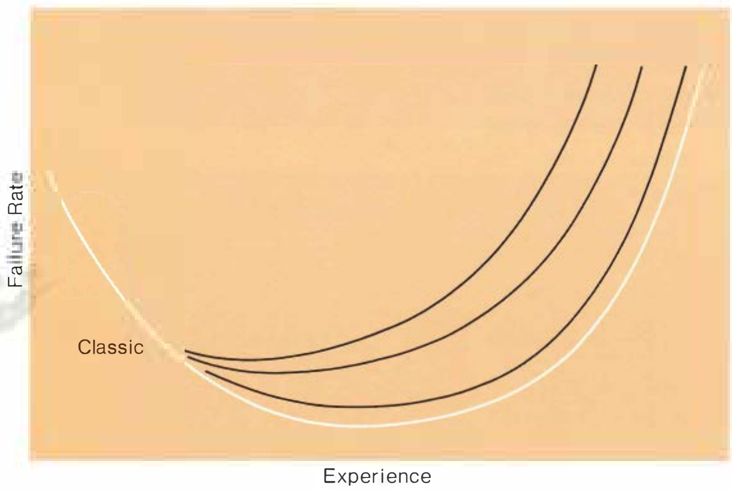


Figure 2 Parts that require maintenance behave almost (but not quite) like those under test. Theoretically, if maintenance procedures could be perfected, the failure rate would match the classic (test) curve. However, it is doubtful that this will happen, because maintenance experience does not transfer easily.

Major outage events

Typically it has taken about 10 years for 50 units of a specific type to be introduced. Because the major outage event is infrequent, it may not show up until several of these new units have been in service for several years. Determining the best way to correct and guard against such an occurrence may take several more years—and in the meantime, the incubating defect remains in those units under construction. The net result is that the infrequent event becomes a dominant distortion in the performance trends observed with most generating equipment.

Obscuring these irregularities by smoothing out the distribution with statistical averaging techniques may be akin to throwing out the baby with the bath water. Characterization of the infrequent event and the responses to it is a worthwhile objective.

The chances are that many infrequent (albeit serious) events would occur in service regardless of the sophistication of product design and implementation because they usually result from the kinds of problems that don't surface without a full-scale, extended systems test. Although the necessary testing is readily accommodated in some industries, the options are much more limited for electric generating equipment. For example, to obtain the steam needed to test a 1000-MW (e) turbine adequately, one must also build the generating unit into which it is integrated. Early commercial operation of the unit becomes the de facto systems test of the turbine.

Case studies of mass-produced items suggest that the frequency of "test-observable only" product failures often follows a pattern. A usual observation is that the frequency of these events decreases at a rate between the cube root and the square root of the total time of service experience, with all units being evaluated. (What is being measured is the rate at which diagnosis and feedback result in product improvement.) The same analogy appears to work for major utility equipment items. It applies best to components that are subject to periodic inspection, overhaul, and repair, but must be modified for items not commonly subject to inspection by disassembly.

Observed performance patterns

Figure 3, year-by-year comparisons of two units, illustrates how these performance-determining factors work—and combine—when a new class of equipment is brought on line. Figure 3a shows the process by which the operator develops his maintenance plan on the basis of day-by-day inputs from operating experience. Figure 3b shows the impact of finding and having to resolve infrequent, high-impact events. Here useful information may be obtained as seldom as once in every four or five years of industry experience.

Figure 3c suggests how these two effects combine to yield an overall performance prediction. Although the timing of an infrequent major event cannot be precisely predicted, the probability of its occurring can be represented. Both initial and subsequent units have a finite chance of performing at maximum potential; however, if a major malfunction is experienced and resolved with an early unit, all later units should be less prone to the same kind of occurrence. Statistically, the later unit isn't guaranteed against malfunction, but it has a higher probability of achieving better performance.

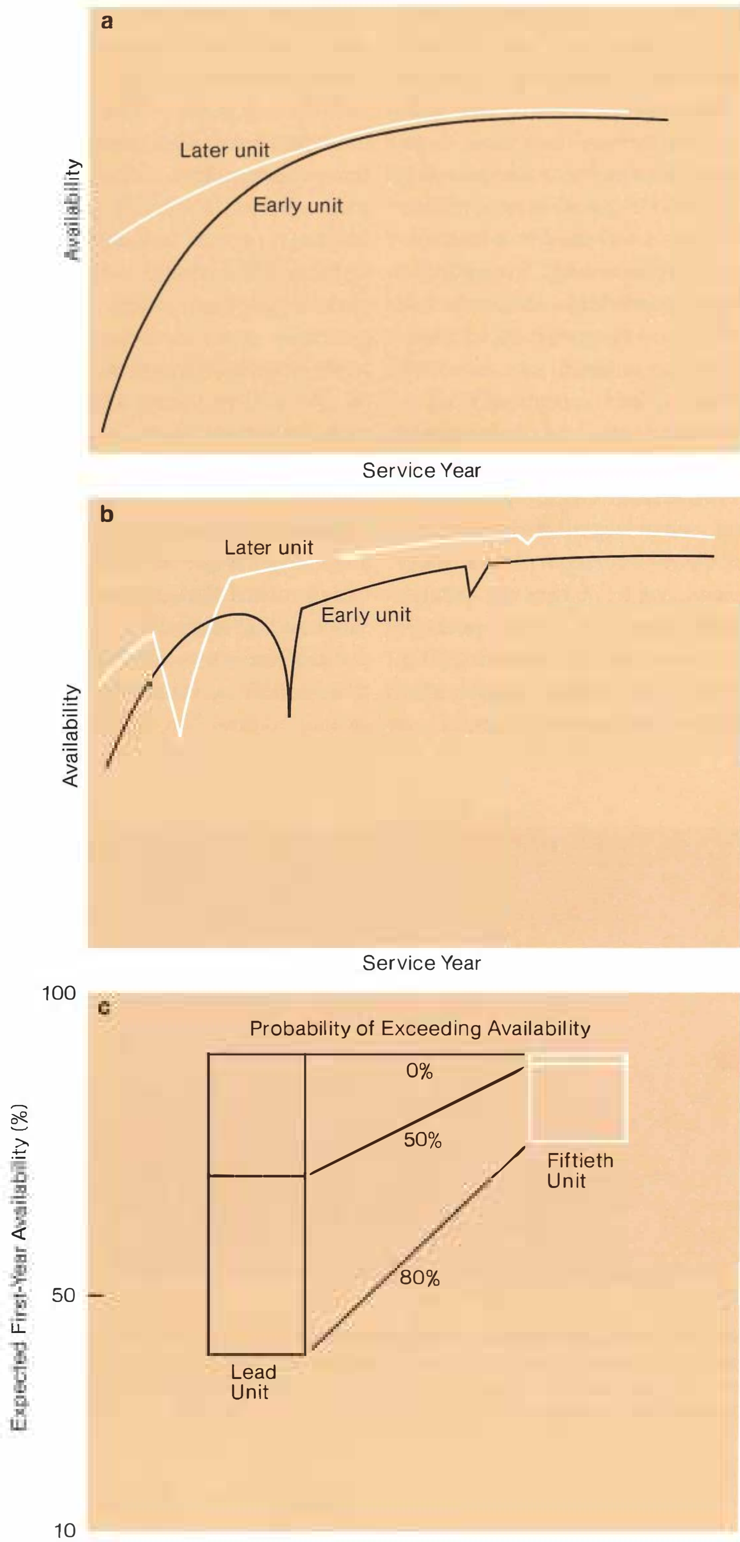


Figure 3 Developing appropriate maintenance procedures takes time. The performance of a unit (measured by its availability to produce power) should gradually improve with service. Later units should reach higher performance faster because they benefit from the experience of the early units **(a)**.

Maintenance development is not the only process at work. Each unit also may be affected by infrequent but major disruptive events that warp the picture **(b)**. These events occur less frequently as more units are built and operated.

Combining these two effects in a performance forecast is best presented in terms of probabilities **(c)**. For a lead unit, there is an 80% chance that first-year availability will be above 40%. Turning that around, there is a 20% chance of subpar (below 40%) performance in the first year. By the time the fiftieth unit has come on-line, the 20% chance relates to the much higher availability of 75%. Similarly, both units have some chance of being outstanding performers with availability near 90%. For the fiftieth unit the odds on this are close to 50%, or one chance in two. For the lead unit, there is one chance in two that the availability will be below 70%.

Maintenance maturity model

If carried out in detail, the maintenance maturity model just described serves to align historical performance data in an orderly array. Although such alignment is of value, it can also raise as many questions as it answers. Is it really possible to make a reasonable estimate of future performance without looking at individual units in painstaking detail? For example, aren't the economic and regulatory environments (key determinants of what designs look like in the first place) so dynamic as to cast doubt on the basic value of historical data? The answer appears to be both yes and no.

For example, the model suggests that there is a major distinction between nuclear and fossil-fired units—one that is virtually unaffected by costs or regulations. The distinction is in the process for dealing with the infrequent major malfunction. A fossil-fired unit normally is designed to operate for up to 10,000 hours before it goes down for a planned maintenance outage of one to two months. If this unit experiences a major turbine malfunction, the first operator action is likely to be a somewhat heated discussion with the turbine supplier. The second action will be to consider switching as much future planned maintenance as possible into the period when the turbine is down for repair. Figuring what actions can be performed "in the shadow" of other incidents is characteristic of fossil-fired plant operation. It turns out to be the reason why examining annual statistics for a plant of this fuel type makes sense.

Nuclear plant characteristics

Nuclear unit owners have much less flexibility in rescheduling maintenance. Their units must be shut down for refueling after a predetermined total energy output has been reached, and most of the major plant maintenance is scheduled for this refueling period. Shifting maintenance so that it can be performed during a large unplanned outage is rarely feasible or effective in reducing downtime. Therefore, the performance of nuclear units must be assessed by looking at refueling and power operations as separate phases (Figure 4).

The conclusions reached from this assessment are in marked contrast to those more commonly extracted from annual data studies. Specifically, there are two distinct learning phases in evidence: one associated with the management of refueling operations, the other with actual power operations. The first refuelings of a nuclear unit seem to fit a bimodal distribution, the longer refueling time values usually being associated with units that have made substantial equipment changes (largely because of changing regulations). Second refuelings follow a more normal distribution and with a few exceptions are substantially shorter (the exceptions to normal distribution reflect the odds at work).

As the nuclear industry is often accused of malfeasance on the basis of interpretations of annual performance statistics, this particular maturity analysis has the effect of highlighting a misconception. What is evident is that one must look at refueling and operations separately in order to make useful projections. Simply annualizing the data is going to introduce distortions, particularly because the present nuclear population, being young, is heavily biased by units in the earliest refueling stages.

Plant size and maturity

More often, the modeling of electric generating unit performance focuses on the somewhat disturbing conclusion that virtually all classes of units that came on line after the mid-1950s are now still in the process of maturing rather than having arrived at some steady state of performance. And this can raise more vexing questions than it answers.

One such question concerns the relationship between unit size and unit performance. The class data that exist suggest that small units perform better than their larger counterparts. This observation has great intuitive appeal and is rarely questioned. But looking at the data another way suggests that this may be true because the smaller units are mature while most of the larger units are not. In selecting a new plant for high reliability over its intended 30–40-year service life, size may not be an important consideration, as all units appear to follow the same maturing cycle regardless of size. So the question for the future and for new technologies may not be one of size at all, but rather of determining what else can be done to accelerate maturity. Here the historical model doesn't answer all the questions, but it can provide some useful guidance.

Using the maintenance model approach

Consider, for example, a question that might arise at EPRI in establishing R&D priorities: Is developing a program to improve steam turbine availability a high-payoff way of increasing the productivity of future electric generating equipment? The answers are probably yes for natural gas, synthetic fuel, and nuclear units; and probably no for coal-fired units. One can better understand the reasoning and the characteristics of the improvement program by examining the maintenance patterns on these systems. Repair and maintenance rescheduling for fossil-fired units tends to be dominated by one particular subsystem—coal-fired units are boiler-dominated. This means that as much as 70% of the maintenance on all other subsystems is performed when the boiler goes down.

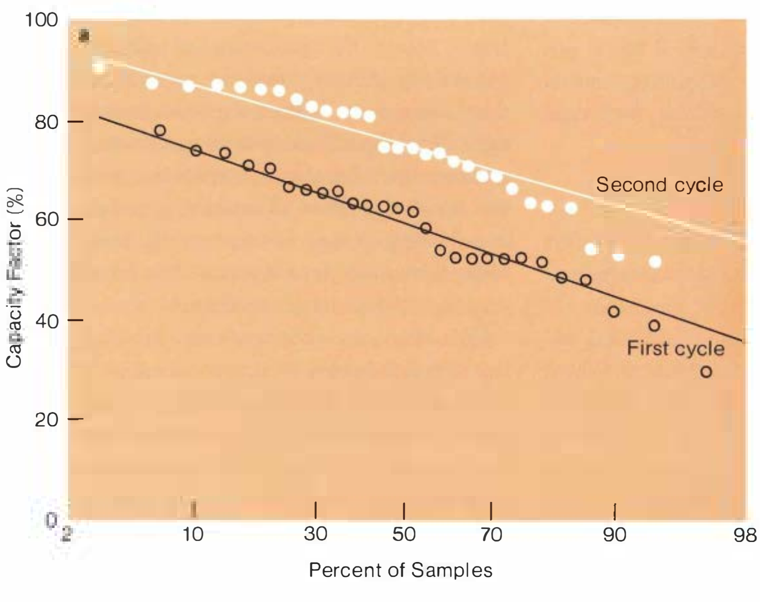
Will a higher-availability turbine alter the situation? Not substantially until something is done to improve the boiler. And since clean fuels are, in effect, a way of doing something about the boiler availability, introduction of such fuels may justify a turbine improvement program.

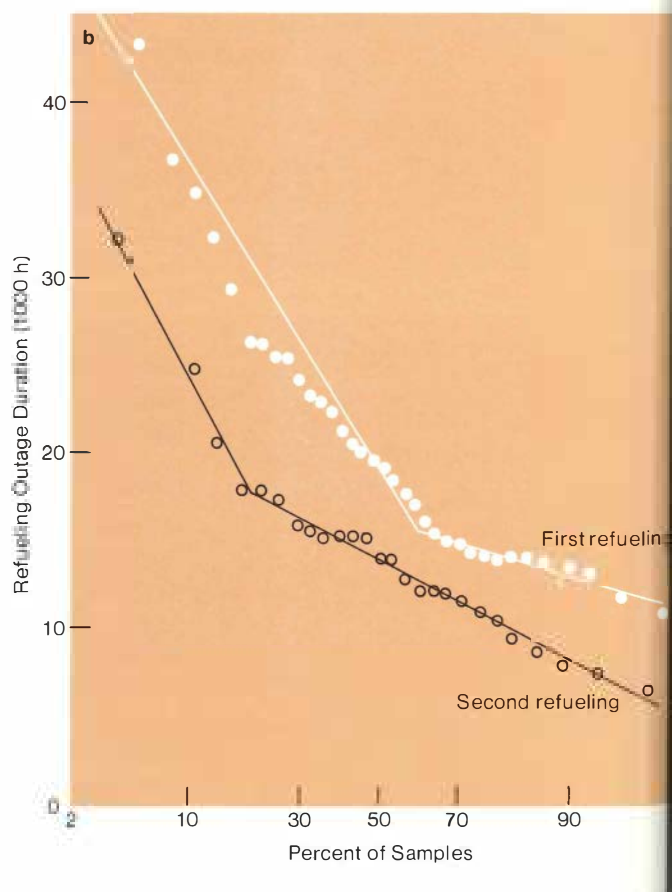
What should the turbine improvement program be? Eliminating the infrequent major malfunction isn't a bad objective, but verification of success may be a long time in coming. In the nearer term, a higher payoff could result from reducing the time required to conduct the major periodic turbine overhaul. This may be among the better ways of reducing the downtime during nuclear unit refueling or during the major maintenance outage for a unit that uses a clean fuel.

Clearly, a historical model is not a panacea but it can be a useful tool—which is about what one should expect.

Figure 4 Performance of nuclear units should not be measured by annual statistics alone because experience is dominated by early-cycle operations. A maturity pattern emerges if power operations **(a)** and refueling outages **(b)** are examined separately. Second-cycle power operations are substantially better than first-cycle operations, and second refuelings take substantially less time than first refuelings. Fairly stable values should be reached by the third or fourth cycle, but there are insufficient data to confirm this prediction.

The nonlinear scale on the graph flattens out the familiar bell-shaped (or Gaussian distribution) curve—that is, if the data plotted fall in a straight line, they have a Gaussian distribution. The power operations (between refuelings) of U.S. nuclear units appear to follow such a distribution. Refueling appears to be better characterized by two such distributions.





At the Institute

Starr Receives Legion of Honor

EPRI President Chauncey Starr received the insignia of the French Legion of Honor at a recent ceremony in Washington, D.C. The medal was presented by the French ambassador, François de Laboulaye.

The Legion of Honor is the highest award given by the French Republic in recognition of outstanding service to France. It was created in 1802 by Napoleon Bonaparte and is given to both French citizens and persons from other countries.

Starr received the award in recognition of his contributions to the development of science and technology, and according to de Laboulaye, especially for his efforts in "promoting and furthering understanding of our country in the United States in the field of scientific and industrial achievements." The award will confer upon Starr the rank of Officer of the National Order of the Legion of Honor. Members of the Legion are appointed for life.

Before his appointment as EPRI president on January 1, 1973, Starr was dean of the UCLA School of Engineering and Applied Science. He came to UCLA after a 20-year industrial career in which he served as vice president of Rockwell International Corp. and as president of its Atomics International Division.

Starr is a member and past vice president of the National Academy of Engineering. He is a founder and past president of the American Nuclear Society and a member and past director of the American Association for the Advancement of Science. He has served on several national and international energy advisory boards and committees.

Cooling Combustion Machinery Research Authorized

The EPRI Board of Directors authorized a 4-year, $20 million research effort at their February 3 meeting that may remove a major technological obstacle to the commercial use of power plants that burn liquid and gaseous fuels made from coal.

The problem is that such fuels burn most efficiently at very high temperatures (1200–1240°C; 2200–2300°F) and that those temperatures cause the high-alloy metals used in the combustion machinery to deteriorate rapidly. The few metals that can be used are quite expensive.

The EPRI research program will demonstrate three suggested techniques for cooling the hot metal parts in the combustion equipment. If temperatures can be reduced to below 700°C (1300°F), a wider variety of metals can be used and the high cost of manufacturing and maintaining the equipment can be reduced.

The research will apply particularly to the combustion equipment of a combustion turbine–steam turbine combined-cycle system (CT–CC), which researchers believe is the most efficient system to use with coal-derived fuels.

In the CT–CC system, the hot gas created by the combustion turbine is used to heat water. The steam is used to drive a steam turbine that produces electricity.

The combined cycle is more efficient than a conventional cycle because it uses exhaust heat that would otherwise be wasted.

The cost of the research program, slated to run through 1981, will be shared by EPRI and major manufacturers of combustion turbines. EPRI's share will be $11.7 million and the manufacturers' portion will be $8.3 million.

In addition to the cooling project, 90 other projects were approved, with a total cost of $43.7 million. Directors also increased the authorizations for 46 previously approved projects by $20.6 million.

They allocated $2.3 million to continue a commercial solar heating and cooling (SHAC) demonstration project that involves seven commercial buildings.

The buildings, including school buildings, low-rise office buildings, banks, and restaurants, will be outfitted during the next two years with SHAC equipment and instrumentation. Data will be collected and analyzed for two to three years.

The project will enable utilities to obtain operating and maintenance experience on a wide variety of SHAC systems and will help them to determine the best ways of combining solar and electric energy.

In another action, the Board announced that Sterling Munro, administrator of the Bonneville Power Administration, Portland, Oregon, was appointed a member of the Board to fill the unexpired term of former director Donald P. Hodel.

It was announced that Robert A. Georgine is a new member of the EPRI Advisory Council, succeeding Charles H. Pillard. Georgine is president of the AFL–CIO Building and Construction Trades Department, Washington, D.C.

Dougherty Delivers IEEE Regional Keynote Address

In his keynote address before a meeting of the Oklahoma section of the Institute of Electrical and Electronics Engineers (IEEE), John J. Dougherty, director of EPRI's Electrical Systems Division, outlined several programs aimed at improving control of power systems.

Held March 1–3, 1978, the conference, which was geared to technical discussions on the control of power systems, was jointly sponsored by the regional IEEE group and the University of Oklahoma.

After acquainting the attendees with EPRI, its objectives, and overall research programs, Dougherty described specific Electrical Systems Division research that deals with power system control. He also outlined other work being done in substation and distribution automation.

In particular, he stressed the need for improved computer programs to simulate and study the effect of disturbances on power systems, such as loss of a transmission line or a generator due to a storm.

"Significant research has been initiated in the field of transient stability, that is, what happens to an electrical system in a period of seconds," said Dougherty. "EPRI has pioneered this area, but much more must be done to study system changes over longer periods, such as over an hour; different computer programs are necessary."

In outlining EPRI's system operations studies, Dougherty discussed the development of better training systems for power control operators and methods of improving the information that the control systems send to the operator. "A training system similar to that used in pilot flight training could contribute significantly to improved power system control in emergencies," he noted.

"The problems that occur in electrical power systems are very infrequent, which means that operators have little practical experience in dealing with those situations when they do occur," Dougherty told his audience. "This is why simulator-type training and periodic refresher courses geared to system emergencies could prove very helpful."

In the area of substation automation, Dougherty explained EPRI's plan to develop a minicomputer that could perform certain operational functions automatically, without the need for an operator. Such functions, for example, would include relieving the load on a transformer when temperatures exceed set limits.

Finally, the EPRI division director discussed research on distribution automation systems. This research involves remote meter reading, remote load management, and distribution system control and monitoring. The last entails actual emergency control of electrical equipment in customer facilities, such as cutting off air conditioners when peak demands are dangerously high and there is a possibility of a blackout.

Pressure Vessel Study Group

Spencer Bush (right) from Battelle, Pacific Northwest Laboratories discusses the latest advances in U.S. pressure vessel technology at the recent semiannual Pressure Vessel Study Group meeting in Palo Alto. Also pictured is Karl Stahlkopf (center) of EPRI's Systems and Materials Department (Nuclear Power Division), as he prepares to discuss the Institute's nondestructive testing research program. Looking on in the background is Alan Whiting of Southwest Research Institute. The meeting was attended by representatives from Germany, France, the United Kingdom, NRC, and several universities. Copies of the proceedings are available from Karl Stahlkopf.

Sagan Appointed Manager of Biomedical Studies Program

Leonard Sagan, M.D., has been appointed manager of the EPRI biomedical studies program. He is the second medical doctor to become a member of the Institute technical staff.

The former associate director of the Department of Environmental Medicine at the Palo Alto (California) Medical Clinic, Sagan joins James McCarroll, M.D., EPRI health effects program manager, in expanding research efforts aimed at identifying possible health effects associated with electricity generation.

EPRI has an extensive research program under way to define how power plant emissions, transportation of fuels, high-tension power lines, and power plant waste disposal may or may not affect human health; also, whether the effects can be mitigated, and if so, how. Sagan's particular research emphasis at EPRI will be on the cancer-inducing potential of power plant chemical emissions.

Sagan is the author of more than 30 medical and scientific papers. He received his B.A. degree from Stanford University, his medical degree from the University of Chicago, and his masters in public health from the Harvard School of Public Health.

He worked for the U.S. Atomic Energy Commission as a physician in nuclear medicine before his affiliation with the Palo Alto Medical Clinic in 1968.

Sagan has served on the medical advisory committees of the Oak Ridge Associated Universities Medical Division and Amnesty International, and has also been a member of the Santa Clara County (California) Medical Society. He is a fellow of the American College of Physicians.

Studies Probe Coal Resources and Production Costs

A series of studies to improve information about the availability of coal resources in the United States and the costs associated with coal production is being funded by EPRI.

This information is important to electric utilities because, as envisioned by the National Energy Plan and in electric utility estimates, coal is expected to play a more dominant role in the production of electricity in the years ahead. Utilities need to be assured of an uninterruptible coal supply, and some are considering purchasing their own coal reserves.

EPRI studies, explains Thomas Browne, assistant program manager in EPRI's Energy Analysis Department, are directed toward providing utilities with resource planning tools that will aid in estimations of coal reserves, production costs, and prices. The studies have produced models and assessments of such components of coal supply as price formation, transportation costs, mining costs, and resource data evaluation. The results of the studies were presented last week at a seminar sponsored by EPRI in Washington, D.C., for government and utility executives.

The quality of current published information about coal resources was evaluated in a study conducted by ICF, Inc. The study uses a case method approach to examine current information on coal resources in Campbell County, Wyoming. As explained at the seminar by Jerry Eyster of ICF, the study concludes that the current published information is outdated and the quality is poor. Eyster pointed out that new information is accumulating that would probably be adequate to give "reasonable resource assessments," but he explained that this information is developing so quickly that it is not now being reflected in the published data base. Hand calculations are so time-consuming, he explained, that the information is not available quickly enough in a usable form.

Another study described at the seminar focused on the development of a computer model for assessing and mapping coal resource information, which would save users from making such calculations by hand. Robert B. Honea of Oak Ridge National Laboratory, the contractor for the project, explained that the model would also reduce computation errors and increase the volume of data that can be produced and assimilated.

On the issue of coal production costs, George Toth of NUS Corp. presented two models developed for EPRI that would provide a systematic approach for determining the costs of opening and operating new coal mines, both underground and surface. The models give utilities and other users planning tools for estimating the annual production cost per ton of coal for such new mines. Cost models were also presented for coal transportation by railroads and waterways. James P. Hynes of Manalytics, Inc., made the presentation.

Influences affecting coal prices were discussed by William R. Hughes of Charles River Associates. This study concluded that the best predictor of long-range trends in the price of coal is the cost per ton of developing and operating a large, efficient new mine, including a return sufficient to attract capital. Other influences considered were labor supply, equipment and materials, productivity, and government intervention. Equipment and material bottlenecks were concluded to be primarily short-term problems, while the structure of the labor force and labor market conditions were regarded as important factors to watch.

The following reports are available through the Research Reports Center: *Coal Mining Cost Models—Underground Mines* (EA-437, Vol. I); *Coal Mining Cost Models—Surface Mines* (EA-437, Vol. II); and *Coal Price Formation* (EA-497). As reports on other projects become available, they will be announced in the *EPRI Journal.*

Corrosion Meeting

Louis J. Martel, program manager in the Systems and Materials Department (Nuclear Power Division), discusses EPRI research in steam generator reliability at the semiannual meeting of the EPRI Corrosion Advisory Committee. Composed of key international research engineers from government agencies, industries, and universities, the committee was formed in 1975 by E. L. Zebroski, director of the Systems and Materials Department. Looking on (from left to right) are Tatsuo Kondo, Japan Atomic Energy Research Institute; W. D. Fletcher, Westinghouse Electric Corp.; and Takashi Kojima, Tokyo Electric Power Co., Inc.

Operations Supervisors Workshop

A two-day course is being planned for June 6–7 to review current power system operation procedures, policies, and problems, as well as to acquaint operations supervisors and engineers with the hybrid simulator.

The course, being sponsored by EPRI and the University of Missouri, Columbia (UMC), will be held at the university. In addition to demonstrating the simulator's use in operator training, the course will demonstrate the hybrid simulator's capability to improve real-time operating procedures and security assessment.

What is the hybrid simulator? The simulator was designed and built at UMC under an EPRI contract. It is a variable-frequency ac simulation of electric power systems that is able to produce both short- and long-term dynamics. The power system is modeled with electronic analog circuits and is controlled by a 16-bit Texas Instruments digital minicomputer. The simulator can represent 16 machines, 72 buses, 26 transformers, and 32 loads.

The hybrid simulator has unique capabilities for training dispatch operators, according to members of EPRI's Electrical Systems Division. The power system response can be observed for a variety of contingencies and operating conditions. The simulator can be operated to demonstrate generator synchronism, emergency control procedures, tie-line control, and the effects of operator error.

Anyone wishing further information about the course should contact Dr. Lewis Walker at (314) 882-3510. Those wishing to attend the two-day course may contact the Engineering Conferences Office, 1020 Engineering Bldg., University of Missouri, Columbia, Missouri 65201; (314) 882-3266. A $100.00 registration fee is required.

NRECA Convention

Lowell Endahl (left), R&D coordinator of the National Rural Electric Cooperative Association (NRECA), and Robert Partridge (center), NRECA executive vice president and general manager, met with Ernest Ballard, a project manager in EPRI's Overhead Lines Program, at the EPRI information booth at the annual NRECA convention, February 8, in Las Vegas, Nevada. Ballard, who is on loan to EPRI from the Tri-State Generation and Transmission Association, a rural cooperative, discusses the new Polysil* insulator material.

*Polysil is an EPRI trademark.

Information Lacking on Health Effects of Nitrogen Oxides

The scientific information available on the possible adverse health effects of nitrogen oxides is insufficient for defining safe industrial emission levels.

Even though federal air quality standards for nitrogen oxides currently exist, a major conclusion of a report released recently by EPRI suggests that more research needs to be conducted before proper guidelines for nitrogen oxide emissions can be established.

The report is based on a one-year evaluation of current information conducted by Flow Resources, Inc. of San Rafael, California, under contract to EPRI (EA-668, *Nitrogen Oxides: Current Status of Knowledge*).

The importance of the report dates back to the 1970 amendments to the Clean Air Act. Among other things, the act established national air quality and emission standards for six hazardous air pollutants, including nitrogen oxides.

However, the report notes that there are key questions relating to nitrogen oxides that are still unanswered. For instance, how do nitrogen compounds combine with other compounds when emitted into the atmosphere? Which nitrogen compounds are potentially harmful to people? How much do power plants, as opposed to other industrial sources, contribute to the formation of nitrogen oxides?

Still other questions concern the contribution of nitrogen oxides from vehicle sources relative to emissions from other sources. The technologies used for controlling ambient nitrogen oxide levels depend on the cause of emission increase, says Cyril Comar, director of EPRI's Environmental Assessment Department.

"For example, if it is found that automobiles, rather than coal-fired power plants, are the prime source of nitrogen oxides in certain parts of the country, different control measures would be taken than if the reverse is true," states Comar.

The report notes that there is little doubt that high levels of certain types of nitrogen oxide compounds can have a potentially adverse effect on human health. However, up to this time, only a small fraction of these compounds have been tested.

"The results of those tests suggest that the levels required to produce harm are far in excess of those commonly encountered in the air, even under very bad pollution conditions," states Anthony V. Colucci of Flow Resources.

In fact, the report states that the toxic potential of nitrogen oxides probably lies more in their role as key components in reactions that produce photochemical smog than in direct impacts on human health.

The report concludes by describing the type of research now needed—particularly studies on more highly concentrated nitrogen oxides, both alone and in combination with other pollutants.

Survey of Utilities' Solar Research

Some 150 of the nation's electric utilities are sponsoring 468 research projects in solar energy, according to a recent survey by EPRI (ER-649-SR, *Electric Utility Solar Energy Activities—1977 Survey*). This represents a significant increase over the 245 projects identified last year in a similar EPRI report.

The survey shows that 74% of the projects are associated with residential and commercial solar heating and cooling systems. These studies range from the design, construction, monitoring, and evaluation of solar heating and cooling systems within utility service areas to projects aimed at determining the impact of such systems on utilities. Some of these projects are being totally funded by the utilities themselves, while others are being arranged in cooperation with DOE or with customers of individual utilities.

Other areas of utility solar research include solar-thermal electric power, photovoltaic and wind energy conversion systems, and solar data acquisition. Much of the solar-thermal electric research and photovoltaic research is being performed in cooperation with the government or with educational institutions.

The wind energy research partly represents utility participation in a DOE plan to build five experimental wind-generating systems, one of which has been operating in Clayton, New Mexico, since January. Three more are scheduled to be operating at the end of the year and the fifth in 1979. The utilities that are participating in these projects are also collecting wind resource data.

Another major area of utility research is the collection of solar radiation data. This work generally involves solar resource evaluation studies, which are currently being undertaken by a number of utilities in the western states.

Other projects vary in purpose, although many include programs to disseminate information on conserving energy through solar heating and cooling of buildings.

Although Louise Cleary, analytical engineer for EPRI, believes the 1977 study is more thorough than the one done in 1976, she notes that the survey is not meant to be the last word on utility-sponsored solar research. Cleary concludes that "utility interest shown during the past few years in solar energy research indicates that the number of utility-sponsored projects will continue to grow."

EPRI Negotiates 63 Contracts

Number	Title	Duration	Funding ($000)	Contractor, EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP475-4	Gas-Cooled Solar Central Receiver: Open-Cycle Pilot Plant Study	8 months	100.0	Black & Veatch *J. Bigger*
RP629-3	Procedure for Prediction of Electrostatic Precipitator Performance	3 months	25.5	Southern Research Institute *W. Piulle*
RP722-2	Preliminary Design and Cost Estimates for a Commercial-Scale Atmospheric Fluidized-Bed Combustion Steam Generator	13 months	278.5	Babcock & Wilcox Co. *T. Lund*
RP725-10	Apitron Electrically Augmented Fabric Filter	4 months	18.4	American Precision Industries, Inc. *R. Carr*
RP799-15	Critical Solvent Pilot Plant—Third Stage	2 months	53.0	Kerr-McGee Corp *N. Stewart*
RP982-6	Evaluation of Stack Gas Control Apparatus and Related Technology	1 year	28.6	Kaiser Engineers *O. Tassicker*
RP986-3	Screening Evaluation of Novel Power Cycles Integrated With Gasification Plants	6 months	59.8	General Electric Co. *M. Gluckman*
RP990-3	Screening Evaluation of Novel Power Cycles Integrated With Gasification Plants	6 months	60.0	Westinghouse Electric Corp. *M. Gluckman*
RP1033-1	Advanced Flue Gas Desulfurization and Test Facility	18 months	1600.0	Tennessee Valley Authority *T. Morasky*
RP1037-2	Dynamic Stimulation of Single-Stage Entrained-Flow Coal Gasification	10 months	129.6	Systems, Science & Software *G. Quentin*
RP1075-1	Characterization of Polycyclic Organic Matter Emissions in Power Plant Effluents	1 year	399.8	KVB, Inc. *M. McElroy*
RP1086-1	An Assessment of the Use of Chemical Reaction Systems in Electric Utility Applications	5 months	83.6	Gilbert Associates, Inc. *B. Mehta*
RP1087-1	Assessment of the Practical Potential for Heat Recovery and Load Leveling on Refrigeration Systems	1 year	119.9	Arthur D. Little, Inc. *E. Ehlers*
RP1092-1	Air Supply System, Solar Receiver Bench-Model Test Program	4 months	293.0	Boeing Engineering & Construction *J. Bigger*
RP1134-2	Process Development for Improved Solvent-Refined Coal	1 year	191.9	Kerr-McGee Corp. *H. Lebowitz*
RP1136-1	Test and Evaluation of Electric Vehicles	9 months	52.5	Southern California Edison Co *F. Kalhammer*
RP1196-1	Field Evaluation of Rotary Phase-Separator/Expander Engine	1 year	200.0	Biphase Energy Systems, Inc. *G. Underhill*
RP1200-2	Development of Carbon Substrates for Phosphoric Acid Cathodes	1 year	78.7	Stonehart Associates, Inc. *A. Fickett*
RP1201-2	Evaluation of New Technical Options for Improved End-Use Efficiency of Electricity	11 months	5.0	Johns-Manville Sales Corp. *E. Ehlers*
Nuclear Power Division				
S103-1	Evaluation of Optical Inspection of Steam Generator Tubes	8 months	47 0	Science Applications, Inc. *J. Mundis*
S105-1	Development of Radiography Techniques to Evaluate Support Plate Integrity	18 months	151.2	Combustion Engineering, Inc., Power Systems Group *J. Mundis*
S107-1	Development of Ultrasonic Test Techniques to Evaluate the Extent of Tube/Tube Support Plate Crevice Blockage	23 months	92.9	Combustion Engineering, Inc., Power Systems Group *J. Mundis*
S122-1	Method of Reducing Carryover and Reducing Pressure Drop Through Steam Separator	10 months	64.1	Combustion Engineering, Inc., Power Systems Group *J. Mundis*
RP434-2	Environmental Testing of Prototype Heater Rods	6 months	25.5	Columbia University *M. Merilo*
RP964-4	Vibration Tests at Indian Point-1	26 months	190.3	EDS Nuclear, Inc. *C. Chan*

Number	Title	Duration	Funding ($000)	Contractor EPRI Project Manager
RP965-5	Incompressible and Implicit Compressible STEALTH	5 months	34.8	Science Applications Inc. *J. Carey*
RP1065-1	Asymmetric Hydrodynamic Loads During a Hypothetical LOCA	3 years	653.0	Intermountain Technologies, Inc *R. Oehlberg*
RP1065-2	Asymmetric Hydrodynamic Loads During a Hypothetical LOCA	3 years	312.5	Science Applications, Inc. *R. Oehlberg*
RP1119-1	Analysis of the Peach Bottom Transient Tests	20 months	21.9	Oregon State University *J. Naser*
RP1120-1	On-Line Nuclear Power Distribution	13 months	98.3	Nuclear Associates International, Inc. *A. Long*
RP1120-2	Core Power Distribution —Control and Analysis	5 months	15.0	Systems Control, Inc. *A. Long*
RP1123-1	Evaluation of Multiaxial Fatigue	2 years	232.5	Stanford University *K. Stahlkopf*
RP1124-4	Turbine Chemical Monitoring	17 months	57.0	Nuclear Water & Waste Technology, Inc. *T. Passell*
RP1124-6	Project Overview: Turbine Chemical Monitoring	3 months	5.2	NUS Corp. *T. Passell*
RP1128-2	Feasibility of Low Water Volume Fraction Lattice Reactor Designs	1 year	133.0	Babcock & Wilcox Co. *R. Sehgal*
RP1161-1	Temperature Sensor Fundamentals and Technology Confirmation	1 year	49.1	University of Tennessee *D. Cain*
RP1170-1	Effects of Heat Treatment on Passive Behavior of Nickel-Chrome-Iron Alloys in High-Temperature Water	1 year	50.0	The International Nickel Co., Inc. *R. Smith*
RP1174-1	Effects of Weld Parameters on Residual Stresses in BWR Piping Systems	23 months	275.0	Battelle, Columbus Laboratories *R. Smith*
RP1177-1	In-Core Fuel Management for Operational Decisions and Problems	18 months	35.2	University of Cincinnati *W. Eich*
RP1227-1	Experimental Assistance for Reactor Safety and Analysis Research	3 years	100.0	SRI International *R. Duffey*

Electrical Systems Division

Number	Title	Duration	Funding ($000)	Contractor EPRI Project Manager
RP670-2	Improvement of Mathematical Techniques for Dynamic Analysis	18 months	352.7	Boeing Computer Services, Inc. *P. Anderson*
RP850-40	Field Demonstration of Communication Systems for Distribution	27 months	1262.9	Westinghouse Electric Corp. *W. Blair*
RP1138-1	High-Voltage DC–AC Interaction From AC Harmonics	18 months	308.9	General Electric Co. *I. Vancers*
RP1141-1	Study of Lightning Current Magnitude Through Distribution Arresters	13 months	223.3	The Detroit Edison Co. *H. Songster*
RP1203-1	Polysil Outdoor Insulating Material Development	15 months	105.0	Lindsey Industries, Inc. *M. Rabinowitz*
RP1208-2	Extended Dynamic Stability Analysis, Using Advanced Techniques	22 months	95.5	Arizona State University *P. Anderson*
RP1208-3	Extended Dynamic Stability Analysis, Using Advanced Techniques	22 months	158.5	Boeing Computer Services, Inc *P. Anderson*
RP1208-4	Extended Dynamic Stability Analysis, Using Advanced Techniques	22 months	148.9	Systems Control, Inc. *P. Anderson*
RP7801-5	Waltz Mill Forced Cooling Test Facility Research	3 years	492.6	Underground Systems, Inc *J. Shimshock*

Energy Analysis and Environment Division

Number	Title	Duration	Funding ($000)	Contractor EPRI Project Manager
RP867-2	Verifying the Usefulness of Engineering Process Models Applied to Forecasting	1 year	39.7	A. I. Fletcher & Associates *R. Riley*
RP1059-1	Measurement of Transuranium and Other Long-Lived Radionuclides in the Environs of Nuclear Power Plants	30 months	355.0	Battelle Pacific Northwest Laboratories *R. Perhac*
RP1112-2	Animal Toxicologic Studies on Fossil Fuel Combustion Products	30 months	1515.2	University of California *J. McCarroll*
RP1147-1	Labor Factor in Energy Supply	17 months	226.1	The Conference Board *J. Chamberlin*
RP1150-1	Estimated Energy Supply from Natural Resources	1 year	159.6	Massachusetts Institute of Technology *A. Halter*
RP1152-1	Industry and Economic Impacts of Restrictions on the Growth of Generating Capacity	3 months	146.0	Dale W. Jorgenson Associates *S. Peck*
RP1153-1	Integrated Regional Electric Power Planning and R&D Analysis	11 months	98.9	University of Texas at Austin *J. Karaganis*
RP1155-1	Characteristics of Acidic Precipitation in the Adirondack Region	28 months	375.0	Rensselaer Polytechnic Institute *C. Hakkarinen*
RP1156-1	Development of a Power Plant Ash Structural Fill Handbook	1 year	64.4	GAI Consultants, Inc *R. Kawaratani*
RP1158-1	Relationship between Energy and GNP in the U.S.	9 months	100.0	Resources for the Future, Inc *S. Peck*
RP1214-1	Simplification of Engineering Process Models for Forecasting Electricity Consumption	1 year	60.9	Stanford University *L. Williams*
RP1217-1	Behavior of Natural Resource Prices	1 year	53 8	Resources for the Future, Inc. *M. Searl*
RP1218-1	Significance of Uranium in Volcanic Environments	30 months	124.2	University of Texas at El Paso *J. Clark and M. Searl*
RP1222-1	Trace Organic Compounds in Urban Atmospheres	2 years	345.9	New York University Medical Center *R. Perhac*

New Power Plant Integrates Three Processes

A new type of power plant now under development may offer greater efficiency and economy than is currently being achieved by conventional coal-fired plants, according to a report released recently by EPRI (AF-642, *Economic Studies of Coal Gasification–Combined-Cycle Systems for Electric Power Generation*).

The power plant would integrate three proven processes: coal gasification; a commercial gas-cleaning process that removes sulfur and nitrogen compounds, as well as particulates, from the gas; and a combined-cycle system.

In a combined-cycle system, electricity is produced from both a combustion turbine and a steam turbine. The exhaust gases from the combustion turbine are used to produce steam, which is used in the steam turbine. The combined cycle is considered the most efficient system for using gaseous fuels made from coal.

Commercialization in the United States of these gasification–combined-cycle (GCC) plants is not anticipated until the late 1980s or early 1990s, according to Michael Gluckman, program manager, EPRI Fossil Fuel and Advanced Systems Division.

The EPRI report (which was prepared by Fluor Engineers and Constructors, Inc.) confirms EPRI's interest in integrating gasification systems with combined-cycle plants. In association with DOE, Commonwealth Edison Co., and the State of Illinois, EPRI is designing a GCC test facility at Commonwealth Edison's Powerton Station near Pekin, Illinois.

A discussion of the various gasifiers now being developed and their impacts on the design and cost of power plants also is featured in the report. It notes that power plants integrated with these improved gasification systems could cost up to 15% less to build and 20% less to operate than comparable conventional coal-fired plants.

GCC plants, in general, emit fewer pollutants than do conventional coal-fired plants. During gasification, most of the sulfur in the coal is converted to hydrogen sulfide, which can be removed from the combustible gases created by the gasification process.

GCC plants also reduce the substantial water consumption associated with conventional plants. A coal-fired plant uses a conventional steam cycle, in which a large amount of water is needed to condense the steam used in electricity generation. In a GCC plant, 50–60% of the electricity is generated by the combustion turbine, which does not need cooling water, according to Gluckman.

Waste Heat May Help Greenhouse Operators

Someday there may be a common sight next to many of the country's power plants: greenhouses.

Growing vegetables and flowers in soil warmed by the waste heat from power plant operations is a novel idea with potential benefits for both the agricultural and the utility industries, according to Robert Kawaratani of EPRI.

If the technology is successfully demonstrated, greenhouse operators would have an alternative source of heat—an important consideration since natural gas and oil are either unavailable or very expensive in many parts of the country. Utilities, in turn, could benefit by selling the waste heat instead of dissipating it to the atmosphere, as is now often done.

Kawaratani, a project manager in EPRI's Environmental Assessment Department, says the system (now being studied on a laboratory scale) could eventually have a power plant's hot waste water piped directly to a nearby greenhouse for soil heating.

Contracted to the Ohio Agricultural Research and Development Center (OARDC) in Wooster, the EPRI project will run three years. Researchers will primarily be improving designs for the heat exchanger, which in this case is the soil-heating pipe. In addition, they will try to solve the problem of the soil's drying out near the heating pipes—a problem that makes the heat transfer less efficient.

According to Warren Roller of OARDC, researchers hope to determine in later experiments whether warming the soil, and hence the roots of vegetables and flowers, can speed up growth. "If so, the air temperature in greenhouses could be lowered to save fuel."

Although the EPRI experiment is concerned only with soil heating, other experiments are being undertaken by utilities and the government to investigate the use of waste heat for both soil heating and air warming in greenhouses. Northern States Power Co., for example, has been supplying waste heat for the past three years to a research greenhouse at a power plant located outside Minneapolis.

Estimates are that the waste heat from a large 1000-MW power plant could be used to heat several hundred acres of greenhouses.

But while power plant–greenhouse operations may prove highly valuable to greenhouse operators, Kawaratani notes that the benefits to utilities are somewhat less certain because of the high costs of transporting hot water via pipelines.

"The power plant–greenhouse hookups would only be economical if the greenhouses are located within a couple of miles of the power plant," states the EPRI project manager. "Otherwise, the pumping costs would probably outweigh any possible benefits."

Washington Report

Nuclear Initiatives Dominate First Quarter

With the coal strike causing fuel supplies to dwindle and job layoffs in many parts of the country, and with President Carter's energy bill still stalled in Congress over the natural gas pricing and oil tax issues, activity in nuclear power has seemed to be on an upswing during the first quarter of the new year.

Initiatives have come from both the public and the private sectors in the areas of alternative fuel cycles, the fast breeder reactor, nuclear licensing, exports, and waste management.

Just a year ago—in one of the first energy statements of his new administration—President Carter announced a major change in U.S. domestic nuclear policy, away from commercial reprocessing and the breeder reactor and toward nuclear fuel cycles that "do not involve direct access to materials usable in nuclear weapons."

This year, at the Fifth Energy Technology Conference in Washington, D.C., EPRI President Chauncey Starr, Deputy Chairman Walter Marshall of the U.K. Atomic Energy Authority, and colleagues from the United States and the United Kingdom proposed a technical solution that would allow commercial reprocessing and development of the breeder to proceed. This concept is described in this month's feature article, "Civex: A Diversion-Proof Plutonium Fuel Cycle" (page 11).

Reaction to the Civex proposal came instantly and strongly. U.S. Senator Frank Church of Idaho, chairman of an energy R&D subcommittee, remarked that "the opportunity is now at hand for the United States to once again capture the lead in creating safe, proliferation-proof use of the plutonium fuel cycle." A subcommittee of the U.S. House of Representatives Committee on Science and Technology voted to add $15 million to DOE's budget for fiscal year 1979 to work on the Civex fuel cycle. Full committee markup of that bill is now awaiting an administration policy announcement on nuclear power and the breeder, but a subcommittee staff member said that he expected the Civex concept to be greeted with "enthusiasm" by the administration.

Indeed, State Department official Joseph S. Nye was quoted in *Newsweek* as saying that Civex is "an example of the kind of fruitful suggestion we want studied." And several weeks after Civex was introduced, DOE Secretary James Schlesinger proposed to Congress that Civex be among the processes included in a $55 million study, in fiscal year 1979, of fuel cycles that might be used with a breeder reactor larger than the Clinch River Breeder Reactor (CRBR).

From the media, syndicated columnist Joseph Kraft hailed the idea as "good news" and a "special boon for President Carter." Kraft wrote that the president "would be well advised now to seize the opportunity for proclaiming this country's full entry into the nuclear age." And *Detroit News* columnist J. F. terHorst wrote perhaps the best statement summarizing the significance of the announcement. Civex, he wrote, "promises to lift the heavy burden of weapons proliferation from the peaceful use of the atom."

The Civex proposal will be presented to the International Nuclear Fuel Cycle Evaluation study group, which was formed last fall at the suggestion of President Carter.

In other actions, after a long struggle with Congress over funding for the CRBR demonstration plant near Oak Ridge, Tennessee, President Carter finally signed the FY78 supplemental appropriations bill granting $80 million for the project. (The administration had originally requested $33 million, a level sufficient only to terminate the project.)

But even as this glimmer of hope seemed to be emerging for CRBR, the administration was sounding its death knell with an official White House statement that the $80 million would be used "to complete the systems design for this reactor and to terminate further CRBR activities in an orderly way."

Not so, responded the General Accounting Office (GAO), an investigative arm of Congress. In what amounted to a temporary reprieve for the project, Comptroller General Elmer Staats said that funds appropriated for CRBR can be "used only for the design, development, construction, and operation of a liquid metal fast breeder reactor and they may not be used to terminate such activities." GAO would disallow any expenditures inconsistent with this opinion, Staats insisted. But later Schlesinger reiterated the president's determination to block construction of the demonstration plant. And, according to Schlesinger, the administration is now disposed toward "redirecting the nation's breeder program to evaluate designs for a larger advanced fission facility."

A DOE task force has completed the "first step toward formulation of an administration policy" on nuclear waste management, John Deutch, Director of the Office of Energy Research and head of the task force, said at a news briefing on March 15. He described recommendations of the working group and said that these points would serve as a basis for an interagency review that was initiated by order of the president that same day. The Interagency Nuclear Waste Management Task Force will have the final responsibility for drafting recommendations that will result in administration policy. The work of the interagency group is to be completed by October 1.

DOE has sent Congress legislation "to improve the effectiveness of the nuclear power licensing process." The proposed legislative changes are expected to cut in half the time needed to complete a plant (10–12 years). The bill promotes early site approvals and standardized power plant designs. Schlesinger, in commenting on the legislation, said the 1973 oil embargo, 1977's natural gas shortages, and this year's coal strike underscored the need to diversify the fuels used to generate electricity. "Today, the cumbersome and uncertain nuclear power plant licensing process serves as a major constraint to nuclear power as a viable option," he said.

In another nuclear action, the president signed into law the Nuclear Non-Proliferation Act of 1978, which places strict controls on nuclear exports.

NRECA Resolution on Nuclear Power

As part of the Thirty-sixth Annual Meeting of the National Rural Electric Cooperative Association (NRECA), the members adopted a series of resolutions prepared by NRECA's Research and Technological Development Committee. The resolutions reflected a feeling of urgency and uncertainty over problems facing rural electric systems.

In the area of nuclear power R&D, a resolution was adopted that expressed deep concern with "de-emphasis of nuclear power as a viable power option of the future and the resulting neglect of research and development involving nuclear power in general and the breeder reactor in particular." The resolution urged that "federal research in the nuclear power field be increased and redirected to deal with the so-called proliferation problem as it relates to nuclear power by a refined and revised fuel cycle and continued development of the breeder reactor."

Another resolution urged the government to pursue R&D in magnetohydrodynamics, and still another urged individual member rural electric systems to investigate load management tools for their individual systems and to begin implementation slowly and carefully where there appear to be clear benefits for their members.

Congressional Support for Fuel Cell Technology

A strong indication that Congress favors continuation of federal participation in development of the fuel cell beyond the 4.8-MW demonstration project DOE is sponsoring with EPRI and United Technologies Corp. was given on March 15 when a House subcommittee approved $25 million for activities leading to commercialization of the technology.

The Advanced Energy Technologies Subcommittee of the House Science and Technology Committee approved the funding contingent on DOE's providing a commercialization plan for the fuel cell and on commitments by utilities and other organizations to purchase approximately 500 MW of power, produced using the technology, for either electricity generation or cogeneration.

"The amendment gives us a signal that Congress believes the fuel cell will make a contribution to solving our nation's energy problems," said Leonard Rogers, DOE's manager for the 4.8-MW program.

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

BATTERY COSTS

Battery energy storage systems are being developed to reduce utility system costs, to improve the capacity factor of baseload generation plants, and to reduce oil consumption by the electric utility industry. EPRI's battery subprogram involves assessment and development of several battery energy storage systems: sodium-sulfur, zinc-chlorine, sodium–antimony trichloride, zinc-bromine, and lithium–iron sulfide (RPs 128, 226, 109, 635, and 116, respectively). How do these battery systems compare with one another and with alternative generation and energy storage systems? In large part, the answer to this question comes down to economic comparisons. Yet most cost projections for advanced technologies to be used in electric utility systems are viewed with great skepticism—an attitude justified by the wide range of cost estimates offered by the technical community. Cost projections for advanced batteries have not escaped this lack of credibility. Back-of-the-envelope calculations have often shown whatever the cost estimator wanted them to show. Thus, EPRI is endeavoring to make battery costing a science, not an art.

The approach to costing

Batteries cannot be costed by the techniques usually applied to electric utility systems. From the viewpoint of the utility industry, battery energy storage systems are unique. The most unusual aspect is that large battery energy storage systems are not made up from large batteries but rather from thousands of small (~1-kWh) cells. This feature of batteries provides important challenges in costing and commercialization, which stem from the following specific battery characteristics:

- Batteries are manufactured rather than site-assembled products.
- Battery price is extremely sensitive to materials costs (materials and components account for 50–70% of the price).
- Substantial investments in working capital, plant, and equipment are required for manufacturing battery systems.

These challenges to costing are compounded by several problems, including the use of variable, ill-defined assumptions and the lack of sophisticated design and cost detail. Consequently, EPRI's objectives in quantitatively assessing future battery selling price were to:

- Standardize costing assumptions
- Complete design and cost studies of the individual battery systems
- Specify critical raw materials and assess future commodity prices and availability
- Identify key cost components and conduct special studies to project and to minimize costs

The first step was to standardize costing assumptions. As with costing in general, the cost estimator has to make some arbitrary assumptions. For batteries, these assumptions deal with three issues: (1) application (e.g., duty cycle, size, voltage); (2) manufacturing and business considerations (e.g., labor, capital, materials, return on investment); and (3) level of technology development. With the assistance of Arthur D. Little, Inc. (ADL) and the major U.S. battery developers, EPRI and ERDA (now DOE) established reasonable and generally acceptable standard assumptions (RP787) by specifying a standard battery (Table 1) and a standard manufacturing facility.

In the second step, EPRI and DOE asked

Table 1
THE STANDARD BATTERY ENERGY STORAGE SYSTEM

Parameter	*Assigned Value*
Energy storage capacity	100 MWh
Voltage	1000 V (end of charge)
Life	2500 cycles (10 yr)
Discharge period	5 and 10 h (constant power)
Charge period	10 h (85% of charge in 7 h)
Energy efficiency	75% (dc out divided by dc in)
Footprint	85 kWh/m² (8 kWh/ft²)
Maximum height	6 m (20 ft)
Module* description	Truckable, weatherproof

*The module is the physical building block of the battery system.

the battery developers to use these assumptions in cost-estimating work. ADL consulted with each of the EPRI developers to arrive at cost estimates. In addition to estimating bottom-line prices, these studies defined raw materials requirements and identified key cost components. Since the developers, who were advocates of the technology, were doing the costing work, an iterative approach was taken: first, costs were projected, then cost reduction approaches were specified, and finally costs were reprojected. This process continued as long as the cost projections were above the target values or until the developer exhausted all cost reduction possibilities. The end result was that cost projections were nearly always close to the goal. Herein lies an important use of the costing exercise—to specify materials, components, and manufacturing concepts that are necessary to achieve a salable product. The question then becomes, how technically viable are the materials, components, and manufacturing concepts that were specified in the cost-reduction exercise? An extensive testing program is being conducted to assess the viability of the selected materials, components, and manufacturing concepts.

The third step was to investigate raw materials requirements, cost, and availability. EPRI's Energy Analysis and Environment Division initiated a project with Charles River Associates Inc. and SRI International to investigate future commodity prices of such materials as lithium, lead, zinc, graphite, chromium, and antimony—materials used in advanced battery systems (RP947).

The last step involves independent assessments of critical cost components and materials. An example of the effort to look at the specific cost issues is a study conducted at Compagnie Générale d'Electricité (France) to assess electrolyte costs for the high-temperature sodium batteries (RP726). Another related study was conducted by Bechtel Corp. to investigate relative costs of various chlorine storage concepts for the zinc-chlorine battery (RP731). Additional projects along these lines will be initiated in 1978.

Results

There have been two important results from this work to date. First, battery systems were evaluated as to how they appeared to meet the cost goals and were ranked (in descending order): sodium-sulfur, zinc-chlorine, sodium–antimony trichloride, and lithium–iron sulfide. The information available is insufficient for ranking the zinc-bromine battery. The second result is the conclusion that advanced batteries have the potential to become an attractive energy storage option. The cost projections fell within $30–$50/kWh for all the battery systems studied. This means that a five-hour battery system with power-conditioning equipment ($80/kW) will cost just under $300/kW—EPRI's goal for battery selling price.

As indicated previously, it is hardly surprising that the developers' projections are within the EPRI goals for battery price. What is significant, however, is that the concepts (for materials, components, and manufacturing) to achieve the cost goals offer technical as well as economic promise. However, the viability of these concepts will not be assured until the life and performance of the battery are demonstrated. Thus, proof of technical viability becomes an important factor in demonstrating economic feasibility. Because of the novelty of much of the technology associated with the development of advanced battery systems, resolution of manufacturing cost uncertainty and technological issues is unlikely until more experience has been gained in manufacturing these batteries—on at least a pilot plant scale—and in long-term testing of large (100-kWh) batteries.

Battery costs and commercialization

The projected range of battery price estimates assumes a semimature state of technology. This means that the price is for a battery manufactured by the first full-scale plant (2500 MWh/yr) in its second or third year of operation. A major issue is, How is it possible to get there? Batteries from pilot manufacturing plants (10 MWh/yr) may cost several hundred dollars per kilowatthour. Even with full-scale manufacturing plants it is likely that months, or even years, will be required to reduce costs to a level where they are reasonably close to the affordable utility cost. This reduction in price with time and quantity of sales follows what is referred to as the learning curve. Who will underwrite this curve and how will it be done? This topic will be the subject of a future status report on the EPRI battery subprogram.

While it is not possible to conclude this report with firm price quotes for batteries, the impact of an integrated and focused costing approach is clear. From this work it has been possible to gain insight into the prospects for battery energy storage; to select materials, components, and operating conditions for the various battery systems; and to arrive at a preliminary comparison of the various advanced batteries. *Project Manager: James Birk*

MATERIALS PROBLEMS AND OPPORTUNITIES

The failure of a power plant component is not necessarily caused by a shortcoming in its construction material. Most failures are the result of a complex interaction of materials, design, and operation. In recognition of this fact, the materials R&D attempts to identify interfaces in coal-fired plants where materials R&D will resolve generic problems in utility equipment or provide an opportunity for improved performance or reliability.

The Materials Support Program interfaces with all 15 program areas in the four departments of the Fossil Fuel and Advanced Systems Division. Some programs are more materials-intensive than others, and materials support projects are distributed accordingly. The group's attention is divided equally between problem solving and exploitation of opportunities for improving system performance and reliability.

FBC boiler tubes

Fluidized-bed combustion (FBC) boilers of both the atmospheric and pressurized types have heat transfer tubes in the fluidized bed itself because of the high heat transfer characteristics and consequent small boiler size of the FBC boiler. The FBC bed temperature is much lower than combustion temperatures in pulverized-coal boilers. Thus, lower NO emission is another bonus of FBC combustion, along with reduced SO emission. It was anticipated that the low bed temperature—below slagging temperatures normally associated with fireside corrosion—would result also in a reduction of boiler tube corrosion. Unfortunately, this expectation did not develop. The corrosion characteristics of boiler tube candidates were evaluated for EPRI in tests at the National Coal Board FBC Test Facility at Stoke Orchard, England (RP388 and RP979). With metal temperatures varying from 540°C (1000°F) to 900°C (1652°F), it was found that corrosion rates were surprisingly high, particularly for normally highly corrosion-resistant materials like nickel-based superalloys. An encouraging finding was that the corrosion performance of austenitic stainless steels was approximately the same as found in pulverized-coal boilers for the same metal temperature. This offers a group of cost-effective boiler tube alloys from which to build FBC superheaters and reheaters in steam-raising FBC.

The product of desulfurization with limestone is calcium sulfate, some of which forms an adherent deposit on the in-bed tubes. The oxygen activity in local regions of the FBC bed is surprisingly low—approximately the same as that found in atmospheres of gasified coal—despite the use of excess air in combustion. Associated with the low oxygen activity is a relatively high sulfur activity, which allows liquid nickel sulfide slag to form on nickel-based alloy surfaces, with accompanying catastrophic corrosion rates. A data base for selection of FBC boiler tube materials will be established by a further series of corrosion tests to be conducted by the National Coal Board at its Leatherhead, England, facility in a boiler with a bed whose area is approximately equal to that to be fed by each coal feed port in anticipated utility FBC boilers.

Other problems that need to be resolved before advantage can be taken of the improved thermal efficiency and reduced plant size and cost of fluidized bed combustors are erosion, hot corrosion, and fouling of the gas turbines used in expansion of the pressurized combustion products in the pressurized FBC boiler. Preliminary erosion-corrosion studies conducted for EPRI in a burner rig at United Technologies Corp., Pratt & Whitney Division (RP543) showed that turbine materials are hot-corroded and eroded by gases with sodium levels and particulate loadings comparable to those expected to pass through hot gas cleanup devices. In order to avoid erosion from particulate matter consisting of ash, unburned coal, or limestone from the bed, it is necessary to keep the particle size below about 2 μm. Under these conditions, the particulate matter may deposit on the turbine parts—that is, fouling may occur. Sodium contents below one part per million in the fuel are necessary to avoid formation of corrosive Na_2SO_4 condensate. We hope to find solutions to these problems through improved hot gas cleanup, periodic cleaning of the turbines, and improved turbine materials and coatings.

Large rotor forgings

A continuing concern related to utility equipment is the quality and reliability of the large forgings used in turbine and generator rotors. Failure of a rotor in service is a catastrophe that is guarded against in the rotor design and in ingot-making and forging practices. In recent years, electroslag remelting processes have been developed that have greatly improved the uniformity and soundness of large ingots. The electroslag remelt operation acts in many ways like an ideal hot top in that heat is continuously put into the molten pool to maintain a supply of high-quality molten metal to fill the ingot as it shrinks during solidification. The straight electroslag remelt process has size limitations that make it possible to produce ingots large enough only for high-pressure rotor forgings—about 30 t. However, two recent adaptations of electroslag remelting technology provide a way to bring its advantages to ingots of the 200-t class, the largest that are used today for the enormous forgings needed for generator rotors. These adaptations are the electroslag hot topping (ESHT) and central zone remelting (CZR) processes, both developed in Europe. The consumable electrode either is remelted through a refining slag while the large conventional ingot is solidifying (ESHT process) or is remelted into a large conventional ingot after the central core has been removed by hot trepanning (CZR process).

Electroslag-processed ingots have the advantage of high yield from ingot to forging (a yield increase of about 50% over conventional types), which compensates to a large degree for the additional cost of the remelting operation. Many of the advantages of electroslag-processed ingots can be obtained with an improved conventional process developed in Japan. This process consists of double slag treatments to reduce sulfur to about one-quarter the conventional level (with corresponding reduction in sulfide inclusion levels) and an improved hot topping practice for increasing central ingot soundness.

EPRI is planning to launch an evaluation program to demonstrate these four advanced heavy forging practices. They will be evaluated in the form of high-pressure Cr-Mo-V forgings. After the forgings are thoroughly evaluated, they will be installed in operating utility turbines for further evaluation.

Titanium low-pressure turbine blades

Titanium has become of major interest in utility condensers employing saltwater cool-

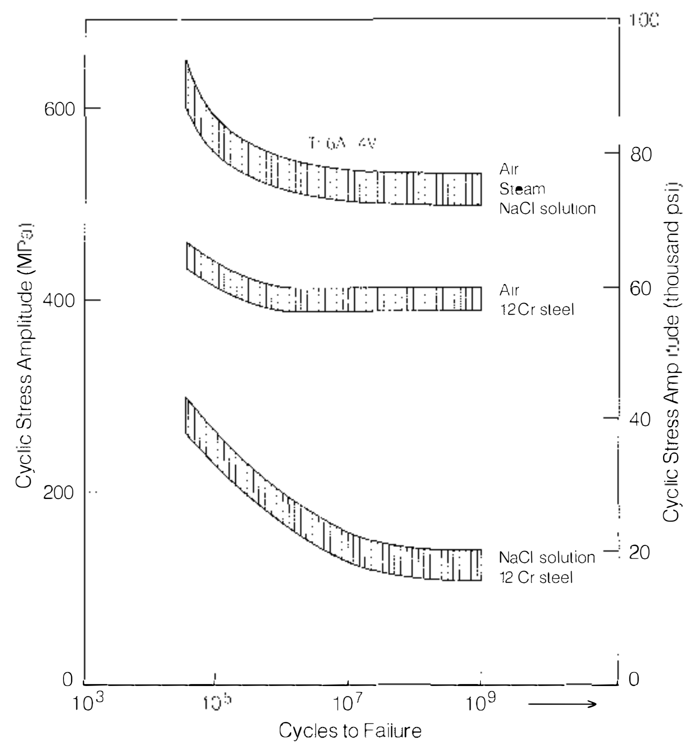


Figure 1 High-cycle fatigue properties of turbine blading alloys—Ti-6Al-4V and 12Cr steel—in air, steam, and salt water at room temperature. The titanium alloy is unaffected, whereas the fatigue properties of the 12CR steel are severely degraded in 1% NaCl, representing steam condensed in fossil turbines.

ing because of its exceptional resistance to erosion and pitting. It is for the same reasons that titanium is of interest as an alternative to 12Cr steel in low-pressure steam turbine blading. The last stages of fossil turbines are subject to deposition of corrosive condensates at the Wilson line where the first wetness occurs. This generally occurs in the L − 1 row of fossil turbines, which suffers from more forced outage than all other rows combined. Titanium and its alloys are protected by a passive film of TiO_2 over a wide range of pH from acidic through alkaline at temperatures up to about 93°C (200°F), which are the conditions found in the last stages of the low-pressure turbine. Titanium does not form pits in this regime of pH and temperature, even in crevices or under deposits; whereas in chloride condensates, the common 12Cr blading steel is susceptible to pitting, a condition conducive to fatigue crack initiation.

An investigation of the status of titanium blading has shown it to be in an advanced state of development worldwide, ready for steam turbine applications (TPS76-641). Most steam turbine makers have experimental blades under evaluation in operating turbines. The blades have run satisfactorily for up to 20 years with no failures reported. Most of the work has been done on blades of Ti-6Al-4V alloy, whose fatigue properties are unaffected by steam and sodium chloride solutions, while the fatigue strength of 12Cr steel is drastically reduced in sodium chloride solution (Figure 1).

A study has been initiated with Westinghouse R&D Center, Pittsburgh, on the effects of impurities in steam and steam condensates on the corrosion fatigue resistance of Ti-6Al-4V alloy and the common blading steels, 12Cr and 17-4PH (RP912). Also, in February the EPRI Board of Directors approved a plan to evaluate the operating characteristics of a titanium L − 1 row to be retrofitted in Commonwealth Edison's Kincaid No. 1 Station, which has been plagued by corrosion fatigue failures in the 12Cr blades of the L − 1 row. This project, which will demonstrate the manufacturing and operating characteristics of titanium blades, is to be cofunded by Westinghouse and Commonwealth Edison Co.

Because titanium alloys have lower damping characteristics than steel blades, the titanium blade operating stresses to be determined by telemetry in the Kincaid retrofit project will be of particular interest. The resistance of Ti-6Al-4V to water droplet erosion is almost as good as that of Stellite, the common erosion shield material—good enough that erosion shields are generally not needed on titanium blades. The cost of finished titanium alloy blading is expected to be only nominally greater than that for steel blading and is expected to be negligible in view of anticipated benefits of improved reliability in critical rows like the L − 1.

Longer titanium alloy blading in the last-stage row offers potential for improved efficiency through larger annular area and a means of increasing unit size within current rotor size limits. Disk and steeple cracking can be reduced by lowering the stress on the blade-root attachment and disk through the 40% lower blade loading. Westinghouse will investigate the magnitude of improvements in efficiency made possible through use of last-stage and L − 1–stage titanium blades that are up to 33% longer (TPS77-746). *Technical Manager: Robert Jaffee*

CLEAN AIR ACT AMENDMENTS OF 1977

This report presents summaries of the Clean Air Act Amendments of 1977 (Public Law 95-95), each including a brief discussion of the amendment's impact on utility control requirements. Following the summaries is a longer discussion of the basis for, and the impacts of, the proposed revisions to the New Source Performance Standards (NSPS). This discussion covers the specific revisions for sulfur dioxide, particulates, and nitrogen oxides, as well as the capability of control technology to support these revisions.

Section 122—unregulated pollutants

EPA will review information on radioactive pollutants, cadmium, arsenic, and polycyclic organic matter (POM) and will establish regulations if it is determined that they will "cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health."

This provides a mandate to EPA for regulation of possibly hazardous trace substances and helps to integrate a toxic substance awareness, which is also present in the Clean Water Act of 1977, the Toxic Substances Control Act of 1976, and the Resource Conservation and Recovery Act of 1976.

Section 108—nitrogen oxide (NO_x) standard

EPA is revising and will soon reissue its NO_2 criteria with reference to short-term exposure periods (≤3 h). Congress specifically directed that the revised criteria "include a discussion of nitric and nitrous acids, nitrites, nitrates, nitrosamines, and other carcinogenic and potentially carcinogenic derivatives of oxides of nitrogen."

A short-term ambient NO_2 standard may be used as justification for more stringent control of NO_x from utility combustion sources. It is estimated, for example, that a 1-h standard in the range of 0.4–0.5 part per million NO_2 would cause 15–25 Air Quality Control Regions (AQCRs) to be in noncompliance. This could affect approximately 30% of the total new fossil generating capacity in the 1975–1985 time period.

Section 123—stack height

In determining emission limitations, no regulatory credit is given for stack heights that exceed "good engineering practice"—defined as 2.5 times source height—or for any other dispersion technique.

This section penalizes most new power plants in determining contribution to ambient pollution standards and increases control requirements on new plants in prevention of significant deterioration areas.

Sections 160–169A—prevention of significant deterioration Sections 171–178—nonattainment areas

A region whose air quality is cleaner than an ambient standard is a prevention of significant deterioration (PSD) area. A utility planning to build a new plant must demonstrate that emissions from the facility will not cause or contribute to air pollution in excess of: (1) any allowable PSD increment or maximum allowable concentration for any criteria pollutant in any classified area more than once per year, (2) an ambient air quality standard in any air quality control region, or (3) any applicable emission standard or NSPS. The facility is subject to the best available control technology (BACT), which is defined as an emission limitation based on the maximum degree of reduction of each pollutant, on a case-by-case basis, taking into account energy, environmental impacts, and economic impacts and other costs. About 70% of all AQCRs will contain Class I mandatory areas or be next to AQCRs that do. Therefore, most AQCRs will have to address these stringent PSD requirements in their state implementation plans. EPA has estimated that these requirements may demand NO_x BACT of 0.3 lb/MBtu by 1979 on coal-fired power plants.

A utility planning to build a new facility or modify one in a region where an ambient standard is being exceeded (called a nonattainment area) must obtain an emission offset (trade-off), so that the emissions from the new or modified equipment will produce less overall air pollution than had previously existed. To achieve this goal, existing sources must use reasonably available control technology, and new sources must comply with the lowest achievable emission rate. This is the most stringent emission limitation in any state air pollution control plan.

These two air pollution control regulations provide more stringent technology-forcing provisions for both new and existing utility plants.

Section 169A—visibility protection

This section establishes as a national goal the prevention of any future, and the remedying of any existing, impairment of visibility (reduction in visual range and atmospheric discoloration) in mandatory Class I federal PSD areas as a result of man-made air pollution. The emission control method that will be used to abate visibility degradation from existing sources is the best available retrofit technology. This technology-forcing requirement takes into consideration the costs to comply, the time necessary to comply, the energy and non-air-quality environmental impacts of compliance, the remaining useful life of the source, and the degree of visibility improvement that may be anticipated.

Section 126–interstate pollution abatement

States also must identify and prohibit any stationary source from emitting an air pollutant in amounts that prevent attainment or maintenance by any other state of an ambient air quality standard or that interfere with measures required to prevent significant deterioration of air quality or to protect visibility. A state or government subdivision may petition EPA to require control of sources in another state.

These provisions may have a major effect on utility siting options and control technology requirements.

Section 120—noncompliance penalties
Section 405—studies on NO_x penalties for stationary sources and economic measures to control air pollution

The noncompliance penalty will be assessed against a major stationary source that is not in compliance with limitations or schedules under a state implementation plan, NSPS, hazardous pollutant emission standards, or interim requirements of an EPA enforcement order. The penalty will include any economic value that accrued to an owner because compliance was delayed beyond July 1, 1979, minus any capital and maintenance expenditures made to bring the source into compliance.

In addition to the noncompliance penalty, the new studies on economic penalties may create the need for regulatory authorities to formulate emission tax strategies as an alternative to the direct regulatory approach.

Section 111—New Source Performance Standards

The NSPS for fossil fuel stationary sources are being revised to include both allowable emission limitations (lb/MBtu) and a percent reduction. This reflects the best technological system of continuous emission reduction, considering cost, energy, and environmental impact (which EPA determines has been adequately demonstrated).

The revision effectively requires use of FGD (plus possible coal cleaning for high-sulfur coal) irrespective of coal sulfur content, combustion NO_x control with possible increased maintenance requirements, and increased use of baghouses, particularly for high-resistivity fly ash.

The NSPS revision may include the following three modifications, which have major technical implications for BACT.

- 90% removal of SO_2, using a 24-h averaging period without bypass provisions. Credit can be given for sulfur removal prior to combustion. This 90% removal efficiency will be required on all fuels unless <0.2 lb/MBtu SO_2 can be achieved with a lower removal efficiency.
- 0.03 lb/MBtu, 99% removal, and 10% opacity for particulates
- 0.6 lb/MBtu NO_x and 65% removal for bituminous coal

Sulfur Dioxide The requirement for 90% removal efficiency is not supported by "adequately demonstrated" FGD technology on coal-fired power plants. The maximum actual removal efficiency tested on any FGD system operating on utility steam generators is 85%. Only two of these utility FGD systems have a design removal efficiency near 90%.

The 90% removal efficiency requirement is expected to increase eastern coal demand by about 200 Mt/yr in 1990 and correspondingly decrease Rocky Mountain coal demand by about 240 Mt/yr. This may increase FGD capacity by 70 GW in 1990 relative to the current regulatory requirements of about 300 GW by that date. The energy penalty associated with this total scrubber commitment will require about 20 GW additional generating capacity. Also, the use of dry sorbent scrubbing may be jeopardized in the West, where water availability is at a premium. Considerable near-term increase in by-product sludge production can also be expected because of the limited experience and cost of regenerative FGD systems. Finally, at 90% removal efficiency, use of bypass gas for reheat purposes is, as a practical matter, eliminated. As a result, a typical 500-MW (e) power plant with scrubber may consume the equivalent of 65,000 bbl/yr of oil in additional fuel for stack gas reheat just to protect downstream equipment.

Eliminating bypass exemptions during malfunction while demanding continuous 90% SO_2 control will have two major impacts. First, it will significantly reduce boiler availability unless spare module capacity is constructed for each new unit. The additional scrubber capacity required for availability purposes alone is expected to be equivalent to 30–40 GW (e) by 1990. Second, it may reduce the load-following capability of electric generating plants, thus forcing unnecessary increased fuel consumption.

The proposed requirement that removal efficiency be based on a 24-hour averaging period will further reduce the achievable removal efficiency of the FGD system and/or reduce its availability and that of the associated steam generator. To date, all removal efficiency data have been reported on a 30-day averaging period. For example, the best data reported on an operating lime/limestone FGD system are 84% control for 100% of the time when averaged over a 30-day period. However, the same unit achieved 84% control less than 70% of the time when averaged over 24 hours.

Table 2 summarizes the major factors (*1, 2*) reported to affect the performance and reliability of operational utility lime/limestone scrubber systems. These 15 systems came on-line during the last five years and represent evolving design and operating experience of seven FGD system suppliers on both high- and low-sulfur coal. Several conclusions are apparent from this experience.

No significant reduction in the frequency or range of factors affecting FGD performance and reliability has occurred over the reporting period. The persistence of the problems indicates that a reliable FGD design and operating basis has not yet been established. The most prevalent limiting factors are:

- Plugging, scaling, and corrosion of scrubber internals, mist eliminators, and reheaters

Table 2 REPORTED FACTORS AFFECTING FGD PERFORMANCE AND RELIABILITY

1972 ——————————

	Will County	*La Cygne*	*Lawrence Hawthorn*	*Cholla*	*Colstrip*	*Sherburne*	*Phillips Elrama*	*Green*
Boiler								
Low-sulfur coal								
Derating required								
Low load factor (<60%)								
Scrubber								
Gas distribution								
Plugging/Scaling								
Nozzles								
Corrosion/Lining failure								
Reduced removal efficiency								
Redesign required								
Design not usable for high-sulfur coal								
Oxidation/Gypsum saturation control								
Mist Eliminator								
Plugging/Scaling								
Erosion								
Corrosion								
Poor efficiency								
Redesign required								
Reheater								
Corrosion								
Plugging/Scaling								
Redesign required								
Rainout								
Expansion Joints								
Pumps (e.g., recycle)								
Dampers								
Piping								
Fans (induced draft)								
Thickener								
Duct Corrosion								
Stack Liner								
Instrumentation/Control								
Operating Procedures								
Open loop								
Continuous maintenance for reliability								

→ Present

e Run B. Mansfield Conesville

- Corrosion and failure of stack liners
- Plugging and failure of piping, pumps, and valves
- Necessity for open loop operation (blowdown of scrubber liquor to control dissolved solids content)
- Inefficient mist eliminator and reheater performance

These major factors have no apparent correlation with manufacturer, operating condition, or year of startup. Encompassing essentially the entire FGD system, they point to a general mismatch between FGD component design, materials of construction, and the operating conditions that these components must withstand and also to a lack of ability to predict or control the FGD process chemistry within design limits.

The primary trend apparent over the reporting period is the introduction of mist eliminator and reheater designs that reduce plugging and scaling. This generally seems to have reduced aerosol removal efficiency, thus contributing to increased stack liner failure and rainout.

Figure 2 describes the percent operability of 13 utility lime/limestone FGD systems as a function of the startup date of each system. Operability is defined as the hours the FGD system was available to operate (whether operated or not) compared with boiler operating hours in the period, expressed as a percentage. These data represent the operating experience during the most recent full year of FGD system operation (generally 1976–1977). Exceptions are the Will County and Conesville data, with the former currently not covering SO_2 removal and the latter reflecting only the first seven months of operation. These data also take into account modifications made to improve the performance and reliability of the earlier FGD installations.

Since the operability factor does not penalize the scrubber during boiler outage

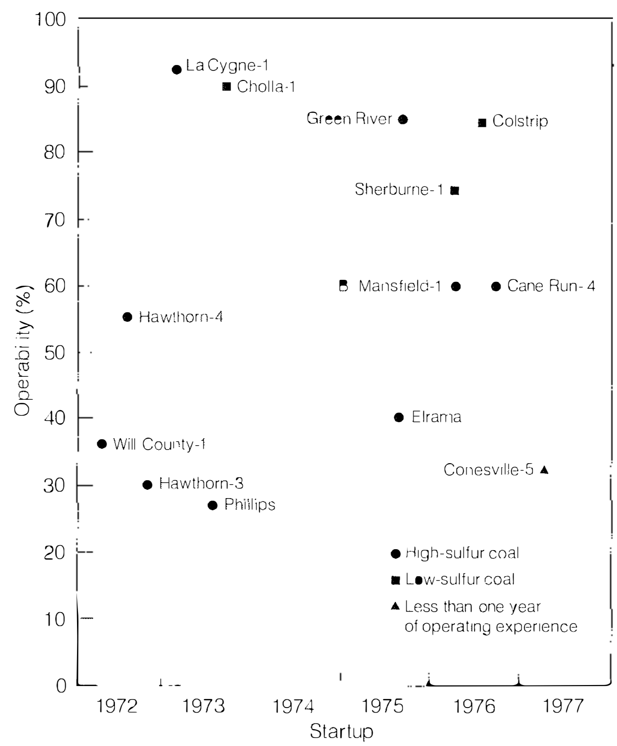


Figure 2 The percentage operability of utility FGD systems represents the hours the FGD system was available to operate compared with total boiler operating hours in the period.

periods, even though the scrubber may not have been operable, these data are typically at least 5–10% higher than the corresponding scrubber availability data often reported. It should also be noted that the low operability of Conesville reflects only the initial operating experience in this new FGD installation and is used as a reference point indicative of early performance on the most recent FGD installations.

Figure 2 is characterized by a wide range of data points that do not lend themselves to defining either operability trends or any distinct operability improvement in the newer FGD installations. An analysis of each installation does provide, however, some indication of the basis for the range of experience.

The high operability of the La Cygne and Green River FGD installations is closely related to relatively low boiler capacity factors (including load reduction and boiler outages). In La Cygne, this permits one or more of the eight scrubber modules to be taken out of service each night for routine maintenance and cleaning of scale and pluggage. In Green River, the significance of the high operability is also reduced because the load factor on the boilers is only 36%, which allows considerable time to maintain the FGD system without interfering with boiler operation. A second important factor affecting the operability at La Cygne is the open-loop operation, which limits the dissolved-solids buildup in the FGD liquor loop.

In the low-sulfur FGD installations of Cholla, Colstrip, and Sherburne, operability has been relatively high. This can be traced to the relatively low SO_2 removal efficiency (50–60%) required of the units. In addition, Cholla and Sherburne operate in an open-loop mode, and Sherburne utilizes nightly cleanup of one or more FGD modules.

High operability seems to be related to the length of operating experience during which trial-and-error design and operating modifications are applied. This is indicative of the prototype status of lime/limestone FGD systems. It should be noted, for example, that although 13 FGD systems are considered here, each one represents either the first or second example of each manufacturer's initial commercial lime/limestone FGD design.

Experience with these FGD installations identifies several factors that may contribute to reliability and operability of lime/limestone FGD systems. While these factors appear necessary with the current FGD state of the art, they may not be sufficient, as indicated by the range of data reported in Figure 2.

- Operation and maintenance (O&M) manpower commitment by the utility of 50–75 trained personnel on a large (500–1000-MW) facility, including qualified chemical engineering staff for operation and management of the facility
- Either a boiler capacity factor and load profile less than typical baseload conditions or excess scrubber module capacity that permits FGD modules to be frequently taken from service for cleanup and preventive maintenance
- Open-loop operation (this will probably become impossible at most sites because of new water pollution regulations)
- Less than 80% SO_2 removal efficiency (also generally impossible for new units if the revised NSPS are implemented)
- Good quality control on the coal consumed to avoid upsetting the design chemistry of the FGD system
- Use of oxidation or gypsum-saturation-reducing reagents, at least in lime FGD systems

Although the examination of operability in Figure 2 provides guidelines for minimizing FGD impact on boiler operations, it does not of itself indicate whether a basis has been established for successfully meeting the revised SO_2 NSPS proposed by EPA. Operating conditions clearly play an important role. Thus, factors such as SO_2 removal efficiency, boiler load profile, and capacity factor are important conditions in making this judgment. For example, none of the operational utility FGD installations have been designed for continuous 90% SO_2 removal.

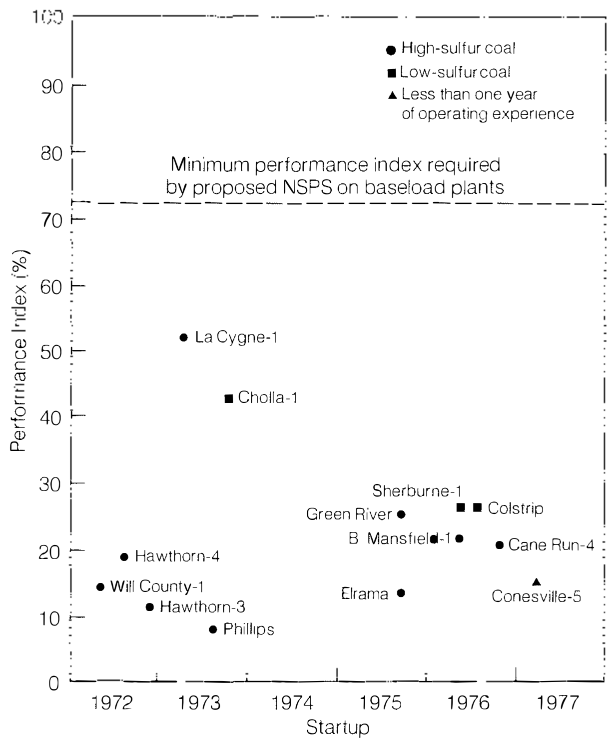
An FGD performance index, shown in Figure 3, has been suggested to relate the current FGD state of the art to the requirements of the proposed SO_2 NSPS modifications. This performance index is the mathematical product of SO_2 removal efficiency, FGD operability, and boiler capacity factor, expressed as a percentage. As a reference point, the revised SO_2 NSPS would require: (1) at least 90% SO_2 removal efficiency, based on a 24-hour averaging period; (2) 100% operability if power production is not to be affected, since bypass is not permitted during periods of malfunction; and (3) maintenance of required operability and removal efficiency during each 24-hour period on new baseloaded coal-fired power plants having load factors of 80–90%.

Thus the revised SO_2 NSPS would require an FGD performance index in the range of 70–80% for most new baseload plants. By comparison, the performance index for the best performing high- and low-sulfur coal-fired plants (La Cygne and Cholla) is 52% and 46%, respectively. A more typical performance index for current FGD systems is 25–30%. These performance index values are also based on a 30-day averaging of removal efficiency. When converted to a 24-hour averaging period, the gap between current practice and revised NSPS requirements becomes even wider.

Since La Cygne represents the result of several years of trial-and-error evolution in maintenance and operating procedures under heavy pressure to maximize operability without regard to O&M manpower, it is probably indicative of the best performance index that can be achieved on high-sulfur coal with the current FGD design and engineering practice. If the FGD performance index is to approach the requirements of the revised NSPS, then either significant improvements must be made in the design, engineering, controllability, and materials of construction associated with FGD systems, or a considerable investment in redundancy must be made beyond current practice.

Particulates Based on extensive EPRI field test results, the proposed reduction in the particulate NSPS to 0.03 lb/MBtu and 10% opacity will be technically and economically beyond the commercial state of the art for electrostatic precipitation (*3, 4, 5, 6*). In addition, no supporting data have been provided by EPRI to support the contention that this level of control can be universally achieved on new utility steam-generating systems. However, technology improvements in development could, if successful, permit this control capability by the early 1980s through fundamental improvement of fine ($<2\mu$) particulate removal efficiency using electrostatic precipitation. The probable immediate result of the proposed standard revision will therefore be a shift to fabric filters (baghouses). Although removal efficiency test results have been encouraging, at the present time baghouses are only being used on four small, atypical utility generation facilities. Examination of these units indicates that a reliable commercial design base for immediate, large-scale application over the range of commercial utility boiler and fuel condi-

Figure 3 FGD performance index, showing operational utility FGD systems and their relationship to the revised NSPS requirements.



tions does not exist and will not for at least three years. As a result, many performance and reliability failures can be expected because of this premature regulatory pressure.

Nitrogen Oxides Research data suggest that reducing NO_x levels below 0.7 lb/MBtu with currently available technologies (off-stoichiometric firing or staged combustion) may increase boiler tube wall corrosion to the point of adversely affecting boiler performance when burning high-sulfur, high-iron coals. For lower-sulfur coals, the problem may be less severe, but the data base is inadequate. Also, capability to load-follow and to achieve full load may be compromised by these techniques (*7*, *8*).

Further research is needed to determine whether a lowered NO_x standard would increase POM emissions or other compounds by increased use of fuel-rich firing techniques for NO_x control (*3*). The field measurement technique for POM is still in its infancy.

Conclusions The requirement for 90% removal of SO_2 without bypass (averaged over a 24-hour period) will exceed the demonstrated FGD state of the art. It will also require substantial increase in scrubber capacity at SO_2 removal efficiencies, for which an adequate design and operating basis does not exist. In addition, such a requirement may delay or penalize the commercial application of atmospheric FBC and SRC–I.

The requirement for reducing particulate levels to 0.03 lb/MBtu and 10% opacity will exceed the state of the art for commercial utility electrostatic precipitation. Technology improvements, if successful, can maintain their viability, but three more years will be required for the development. In addition, fabric filtration (baghouses) will be forced prematurely. A reliable design basis for broad utility use does not exist; as a result, many performance and reliability problems can be expected.

Finally, the requirement to reduce NO_x levels to 0.6 lb/MBtu for bituminous coal will decrease boiler availability through increased boiler tube corrosion rates, particularly with high-sulfur, high-iron eastern coals, and the fuel-rich combustion atmosphere may cause carcinogenic POM emissions.

The proposed NSPS revisions are projected to reduce sulfur dioxide emissions by less than 10% by the year 2000, compared with current regulations. Reductions in total particulate and NO_x emissions created by these revised NSPS applying only to utility generation are even less significant.

These proposed standards, particularly for SO_2 and particulates, exceed the capability of the present technology design and operating basis for the utility industry. This raises issues of reliability, generating capacity, energy loss, and cost. Relatively small changes in the proposed standards could alleviate most of these inequities.

Recommendations Definition of BACT should be limited to capabilities that have been adequately demonstrated in extended successful operation (1 year) on a variety of commercial utility sources (100 MW [e] or greater) that represent the range of boiler design and fuel conditions in use by the utility industry. These criteria lead to the following limits.

For SO_2, removal efficiency should not exceed a maximum of 80% for FGD on high-sulfur coal. A reduced percentage reduction formula should be considered for lower-sulfur coal. Removal efficiency should be based on a 30-day averaging time, with bypass exemption permitted during malfunction.

For NO_x, the limits do not technically support requirements more stringent than current NSPS, which require 0.7 lb/MBtu in removal efficiency.

For particulates, current demonstrated experience does not support control levels more stringent than 0.06 lb/MBtu.

Any proposed NSPS changes at this time should be limited to conventional fossil fuel combustion sources. The application of these requirements to emerging technologies may act as a deterrent to their development and use within the utility industry. Even though an unencumbered advanced technology may have both economic and overall environmental advantages, the penalties associated with achieving the proposed standards, as well as uncertainties on further reductions implied by the BACT concept, may delay or prevent its commercialization. NSPS for emerging technologies should be based on emission and operating data gained from commercial demonstration-scale facilities and should consider overall environmental performance. *Project Manager: Stephen Baruch*

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R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

EVALUATION OF STEAM GENERATOR INSPECTION METHODS

Eddy-current testing is the only inspection method presently used and accepted to satisfy regulatory requirements for in-service inspection of nuclear steam generators. With this inspection method, bobbin-type differential-coil eddy-current probes are inserted to contact the inside surface of the primary side of the tube and are drawn through the length of the steam generator.

In the past, eddy-current testing has been very successful in detecting such problems as wastage and corrosion in straight sections of the steam generator tubing. However, recent experience has shown that tube deformation, known as denting, in the tube support area produces complex eddy-current signals that may mask flaws. In addition, denting and ovalization of tubing restrict access by the inspection probe.

In response to the need for improved nondestructive examination (NDE) technology, NDE systems development for steam generator inspection is being funded by EPRI, government agencies, inspection groups, nuclear steam supply system (NSSS) manufacturers, and foreign groups. Multifrequency eddy-current tests, new probes, and ultrasonic systems are in various stages of development.

However, the performance and applicability of the technology are essentially undefined. To study the performance of the new systems and define a baseline for existing steam generator inspection capability, EPRI recently initiated a technical round-robin program.

The initial objectives of the program were to determine the nature of present steam generator NDE inspection problems, to determine the performance of present and developing NDE systems related to those problems, and to plan remedial action. Three systems were evaluated by a panel of in-service inspection specialists and theoretical NDE consultants. The panel was composed of one NDE inspection specialist from each of the three PWR NSSS manufacturers, Babcock & Wilcox Co., Combustion Engineering, Inc., and Westinghouse Electric Corp. The remaining three panel members were from EPRI, Southwest Research Institute, and Battelle, Columbus Laboratories. EPRI and Battelle are research organizations, whereas Southwest Research is an independent in-service inspection group. The groups supplied examples of defective tubing and aided in developing a realistic test program.

As part of the evaluation, simulated in-service inspections were performed, using a steam generator mock-up that contained realistic defective tubing representative of the types that cause major industry inspection problems (Figure 1). Considering the present three steam generator designs, the task of designing a realistic mock-up initially appears monumental. However, the problem is not insurmountable, since the inspection systems to be evaluated require access only to the tubesheet and the inside surface of the heat transfer tubing. An air-transportable mock-up was designed, since several of the systems that were to be evaluated were in the laboratory or prototype stage of development and their transport from the laboratory was not feasible. Transporting the mock-up to the various NDE development laboratories was also optimal from a scheduling and economics standpoint. The mock-up was designed and built by Battelle-Columbus.

Although the study addressed NDE problems associated with all existing NSSS steam generator designs, one tubing size was selected for all test specimens to simplify the logistics of the program. For the same reason, samples were all 22-mm (7/8-in) nominal

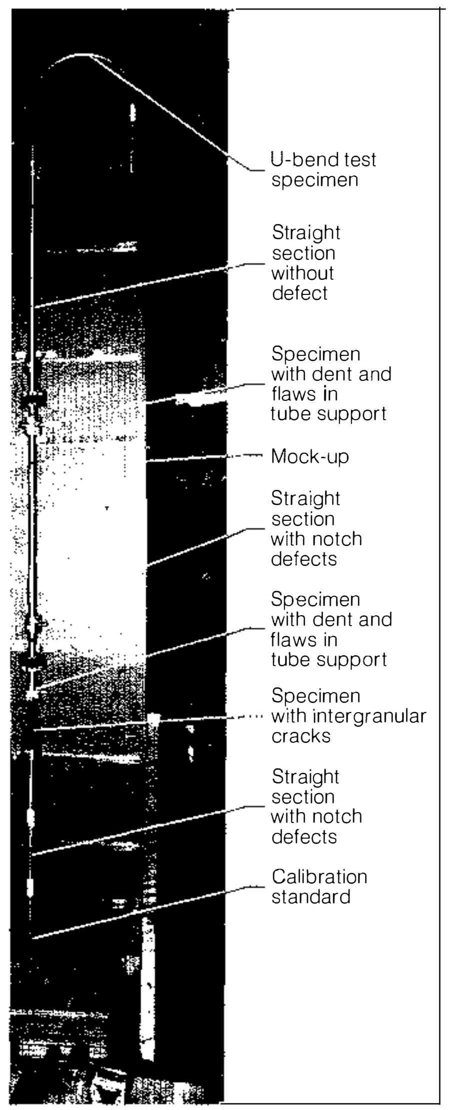


Figure 1 Steam generator mock-up, showing types of flawed tubing evaluated in NDE round-robin study.

outer diameter, 1.27-mm (0.05-in) wall Inconel 600 steam generator tubing of a configuration typical of several steam generator designs, including the Westinghouse Series 51 PWR steam generators. The tubing samples were either supplied by members of the NDE evaluation panel from existing test samples or fabricated specifically for the EPRI study. The samples included specimens loaned to the program through the courtesy of Dr. John Weeks of Brookhaven National Laboratory from an ongoing program being conducted by Brookhaven and Battelle-Columbus. The various samples contained notches, wastage, major and minor denting, major denting with ovalization, pitting, and corrosion. U-bends and tube supports were included in the samples.

The following three steam generator NDE systems were evaluated:

- The basic single-frequency system developed by Zetec Inc. makes use of equipment and techniques that reflect the present state of the art of the industry. The system uses a bobbin-type differential-coil inspection probe. The system is rugged and simple but is highly operator-dependent. A prototype system using a rotating eddy-current testing probe was also evaluated. Tests of these systems were performed at the Zetec laboratories in Issaquah, Washington.

- The Holosonics/Intercontrole system represents state-of-the-art French field inspection technology and utilizes a multifrequency eddy-current approach to improve detection and analysis of flaws in the presence of extraneous signals (e.g., from tube supports). Final data analysis is manual. Other components of the system are significantly different from present U.S. field equipment. This system was evaluated at the offices of Holosonics/Intercontrole, Richland, Washington.

- The Battelle, Pacific Northwest Laboratories system is a multifrequency system developed with EPRI funding. It uses a modified Zetec eddy-current testing probe, combined with an instrumentation system that acquires four-frequency data during inspection and automatically analyzes data from two of the frequencies to eliminate extraneous signals from probe wobble, tube supports, and so on. This system also was evaluated at the Zetec laboratories in Issaquah, Washington. It was in the prototype development stage, and the round-robin study was the first evaluation under simulated field inspection conditions.

Analysis of the considerable amount of data generated in this study is currently taking place and will continue. The first detailed results are expected to be published later this year. As a follow-on to this study, EPRI has initiated a project on the evaluation, quantification, and qualification of steam generator NDE technology (RP1172). This project will continue the steam generator NDE performance studies, using an NDE evaluation panel and an air-transportable mock-up. *Project Manager: Eugene Reinhart*

NONDESTRUCTIVE EVALUATION OF STEAM TURBINE ROTORS

In January 1976, EPRI initiated a research project (RP502) to develop a lifetime-evaluation system that utilities could use in assessing the run/retire options for steam turbine rotors (discussed in the September 1977 issue of the *EPRI Journal*, pp. 41–42). Rotors of interest are the 1950-vintage designs manufactured from air-melted Cr-Mo-V steel. This type of material typically has many detectable inclusions, holes or pores from gas in the ingot, shrinkage porosity clouds, and other discontinuities. Presence and growth during service of discontinuities in large steam turbine rotor forgings are of major concern, as failure of these rotors is extremely costly in terms of potential personal injury or loss of life and in terms of large financial effects, such as loss of revenues and costs of replacement power. The current in-service inspection of these rotors is thus a key part of the quality control programs of electric utilities to ensure the safe and continued operation of power generating stations.

Inspection is also a key element in developing a broad-based rationale for predicting rotor lifetime. It is necessary to determine the current state of rotor inspection methodology to make realistic assumptions in the prediction models and to identify those areas where additional research should be done to improve the state of current NDE practices for steam turbine bore regions.

During fabrication, the central region of the forging is bored out to remove core material (since most of the metallurgical inhomogeneities believed to contribute to failures are located there) and to gain access for inspection purposes. This bore surface is where stresses are at a maximum. Using the central bore holes, examinations can be made of the bore surface (rotor ID) and of the near-bore volume where stresses remain high.

Inspections from the bore are designed to find both large, singular internal fissures and dense clouds of smaller fissures and inclusions above a certain size. Both of these discontinuity types have potential for contributing to eventual rotor failure. A typical rotor inspection involves the independent use of surface, near-surface, and volumetric examination methods.

Bore surface examination involves looking through a borescope to detect cracking at the bore surface. Findings are verified and expanded with magnetic-particle techniques. The bulk of the rotor volume is inspected by ultrasonic methods that interrogate the interior region from near the bore surface to the outside diameter of the rotor. This is done by a mechanical positioning system that moves the ultrasonic test head axially and circumferentially within the bore, either in discrete steps or by continuous incrementation. Indications often can be confirmed by searching inward toward the bore with ultrasonic sensors that are placed on the rotor periphery.

The original purpose of bore inspections was to detect gross cracking conditions that were likely to lead to rotor imbalance and eventual failure if neglected. However, with the advent of fracture mechanics and the increase in service age of many rotors, inspection data are being used more and more for detailed evaluation of the size and distribution of internal discontinuities. Detected discontinuities (individual or collective) are then evaluated analytically to estimate remaining service life.

From Battelle-Columbus efforts on RP502, it has been determined that there are performance differences among the various inspection systems in use for rotor inspection. It is desirable to establish minimum performance criteria against which all inspection groups can test their capability. Such a test could consist of a performance demonstration prior to conducting an inspection. Generally speaking, a system's performance must:

- Show a high degree of reliability in detecting discontinuities of a given size throughout each specified region of each rotor

- Be capable of characterizing the natural discontinuities it detects with regard to general size, shape, and orientation

- Have sufficient resolution so that clusters and clouds can be accurately discriminated

- Be able to distinguish the presence of discontinuities near the bore surface

- Reliably detect and characterize discontinuities in successive inspections

With these points in mind, the following tentative acceptance criteria are proposed for rotor inspection systems.

▫ System sensitivity and reliability: Each system should be able to detect a single 1.5-mm ($\frac{1}{16}$-in) flat-bottom hole located 3–38 mm ($\frac{1}{8}$–1$\frac{1}{2}$ in) from the bore surface. This should be demonstrated by passing the transducer system through a calibration block containing several such flat-bottom holes. Routine scanning parameters should be used. To qualify, the system must detect all the holes in 9 out of 10 tries.

▫ System resolution: Each system should be able to resolve the presence of three 1.5-mm ($\frac{1}{16}$-in) side-drilled holes spaced 4.8 mm ($\frac{3}{16}$ in) apart and arranged in various patterns. If automatic recording equipment is used, the three holes must be seen distinctly on the chart.

▫ System coverage: Each system should be incremented in either the z or the θ direction such that a 1.5-mm ($\frac{1}{16}$-in) flat-bottom hole located 6 mm ($\frac{1}{4}$ in) from the bore surface is detected on three consecutive scans.

▫ Shear wave system sensitivity: Each system should be able to detect an 0.8-mm ($\frac{1}{32}$-in) side-drilled hole located 6–38 mm ($\frac{1}{4}$–1$\frac{1}{2}$ in) from the bore surface.

▫ Shear wave system resolution: Each system should be able to resolve the presence of three 1.5-mm ($\frac{1}{16}$-in) side-drilled holes spaced 4.8 mm ($\frac{3}{16}$ in) apart and arranged in various patterns.

▫ Shear wave system coverage: Each system should be incremented such that a 1.5-mm ($\frac{1}{16}$-in) flat-bottom hole located 6 mm ($\frac{1}{4}$ in) from the bore surface is detected on three consecutive scans.

▫ Data report format: Data reports generated from the rotor inspection should be in consistent format so that subsequent inspections can be compared with earlier versions. The most complete way would be to supply the owner with a tabulated list of every detected indication, including exact location, maximum signal amplitude, equivalent flat-bottom hole size, and additional comments as to whether it is a single indication, part of a cluster, or a cloud indication.

These recommendations were summarized by Dr. Matthew J. Golis at the EPRI-sponsored RP502 Project Review Workshop held in December 1977. Dr. Golis further emphasized the need to separate the inspection steps of flaw location and subsequent "sizing." The choice of the axial and circumferential increment sizes is typically influenced by the utility's desire to keep the inspection duration as short as possible. This can make the increment size fairly large, which is sufficient for locating but not at all adequate for sizing. Fortunately, the sizing mode of inspection is typically required only over relatively small, selected lengths of the bore; omitting this step prevents knowing the flaw's configuration, and therefore the key purpose of the inspection can be lost. Later in 1978, EPRI will issue a special report on nondestructive evaluation of steam turbine rotors (an analysis of the systems and techniques utilized for in-service inspection), from which this summary was obtained. *Program Manager: F. E. Gelhaus*

STEAM GENERATOR OWNERS GROUP

The Steam Generator Owners Group, made up of utilities owning PWR nuclear power plants, was established in early 1977 for the specific task of finding the best solutions to steam generator problems. The Owners Group was conceived when it became evident that solutions to the growing number of steam generator problems would not be forthcoming without a concerted effort on the part of interested utilities. There are 46 utilities in the United States that have or plan to have a total of 125 PWR units in operation by the end of 1986.

The problems

The industry has had a series of problems with steam generators, including contamination, vibration, fretting, water hammer, cracking, wastage, pitting, denting, high-cycle fatigue, and erosion-corrosion. There is no assurance that present practices will control deterioration to the point that a 40-year steam generator lifetime without replacement may be expected. Experience to date warns against such an expectation.

At least two utilities have already decided to replace steam generators in four units that will have had less than 10 years of commercial operation at the time of planned replacement. These replacements will be expensive and will require extensive outages. Preliminary evaluation by the Owners Group indicates that major component redesign and system modification will probably be required to maximize steam generator life.

A major utility industry effort has been initiated to develop methods for improving the current situation to the point that each owner can select the options most appropriate to the situation and develop the utility's individual plan. The Owners Group is required because the costs consequential to steam generator degradation are very high, and because system aspects of nuclear power plant design tend to spread responsibility among many parties. The three major vendors have stated that they are not able to fund the level of effort that the Owners Group has determined will be required to serve the best interests of the utility industry. However, they have agreed to participate in the program by performing work on a no-fee, cost-sharing basis.

Owners Group organization

On July 26, 1977, the Owners Group met in Chicago to adopt a draft charter and elect an executive committee. Twenty-one utilities (20 from the United States and 1 from Europe) joined the Steam Generator Owners Group and committed over $30 million to support the program; other utilities are expected to join in the near future. Allocation of costs among members of the Owners Group required dividing the affected plants into the following categories:

▫ Problem units, with recirculating steam generators that are dented

▫ Operating units with recirculating steam generators not known to be dented that are now or will be in operation by 1980

▫ New units with recirculating steam generators scheduled to begin operation between 1981 and 1986

▫ Units with once-through steam generators (OTSG), regardless of startup date. The 20 U.S. members of the Owners Group own 60 of the 125 PWRs in operation or planned to be in operation in the United States by 1986: 10 of 14 problem units, 16 of 34 operating units, 27 of 50 new units, and 7 of 27 OTSG units.

The Owners Group asked EPRI to manage the technical program. In March 1977, EPRI established the Steam Generator Project Office, directed by Bill Layman, who reports to Milt Levenson, director of EPRI's Nuclear Division. The Owners Group Executive Committee is chaired by W. E. Caldwell, Senior Vice President of Consolidated Edison Co. of New York, Inc. The Licensing Advisory Committee and the Technical Advisory Committee have been established to advise the Executive Committee on the licensing and technical aspects of the program.

Technical program

To understand why these utilities have pledged more than $30 million, the dilemma they face must be understood. Steam gen-

Table 1
PWR STEAM GENERATOR PROBLEMS

Unit	*Start of Commercial Operation*	*NSSS Manufacturer*[a]	*Corrosion*				*Vibration*		*Water Hammer*	*Carry-over*
			Thinning	*Denting*	*Stress Corrosion Cracking*	*Unidentified Signal (tubesheet)*	*Antivibration Bar Wear*	*High-Cycle Fatigue*		
Connecticut Yankee	January 1968	Westinghouse	X	X			X			
San Onofre	January 1968	Westinghouse	X	X			X		X	X
Zorita (Spain)	August 1969	Westinghouse	X							
Beznau-1 (Switzerland)	December 1969	Westinghouse	X		X					
Ginna	March 1970	Westinghouse	X	X	X				X	
Mihama-1 (Japan)	November 1970	Westinghouse and C–E	X							
Point Beach-1	December 1970	Westinghouse	X	X	X					
Robinson-2	March 1971	Westinghouse	X	X	X					
Palisades	December 1971	C–E	X	X	X					
Beznau-2 (Switzerland)	March 1972	Westinghouse	X	X						
Mihama-2 (Japan)	July 1972	Westinghouse	X						X	
Point Beach-2	October 1972	Westinghouse	X	X						
Surry-1	December 1972	Westinghouse	X	X						X
Turkey Point-3	December 1972	Westinghouse	X	X						
Maine Yankee	December 1972	C–E		X[b]						
Surry-2	May 1973	Westinghouse	X	X					X	X
Zion-1	June 1973	Westinghouse							X	
Oconee-1	July 1973	B&W						X		
Turkey Point-4	September 1973	Westinghouse	X	X					X	
Fort Calhoun	September 1973	C–E								
Prairie Island-1	December 1973	Westinghouse								
Zion-2	December 1973	Westinghouse								
Kewaunee	June 1974	Westinghouse								
Indian Point-2	July 1974	Westinghouse	X	X					X	
Three Mile Island-1	September 1974	B&W								
Oconee-2	September 1974	B&W						X		
Takahama-1 (Japan)	November 1974	Westinghouse	X							
Arkansas-1	December 1974	B&W								
Oconee-3	December 1974	B&W						X		X
Prairie Island-2	December 1974	Westinghouse								
Doel-1 (Belgium)	February 1975	Westinghouse				X				
Rancho Seco	April 1975	B&W							X	
Ringhals-2 (Sweden)	May 1975	Westinghouse		X[c]					X	
Calvert Cliffs-1	May 1975	C–E							X	
D. C. Cook-1	August 1975	Westinghouse				X				
Tihange-1 (Belgium)	September 1975	Westinghouse				X				
Genkai-1 (Japan)	October 1975	Westinghouse								
Doel-2 (Belgium)	November 1975	Westinghouse				X				
Takahama-2 (Japan)	November 1975	Westinghouse								
Millstone-2	December 1975	C–E		X[b]						
Trojan	May 1976	Westinghouse								
St. Lucie-1	June 1976	C–E								
Indian Point-3	August 1976	Westinghouse								
Mihama-3 (Japan)	December 1976	Westinghouse								
Beaver Valley-1	December 1976	Westinghouse								
Salem-1	December 1976	Westinghouse								

[a] Westinghouse: Westinghouse Electric Corp.
C–E: Combustion Engineering, Inc.
B&W: Babcock & Wilcox Co.
[b] Only all-volatile treatment.
[c] Limited phosphate treatment.

erator problems require a large amount of time and money to correct because of their number and variety. The extent of the problems is shown in Table 1, which lists most of the world's operating commercial PWRs. From the table, it appears that it is only a matter of time in operation until a unit experiences problems. Unless appropriate corrective actions are taken, all PWR owners and prospective owners face a significant probability of steam generator replacement prior to the end of a 40-year power plant lifetime. Estimates of steam generator replacement cost and replacement power costs during the outage have ranged from $100 million to more than $300 million per plant. The Steam Generator Owners Group technical program was developed in response to this expensive problem.

Corrosion problems were addressed first, partly because there are more of them, but primarily because of the more significant current impact—namely, denting and its effects (Figure 2). Denting begins with the corrosion of the tube support plate in the crevice adjacent to the tube. The crevice fills with corrosion products, which occupy a space equivalent to twice the volume of the carbon steel support plate they come from, and as the corrosion products continue to grow, the tubes are squeezed and dented. As this process continues, the support plate deforms and "hourglassing" of the flow slots results.

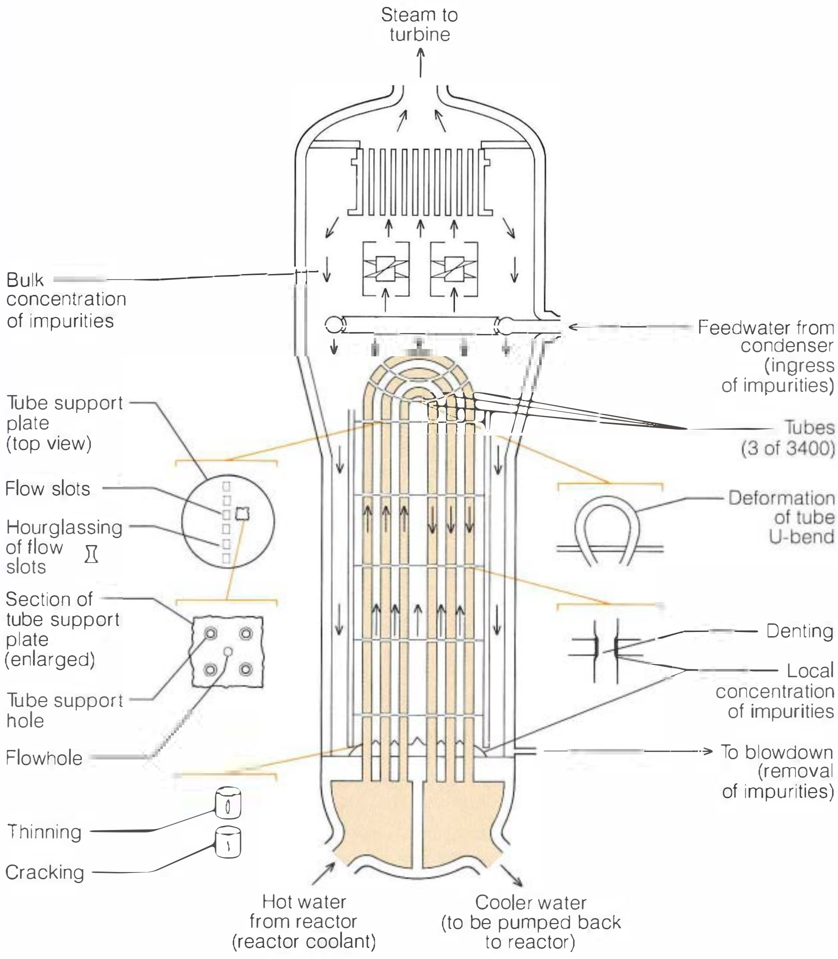


Figure 2 Various forms of corrosion in steam generators, including denting and its side effects, are caused by the ingress of aggressive impurities and their subsequent concentration and attack on steam generator materials.

Denting, like some other effects of corrosion in steam generators, results from the attack of concentrated aggressive chemicals (impurities) on the materials of the steam generator. Corrosion attack can be minimized by reducing the ingress of impurities, or reducing the attack itself. A logic tree was developed that specifically addresses the corrosion problem. Methods of reducing the ingress of impurities include feedwater cleanup (e.g., polishers and filters), secondary-system corrosion reduction, and reduction of inleakage to the secondary system. Methods of reducing the concentration of impurities include improvement of thermal hydraulics, removal of impurities (e.g., by blowdown), and redesign of the steam generator in the area where concentration occurs. Methods of reducing the attack of aggressive impurities include reduction of the susceptibility of materials and reduction of the aggressiveness of the impurity (e.g., neutralization). Although this logic tree does not include specific solutions, it does address the known and expected types of corrosion damage, including denting, wastage, pitting, cracking, and erosion-corrosion.

A similar approach was taken for the other problems. The solution to each problem involves improvement of the thermal hydraulics of the steam generator. The resulting combination of these logic trees addresses corrosion attack, vibration, water hammer, and carry-over—all the known and expected steam generator problems.

To complete the program logic tree, however, it was necessary to add two other branches. The first was added to provide program support in the form of problem definition, including inspection, safety analysis, and surveillance. The second was added to address the avoidance or correction of the damage. The result was the complete steam generator program logic tree for solving steam generator problems. When specific branches (subprograms) were added to this tree, the recommended steam generator program (Figure 3) resulted. This program, which was approved by the Owners Group in July 1977, includes 34 subprograms, estimated to require $40 million of Owners Group funds and five years to complete. Actual work on the first contracts under this program started in November 1977.

The expected results of the program are economic and technically sound solutions to current and future steam generator problems. *Project Manager: John Mundis*

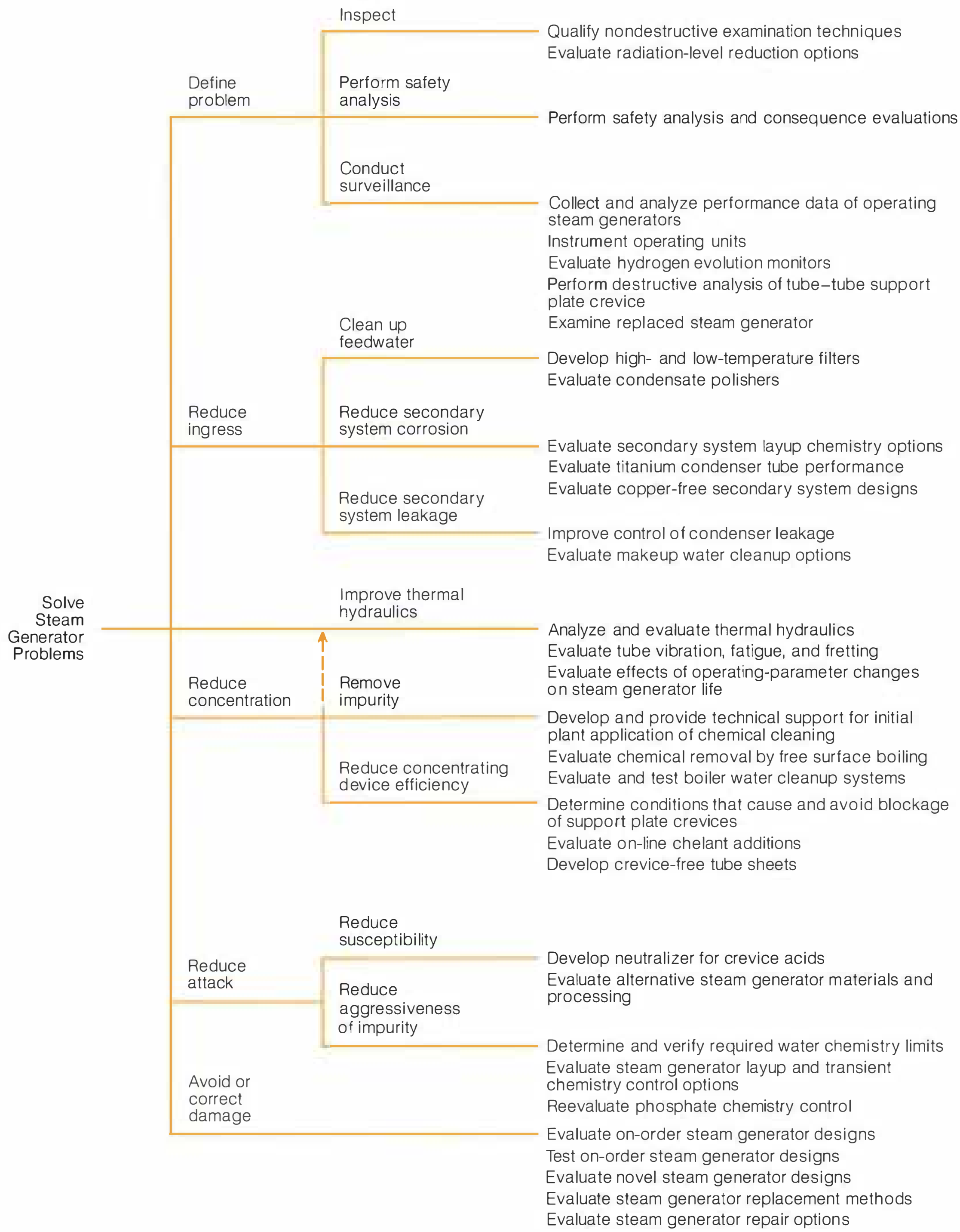


Figure 3 The 34 subprograms that make up the Recommended Steam Generator Program were approved by the Steam Generator Owners Group in July 1977. This program addresses all known and anticipated steam generator problems and is estimated to require $40 million and 5 years to complete.

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

Last year was a rewarding one. Over 60 of our nearly 200 projects were completed during 1977, and all but a few achieved their goals; those that didn't were generally in areas not worth further pursuit.

We expect to publish some 60 final reports this year on research completed either late in 1977 or in 1978. This compares with 43 final reports issued last year by the Electrical Systems Division. In the early years of the Institute, many research projects were being put in the pipeline. We have now reached the point where a continuous flow of results are coming out the other end.

Our goal in many of these research projects is to develop useful information for the industry. Papering the libraries of the member utilities with final reports does not necessarily accomplish that objective. However, reports in such a large quantity are indicative of the emphasis we have placed on short- and intermediate-term results.

In an effort to ensure full dissemination of such information, we have developed seminars and workshops that will report the results in technical societies' papers (IEEE, APC, CIGRE, and others); when appropriate, we involve member utilities in field tests of new products. Last year this division sponsored workshops or seminars on fault current limiters, Polysil* insulators, light-fired thyristors, underground tunneling methods, distribution test laboratories, insulating oils, and computer parallel processing. This year we have already held seminars on compact transmission line design, gaseous dielectrics, and power system reliability. Others are planned on load management and longitudinal loading of transmission towers.

The R&D funding for the Electrical Systems Division is trending more and more toward projects that will yield short-term results. For example, our 1979–83 five-year plan indicates that 85% of our expenditures will be concentrated on technologies that should benefit the industry within the next 10 years. Electrical Systems is basically a hardware division, and our main interest is to have the components developed in our research programs actually placed in commercial service. Without that, the whole concept of centrally directed research loses validity. *Division Director: John J. Dougherty*

*Polysil is an EPRI trademark.

DISTRIBUTION

Six important distribution research projects are getting under way during 1978. All but one should be completed in about two years, thus providing utilities with near-term solutions to such critical problems as concentric neutral corrosion, excessive fault currents, and disruptive transformer failures. Criteria for development of an improved current-limiting fuse and a more effective and reliable lightning arrester will be determined. Design of a distribution data base will complete the package.

Concentric neutral corrosion

The objective of one project is to develop an understanding of the mechanisms that cause copper concentric neutrals of solid dielectric extruded cables to corrode (RP1144). It is estimated that the average installed cost of concentric neutral cables to serve underground residential distribution is $30,000 per mile. Observed incidences of neutral corrosion continue to increase, and utilities have conducted aboveground surveys and cable dig-ups to assess the seriousness of the problem. It is necessary that the industry understand the causes of this corrosion and discover how to achieve a normal cable-life goal of 30–40 years.

Five basic mechanisms are suspect:

- Galvanic action. This usually involves the presence of dissimilar metals. Therefore, the effects of tin and/or alloy coatings on the corrosion process will be investigated.
- Ac currents. It is believed that ac currents do not initiate corrosion, but there is some evidence that they accelerate corrosion after it has started. The effects of ac will also be investigated.
- Rectification. This occurs when dc currents leave metals and flow into an electrolyte. The possibility that ac currents are undergoing rectification will be studied.
- Local cells. It is known that local cells are responsible for some corrosion activity but are not a primary contributor. Therefore, this mechanism will not be a part of the investigation.
- Long-line cells. These cells are probably a significant contributor and will be studied.

Numerous full-size cable samples will be buried in soil of controlled chemistry and backfill. The bare concentric wires will consist of coated and uncoated copper strands as well as aluminum strands. Some of the samples will be connected to pass ac currents through the neutral strands, and other samples will be deenergized. Monitoring equipment will include components that will detect whether ac currents are being rectified. Standard control samples will be maintained for comparison purposes. Periodically, portions of the samples will be cut off, weighed, and chemically analyzed to identify corrosion products. Florida Power & Light Co. is the contractor. *Project Manager: William Shula*

Fault current control

The objective of a 34-month project with the McGraw-Edison Co. is to develop and test a full-scale laboratory model of a vacuum-based, fault current limiter (RP1140). The development of suitable fault-current-limiting equipment for distribution circuits would reduce the level of fault current to which the equipment would normally be exposed. Instead, all downstream equipment would be subjected to fault current magnitudes that are within the rating of the equipment. This would allow the replacement of interrupting equipment to be delayed indefinitely. In new installations, an effective fault-current-limiting device would enable the use of lower-cost components, such as breakers, cutouts, reclosers, and other related equipment. The savings to the industry would be significant.

The contractor will use all available information relating to fault current limiters, including results from RP281, RP564, and the work of Dr. A. S. Gilmour in particular (RP476 and RP993). Included in this project is the development of the required energy-absorbing and current-limiting capability, circuit-interrupting capability, and the capability to use the device as a recloser on distribution systems rated 15–72 kV. *Project Manager: Robert Tackaberry*

Disruptive transformer failure

In another project, the objective is to develop pole- and pad-mounted distribution transformers that have improved safety features, are lower in first cost, and have operating characteristics superior to those of existing oil-type units (RP1143).

The transformer resulting from this three-year research effort would not be subject to disruptive failure, thus providing an important safety benefit for personnel and environment. In addition, the potential for improved reliability, smaller size, and lighter weight also exists, which contributes to savings for utilities.

This development will be based on a completely new transformer coil and core design that uses new insulating materials as well as advanced insulation application and coil-winding technology. McGraw-Edison Co. is the contractor. *Project Manager: Robert Tackaberry*

Improved current-limiting fuse

A contract with Phoenix Electric Corp. (RP-1142) involves the design, construction, and testing of a current-limiting circuit protector (fuse) that uses a novel "explosive charge" technique, combined with a "sensing and trigger" circuit, to initiate, time, control, limit current, and clear.

Present current-limiting fuses are designed to limit let-through current. They also interrupt the circuit, thus acting as effective isolating links. Because of the current-limiting action of these fuses and the rapid circuit interruption, the thermal duty and electrodynamic forces on the system are minimized. Unfortunately, present current-limiting fuses cannot handle higher continuous currents (above 100 A) and still provide low let-through current characteristics.

A fuse that could predictably limit the magnitude of short-circuit currents and interrupt current within the first loop of fault current would permit utilities to indefinitely postpone replacement of existing equipment that can no longer handle today's fault currents. In addition, the device would permit reduction of fault current withstand requirements for new equipment, which would reduce cost. The design phase of this project should take one year. *Project Manager: Ernest Ballard*

Lightning arrester

Despite protection offered by conventional lightning arresters, approximately one-third of all distribution transformer failures occur during lightning storms and are presumably caused by lightning. Distribution arresters are also used to protect overhead structures, lines, and other overhead equipment, such as shunt capacitor banks and underground systems supplied by risers from overhead lines.

Arresters designed from the data base to be obtained from the study of lightning current magnitude through distribution arresters (RP1141) should reduce equipment loss (and resultant replacement cost) and improve service reliability. The data are needed to determine the changes that should be made in the criteria for the design and application of distribution arresters in order to improve their performance.

Approximately 3500 arresters, which have been in service for 10–15 years, will be removed by 13 cooperating utilities. Certain in-service data for each arrester will be recorded—for instance, particular protective function, proximity to an adjacent arrester, and type of exposure to which it has been subjected (i.e., isokeraunic level, rural-open, suburban, rural-wooded, and so on). Each arrester will be opened and inspected to identify the number and magnitude of surge currents that it has experienced, as well as the number of power-follow currents. Any significant abnormalities detected during the visual inspection will be recorded. A correlation between arrester exposure, discharge current, and power-follow occurrences will be developed.

The contractor for this one-year project is The Detroit Edison Company. *Project Manager: Herbert Songster*

Distribution data base

The design and implementation of a distribution data base are very costly. A previous EPRI project (RP329) has shown that many commonalities can be expected between data bases designed by different companies. This repetition of efforts is often unnecessary. Those utilities planning to implement a distribution data base can profit from knowing where these commonalities exist and how they can be avoided.

In the present project (RP1139), Boeing Computer Services, Inc., will:

- Determine the existing and potential functions that a distribution data base should support, so that these functions can be emphasized in data base design
- Estimate manpower needed to establish the data base and the supporting computer resources
- Estimate the manpower and resources needed to implement the automation of the distribution functions for the data base
- Prepare guidelines that will allow utilities to choose the optimal design of a data base for their specific needs

Project Manager: William Shula

UNDERGROUND TRANSMISSION

Forced-cooled cable

The design and fabrication of a 365-m (1200-ft) forced-cooled cable have been completed (RP7823). This cable is part of a forced-cooling test facility developed for testing cable oils and formulating criteria for optimized cable-cooling performance. A computer controls the current, temperature, pressure, and oil flow rate. Hundreds of thermistors are attached to the conductor insulation material and to the shield of each of the three cable phases. In addition, hot-wire anemometer probes for measuring flow rates and numerous pressure transducers inside the containment pipe provide input to the computer. This combination of sensors makes this 138-kV cable system one of the best instrumented in the world. The refrigeration unit supplying the chilled oil is a versatile one, because it can supply flow rates of 0.003–0.04 m^3/s (40–650 gal/min). It uses a bypass system, with an inlet oil temperature range of −6.6°C to 21°C (20–70°F).

This forced-cooling facility is a welcome addition to EPRI's Waltz Mill cable test facility in Pennsylvania and is now part of the operating agreement for testing and evaluating ac losses, friction factors, and heat transfer coefficients as functions of temperature, heat load, Reynolds number (a value relating viscosity, density, and flow), and cable configuration.

New work to be done at Waltz Mill will fully utilize the forced-cooled test device to set parameters for three cable oils under various load conditions. Information on pressure drops and increased friction factor for cables in known snaked positions will be part of this follow-on testing. The relationship between optimized flow and heat transfer for twisted cables will be determined.

After three years of testing and correlation of thermal and hydraulic parameters, a forced-cooling design manual and handbook will be made available to utilities, enabling them to optimize present in-service cable capacity and design proper new circuits. *Project Manager: Thomas Rodenbaugh*

Flexible gas cable

The specific objectives of the flexible gas cable project are to develop, manufacture, and test a 345-kV flexible, compressed-gas-insulated cable capable of being placed on a reel for shipment in long lengths (RP7837).

The project is hardware-oriented and mainly involves the design, manufacture, and testing of prototype components. The prime contractor on this project is Gould Inc. Kabelmetal, of Hanover, West Germany, is a major subcontractor. A key part of this project is the purchase of a machine from Kabelmetal that can form aluminum coil stock longitudinally into a tube, insert conductor and insulators, and weld and corrugate the tube in one continuous operation (Figure 1). The order for this machine was released in December 1977, and the machine is scheduled for shipment and installation in the United States by mid-1979. A full reel of 345-kV flexible gas cable is scheduled for production in the United States during the first quarter of 1980.

A prototype (300-mm-diam, 100-m-long) flexible compressed-gas cable is presently undergoing a short evaluation test at the Waltz Mill cable test facility.

It is estimated through economic analysis that the flexible system would be at least 25% less expensive on an installed basis than a rigid isolated-phase gas cable. A flexible system holds the promise of cost savings through:

- Greater ease of handling and shipping
- Reduction of trench size during excavation
- Use of long flexible sections that can be coiled on a reel and shipped directly to the job site, thereby reducing field assembly problems
- Easy routing around unforeseen obstacles
- Automated production, with factory testing and sealing of the gas chamber

Program Manager: Ralph Samm

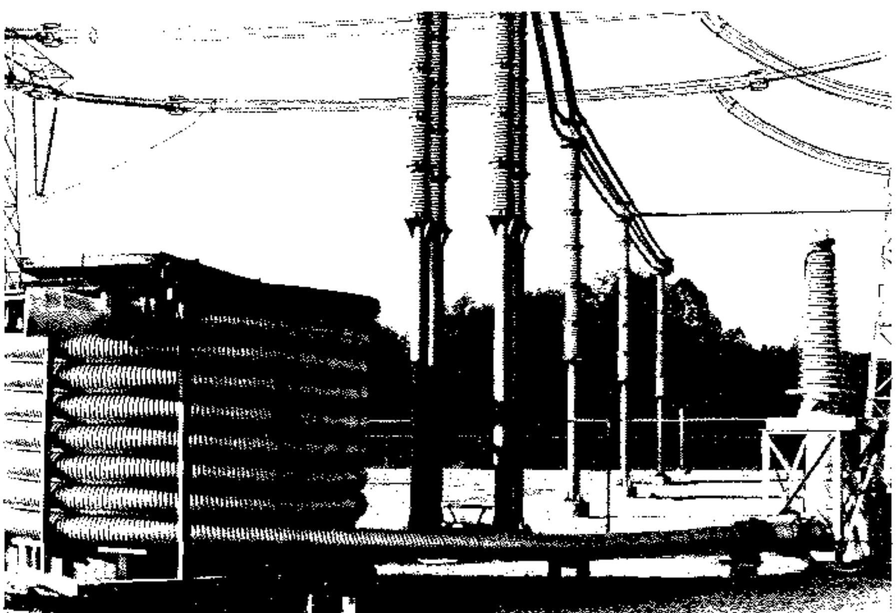


Figure 1 Short-term withstand test on 100-m, 300-mm-diam cable setup at the Waltz Mill cable test facility in Pennsylvania.

OVERHEAD LINES

Inductive coupling of ac potentials onto gas pipelines has been under investigation at the Illinois Institute of Technology Research Institute (IITRI) for the past two years (RP742). This project is jointly sponsored by EPRI and the Pipeline Research Committee of the American Gas Association (AGA).

System operators have long been plagued by the fact that voltages predicted in buried pipelines by popular theory differed by an order of magnitude from those actually measured. The problem stemmed from the fact that analyses that are valid for coupling to insulated communication lines are not valid for buried pipelines, even if the line is coated with an insulating material. Therefore, it was necessary for the contractor to take a fresh look at fundamental coupling phenomena.

The IITRI engineers chose to adopt an approach that treats the pipeline as a lossy transmission line. Therefore, factors such as pipeline diameter, coating resistivity, depth of burial, longitudinal resistance and inductance, and earth resistivity must be taken into account in constructing a realistic model of an underground pipeline.

One of several interesting results of their analysis is that the highest pipeline voltages do not appear near the middle of long, parallel gas and electric lines, as previous theories suggested. Instead, the new theory suggests that the highest pipeline voltages will appear at a discontinuity, either in the pipeline or in the transmission line. For example, a voltage peak will occur at the point where a pipeline and transmission line diverge after being parallel for several miles.

This analytic technique has now been tested in a number of locations of varying conditions and complexity. In all cases, tests have confirmed the theory. Some tests are continuing. In addition to developing predictive techniques, IITRI has also designed and tested a number of mitigation techniques. These should prove useful in problem situations.

As soon as the investigative work is complete, the engineers at IITRI will write a handbook, which will be published by EPRI and AGA. *Project Manager: Richard Kennon*

POWER SYSTEM PLANNING AND OPERATIONS

Long-term power system dynamics

In an EPRI project that was completed in 1974, General Electric Co. undertook to determine the significant long-term dynamics of a power system through examination of major power system disturbances and to identify a set of measures for improving a power system's ability to resist major system disturbances (*1*). The project resulted in the development of a prototype digital computer program, LOTDYS (long-term dynamic simulation), which is capable of simulating power system performance for periods of up to 20 min following major disturbances (*2*). This program contains models of power-generating units, loads, transmission system elements, and controls within a novel computing framework that will permit reasonable computer running times for studies of long-term dynamics (Figure 2).

The program is designed for the study of system transients taking place over a period of up to 20 min. To do this economically, it ignores certain fast phenomena, such as the synchronizing-power and rotor-angle swings with periods of less than 10 s.

The initial project (RP907) was continued in RP764-1, which concentrated on improving LOTDYS to make it capable of handling larger power systems. It will also use less computer time and space, have greater flexibility, and include additional models (*3*).

The work was divided into two tasks, each having several subdivisions. The first task, concerning LOTDYS computer program improvements, was further split into these four subdivisions: sparsity programming, expansion of the LOTDYS capability for larger system representations, examination of extrapolative load-flow process, and revision of the initial start of LOTDYS to permit restart.

The second task, which dealt with modeling improvements, resulted in the addition of three models to the LOTDYS ensemble—models of combustion-turbine-driven units, boiling water reactor plants, and volts-per-hertz regulators.

The project increased the efficiency and applicability of the previous LOTDYS program (RP907) for simulation of long-term power system dynamics. The program was enlarged over its prototype scale to handle medium-size power systems, while retaining all the features and models developed before. The present program has the capability of representing 100 generating units, 300 buses, and 500 lines, and this capability has been tested. The cost of computation in the simulation has been reduced to approximately one-tenth of that required for RP907.

These improvements in the capability of LOTDYS for power system simulation were made so that long-term power system dynamics, problems, and solutions could be investigated further. On completion of the projects described above, recommendations were given that further work be initiated in the following areas:

- Sensitivity studies to determine the form and accuracy of data associated with the various power system components
- Evaluation of a number of strategies to reduce the likelihood of cascading failures
- Development of a production-grade version of the prototype long-term response simulation program
- Analyses of recent power system incidents to provide a validation basis for LOTDYS, to suggest improvements (such as additional features or models), to suggest additional means for limiting the frequency or severity of power system cascading failures, and to gain familiarity with the methods of analysis
- Preparation of guidelines for determining which data need to be most accurately determined, where these data may be found, and what methods should be used for translating data into short-term and long-term simulation program input

These recommendations formed the basis for present research (RP764-2), which is divided into four tasks.

Task 1: Development of System Scenarios
The goal of this task is to analyze power system incidents (five actual, one hypothetical) by short-term and long-term simulations.

Four analyses of recent incidents are being made by General Electric, with data and technical guidance from Consolidated Edison Co. of New York, Inc., Florida Power & Light Co., The New York Power Pool, and Southern Company Services, Inc.

The fifth analysis is being made by engineering personnel of Pacific Gas and Electric Co. and concerns a recent incident that occurred on its utility system.

These five analyses will be continued until a reasonable match with the major consequences of each of the power system incidents has been reproduced in the digital

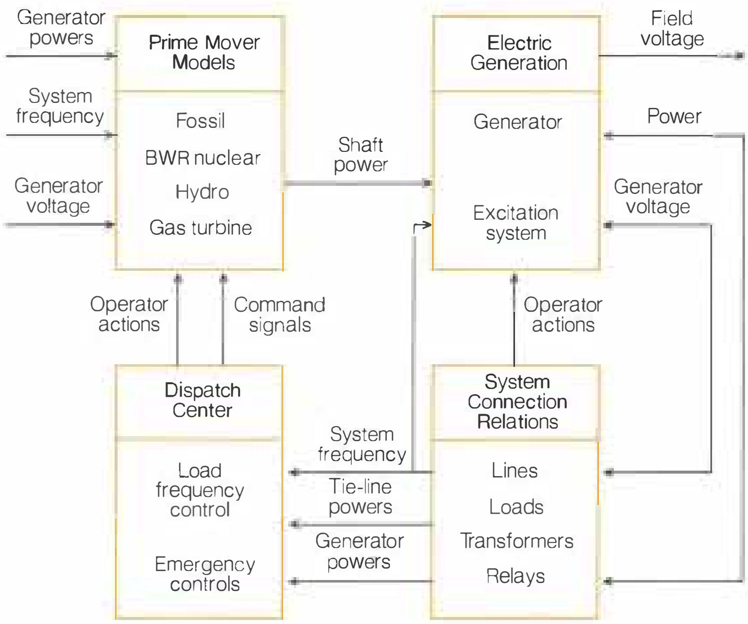


Figure 2 Interconnection of models in LOTDYS, showing transfer of information during computation.

simulations. A sixth analysis will be made of a hypothetical system incident based on a power system model developed in RP907. It will include elements representative of the range of power system configurations in the continental United States and features of real power system incidents.

The hypothetical system will serve as a test bed for the sensitivity analyses in Task 2 and for the corrective measures strategies to be studied in Task 3. In the course of obtaining a match between recent power system upsets and simulation analyses, greater experience and insight into the requirements and sources of data will be obtained for use in Task 4.

Task 2: Sensitivity Studies In order to aid power system analysts in the selection of data for use in system studies, an assessment will be made of the accuracy requirements of simulation data and of the effects of changes in model structure. This exploratory effort will provide an estimate of the adequacy of present data sources and strong indications of work direction for Task 4 and subsequent work.

Task 3: Selection and Evaluation of Alternative Measures to Improve Security The goal of this task is to select and evaluate a group of candidate measures for improving the ability of a power system to withstand a possible cascading failure and for reducing the extent of the system failure should one occur.

As a result of this task, power system analysts will have a set of evaluated measures for mitigating the effects of power system disturbances, including an assessment of the relative merits and potential drawbacks of each measure. These assessments should be useful in applying the remedial measures to specific systems and in determining the direction of future generic system evaluations.

Initially, remedial measures (as many as possible) will be collected through reviews both of the incidents surveyed in RP907 and of subsequent incidents. Additional measures will be suggested by the investigators and by an industry advisory group created for this project.

Remedial measures may consist of system design modifications, new automatic controls or modifications to existing controls, changes in operating practices, or combinations of these. For example:

- Use of combustion turbines to provide a portion of spinning reserve
- Rapid starting and loading of generation, such as combustion turbines and hydro units
- Modification of turbine governor characteristics
- Bypass of heaters in steam cycle plants to reduce turbine steam extraction
- Incorporation of volts-per-hertz regulators in generation voltage controls
- Maintenance of in-service generator voltage regulators
- Remote blocking of automatic tap changers
- Modification of load-shedding practices
- Rapid and automatic islanding

All remedial measures will be reviewed, and the five most promising will be selected for in-depth generic studies, using the hypothetical system scenario devised in Task 1.

Task 4: Development of Model Data Guidelines The objective of this task is to provide guidelines for determining what power plant and power system data are required, where to find data not now routinely available, and how to translate the data into input for long-term and short-term system simulation programs.

Research is now being concentrated on Task 1, testing the LOTDYS program on hypothetical system disturbances. A great deal is being learned about the program operation, and the modeling is constantly being evaluated and improved. In most cases, the LOTDYS program results can be shown to match system behavior reasonably well, once the input data and sequence of events are accurately represented.

A supporting project (RP764-4) is being conducted by nuclear engineers at the University of Tennessee to prepare a suitable model for a pressurized water reactor. This will complete the family of power plant models needed for long-term simulation studies. General Electric will incorporate this new model into the LOTDYS program and test its performance.

The current status of LOTDYS is that of a research computer program. Future work will streamline the code and the user interaction for utility production use. At this time the program can be used, but some effort is required to master its structure and input requirements. A few utilities are experimenting with the program in its present form, and their work with the code is helping to identify user problems. Inquiries from other interested EPRI member utilities are welcome. These pioneering efforts will be helpful in speeding the correction of operating difficulties and errors. *Program Manager: Paul Anderson*

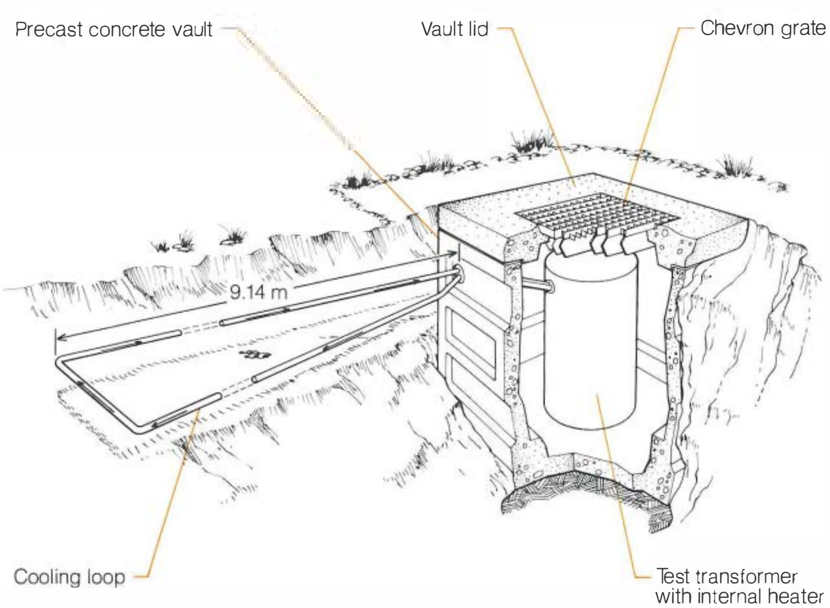
SUBSTATIONS

Transformer cooling

Although the load capabilities of power transformers are dominated by thermal limits, transformer cooling system design has remained basically unchanged for several decades. Meanwhile, there have been significant advancements in heat transfer equipment and heat transfer fluids. The objective of one project, now completed, was to investigate the potential for significantly improving transformer thermal performance by implementing two-phase heat transfer techniques that take advantage of the latent heat of vaporization (RP479).

Both active (energy-consuming) and passive equipment were considered. For power-class transformers, for example, this included a forced-flow heat pipe, which permits greater flexibility in coupling the hot oil in ambient air, and a heat pump system, in which a vapor compressor reduces the transformer oil temperature to below that of ambient air. Cost comparisons were made for both systems, with the former appearing cost-competitive in forced-air operation and the latter appearing cost-competitive in the thermal dissipation range of 20–200 kW. Additional effort was directed toward studies of improved single-phase cooling systems for power transformers, including the development of a more precise technique for modeling thermosyphon flow and the application of the model to the design of finned aluminum transformer radiators. The designs identified during this portion of the study appeared superior to those of conventional systems in terms of cost per unit thermal capacity, and they also permit reductions of up to 60% in weight.

The use of two-phase heat transfer techniques was considered in particular detail for applications where effective heat rejection is difficult to accomplish with existing technology. For underground transformers, reflux condenser systems were considered as a means of increasing load capability. In particular, heat pipes linking the transformer to surrounding soil were found to offer an optimal method of cooling (Figure 3). This conclusion was based on extensive analyses of the various thermal interfaces present and on economic models of installed system costs. To confirm the thermal analyses, a full-scale test facility was constructed.



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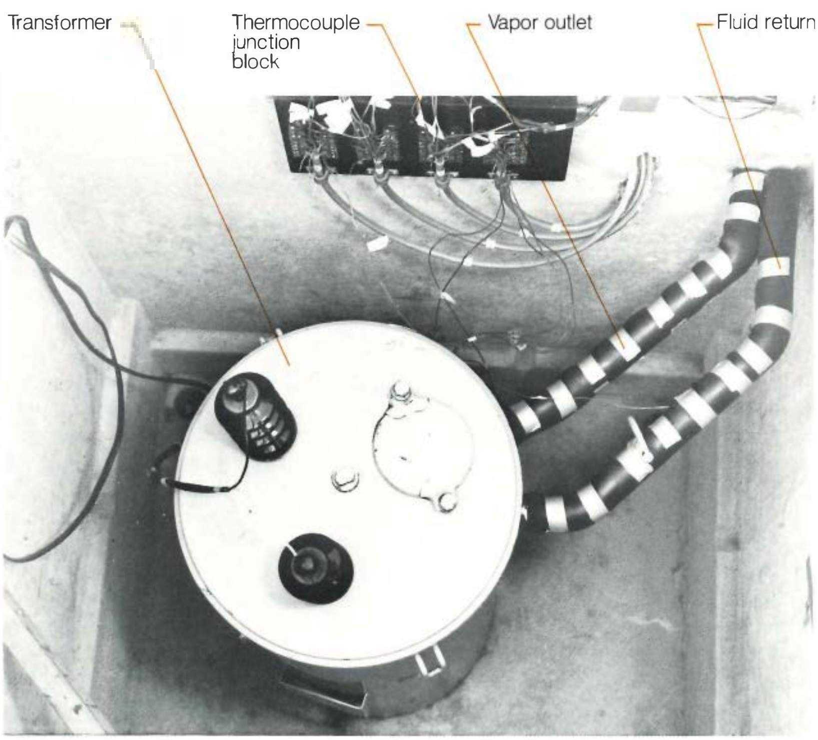

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Figure 3 Transformer installation layout (**a**) at test facility with external cooling loop. This layout offers better overload capabilities than conventional schemes. Transformer test vehicle (**b**) installed in vault, with insulated lines connecting transformer to external cooling loop.

Tests showed that a cost-effective method of reducing top-oil temperature would be to use a closed vault and a buried, heat-pipe heat rejection system. This compares favorably with a conventional open vault, air-cooled installation with a thermal dissipation rate equal to that of a modern 50-kVA transformer. The final report on this research is now available (EL-588).

An additional benefit of this transformer-cooling investigation was the development of two possible methods of measuring core and coil temperatures. These were developed to a laboratory proof-of-concept stage. One of these newly developed hot spot detectors is based on the temperature-dependent light-absorption characteristic of a gas; in the other design, the temperature-dependent vapor pressure of a two-phase system acts as the indicator. The former unit, which was the more successful of the two, utilizes a small glass cell (2 mm diam) filled with a mixture of N_2O_4/NO_2 (Figure 4). Temperature-induced changes in the light absorption of this mixture are monitored via fiber optics and remote optoelectronics, thus permitting operation of the transducer in strong electric fields. Operation in temperatures up to 200°C has been demonstrated.

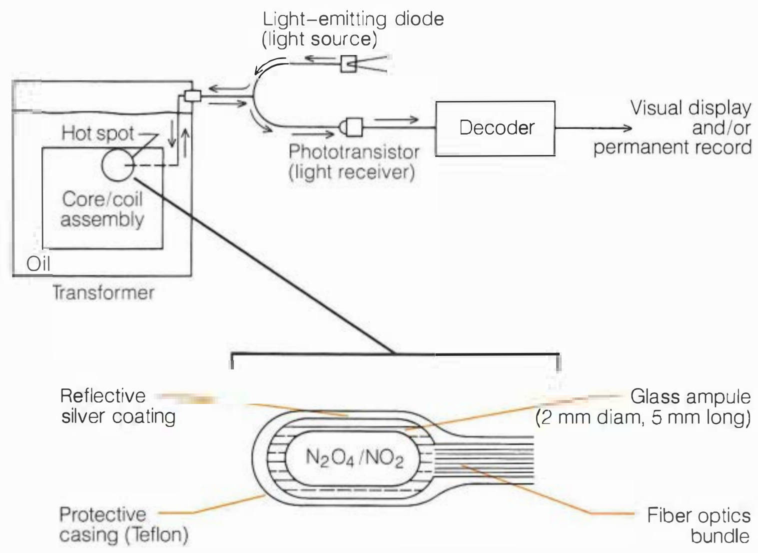
The success of basic concepts developed for this novel hot spot detector resulted in funding for a new and separate R&D project (RP1137). *Project Manager: Ed Norton*

Transformer noise abatement

A project on transformer noise abatement stems from research done in England (RP579). The approach uses a unique noise shell consisting of close-fitting, tuned, sound-barrier panels mounted on the outside of a transformer tank (Figure 5). The purpose of the research is to verify the sound-enclosure theory and to develop design rules for its application to power transformers. This involved both laboratory experimentation and field tests, culminating in the installation and test of an experimental shell on an existing transformer by Wisconsin Electric Power Co. The following conclusions have been drawn from the work to date.

- A noise reduction of 15 dBa is a practical reality.
- Sound spectra of similar transformers are consistent, allowing simultaneous design of both the transformer and the noise shell.
- All sides of a transformer tank must be covered for reductions greater than 10 dBa.
- Stiffening ribs are important noise sources,

Figure 4 Conceptual hot spot detector for a transformer, using temperature-dependent, optically absorbing gas.



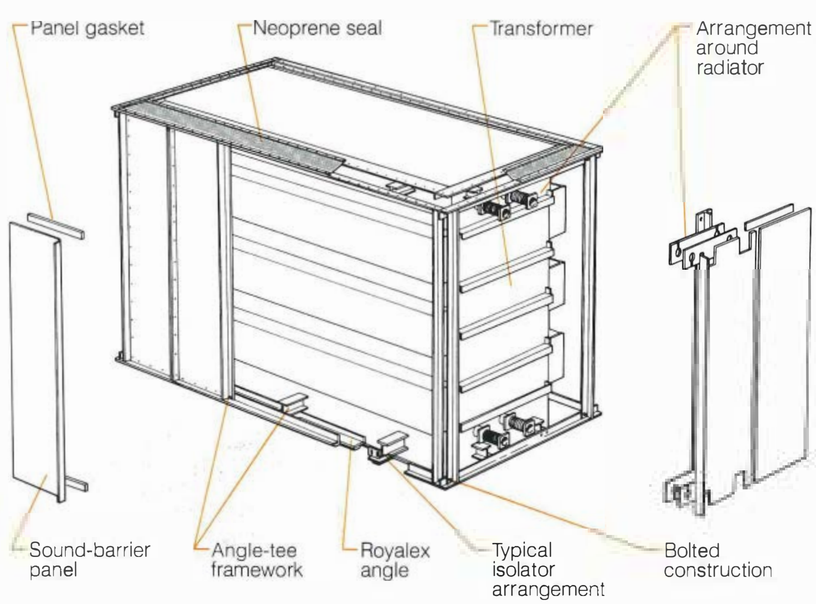


Figure 5 Exploded view of tuned noise-abatement panels, which can easily be attached to new or existing transformers.

as are radiators. For effective sound abatement, the radiators must be isolated from the unit via stainless steel bellows.

▫ Treatment of the top and bottom of the tank depends on the noise reduction goal and the configuration used (e.g., gas cushion versus oil-filled, pier versus base mount).

▫ Two materials are preferable for shell construction because of economics and ease of manufacture—11-gage steel and ABS plastic.

A follow-on project, in addition to optimizing the reduction of noise, will develop alternative concepts for a retrofit shell that can be applied to either new transformers or units in the field (RP995).

With the acceptance of tuned panels for sound abatement, utilities will be able to moderate audible noise generated by transformers without the use of cumbersome and costly sound absorption enclosures. When properly designed, the panels will not interfere with shipping, handling, or installation of the transformer units.

Finally, the installed cost of the new configuration would be lower than that of the presently available modes of sound abatement. *Project Manager: Ed Norton*

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R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

ENVIRONMENTAL ASSESSMENT

This status report reviews the progress and outlook of the Environmental Assessment Department some three years following its inception. The major thrust during this period has been assessment of the effects of fossil fuel combustion on air quality, water quality, and human health—an emphasis that anticipated the national commitment to the use of coal. A significant program has been initiated on effects from high-voltage transmission lines and right-of-way maintenance. In regard to nuclear power, studies have concentrated on the plutonium issue and on comparative health costs of the different options for electricity production. To date, a total of $33 million has been authorized for 97 projects, to be completed over the next 2–3 years.

The research supported by the Environmental Assessment Department is organized into three programs: Physical Factors; Ecological Effects; and Health Effects and Biomedical Studies. To understand biological consequences, we need reliable methods of measurement and monitoring and knowledge of the nature, transport, and ultimate fate of pollutants. Providing such information is the basic goal of the Physical Factors Program. In addition to evaluating the effects on ecosystems of chemical substances and of physical agents (such as heat and electric fields), the Ecological Effects Program also deals with the beneficial uses of waste products and with the development of specific data bases. Within the Health Effects and Biomedical Studies Program, the primary emphasis has been on obtaining information on the amounts of pollutants that may be safely emitted from power plants. Such data should be useful to industry, to research and development planners of control technology, and to regulatory agencies, for setting realistic standards that will be protective of public health yet not impose an unwarranted financial burden on the industry, the economy, and the ratepayer. *Department Director: C. L. Comar*

PHYSICAL FACTORS PROGRAM

Initial emphasis has been on developing analytic procedures and on making field measurements for pollutant identification. Some notable successes have been achieved. One project by Radian Corp. evaluated error in the measurement of atmospheric sulfate concentrations and revealed that SO_2 vapor on a filter can convert to sulfate particles (RP262). Hence, many previously reported sulfate values have been too high because these values represented both the actual sulfate in the atmosphere and that formed on the filter from SO_2.

Another project, by the University of Tennessee, resulted in a technique based on matrix isolation spectroscopy for identifying individual polycyclic organic molecule (POM) compounds in a mixture. The technique involves mixing a vaporized sample with a large volume of an inert gas (the matrix), which, in effect, isolates individual molecules from the influence of neighboring ones. The gaseous mixture is then deposited on a cryogenic surface (at −253°C) for spectroscopic examination by fluorescence or infrared radiation. With this technique, the highly toxic benzo-a-pyrene, for example, can be distinguished from its isomer, the innocuous benzo-e-pyrene—a distinction that is normally very difficult to make.

SRI International's project on analytic techniques has resulted in the development of a truck-mounted laser unit that is capable of measuring atmospheric concentrations of SO_2, NO_2, and O_3 from a remote site (RP1060). The device will operate under any weather condition and can make analyses over a discrete interval (e.g., between 305 and 427 m [1000–1400 ft]) from ground level to 2286 m (7500 ft).

In addition, New York University is conducting a measurements program in New York City, which has provided data on trace metal distribution in the atmosphere and, more important, has identified the sources from which the metals come (RP439). The study has shown that the contribution to the particle loading in the atmosphere from oil burning has been halved over the past eight years, whereas the contribution from automobiles has doubled in the same period.

The Physical Factors Program is shifting its main effort from measurement techniques toward understanding the transport and fate of pollutants. Perhaps the most important achievement in this area is the successful inception by Environmental Research & Technology, Inc., of the $6.25 million sulfate regional experiment (SURE), an air quality measurement project in the northeastern United States aimed at defining regional ambient sulfate concentrations in terms of local SO_2 emissions (RP862). The ultimate goal is to identify the utility industry's contribution to regional levels of sulfates. The difficulty of this task arises from the fact that SO_2 (not sulfates) is emitted from power plants. The sulfates are formed by later chemical reaction with the atmosphere, and no simple relationship between amounts of emitted SO_2 and regional concentrations of sulfates is known. SURE hopes to discover that relationship by integrating air quality measurements with data on chemical transformation, kinetics, wet and dry deposition of pollutants, and natural emissions of sulfur compounds. The impact of SURE on federal policy may be profound.

EPA is almost certain to establish an ambient sulfate standard, which will, in effect, create limits on SO_2 emissions; but because the relationship between such emissions and ambient sulfate levels is obscure, EPA cannot yet specify what reduction in emitted SO_2 will bring about a desired sulfate level. To a large extent, the federal government is looking to SURE for clarification of the SO_2-sulfate problem. Cooperation between SURE and federal agencies has been excellent.

To date, the program has been focused on air pollution resulting from coal burning —in particular, pollution from sulfur compounds. Over the next 12 months, however, a major research effort will be initiated on nitrogen compounds and organic pollutants, especially those related to coal conversion processes (liquefaction and gasification).

In addition, major programs are already under way on the problems of visibility degradation and acid precipitation. Emphasis on air pollution will certainly remain strong. However, research is being directed increasingly toward studies of pollutants in terrestrial and aquatic environments and pollutants from fuels other than coal. Support for the development of improved measuring techniques will certainly continue, with strong emphasis on remote measuring devices, particularly those involving lasers. *Program Manager: Ralph Perhac*

ECOLOGICAL EFFECTS PROGRAM

Emphasis has been on the effects of cooling systems (fish impingement on intake screens, plankton entrainment in the cooling system, and thermal and chemical discharges); on construction and maintenance of overhead transmission line rights-of-way; on transmission line electromagnetic fields; and on acidic deposition. In addition to research projects, about a dozen workshops, conferences, technical planning studies, and state-of-the-art studies have been completed.

From industry sources, the Atomic Industrial Forum (AIF) has identified and compiled information and data relevant to assessing impacts of thermal power plant cooling systems on aquatic environments (RP877-1). The resulting documents contain information that can be used by the industry as bases for critical reviews of cooling-system effects and as reference material to guide new studies being undertaken. It is more efficient and less costly for EPRI to support the creation of such an annotated bibliography than for each electric power company to do so separately. Complementing the work of AIF, the Oak Ridge National Laboratory (ORNL) is compiling an annotated bibliography and creating a central depository for information and data found in open and government literature (RP887-2). Both the AIF and ORNL bibliographies are available for data retrieval on a cost-reimbursable basis, and the data depositories are also available for use. The two bibliographies are in the process of being combined, and a user's manual is being prepared for publication.

Also to be published are three selective subsets of the merged bibliography, which cover chemical effects, impingement, and entrainment. A review of the literature on thermal effects (based on the bibliography) was published recently by Charles C. Coutant and Sylvia S. Talmadge (*Journal of the Water Pollution Control Federation*, Vol. 49 [June 1977], pp. 1369–1425).

An intensive study by the Illinois Natural History Survey of the ecology of a cooling lake is in its concluding phase (RP573). All experimental work and the mathematical model of the lake ecosystem have been completed, and final data synthesis and analysis are under way. Preliminary analysis of the data comparing the ecology of the cooling lake (Lake Sangchris) with a similar lake not used for cooling (Lake Shelbyville) indicates that although there are some differences in species presence and abundance at all trophic levels and some differences in spatial and seasonal dynamics of species and communities, the structure and functioning of the Sangchris ecosystem are not radically different from those of the Shelbyville ecosystem. Sangchris supports an excellent largemouth bass sport fishery, and there is no evidence that the power plant is having any major detrimental impact. In fact, there is evidence that the heating of lake water by the power plant may be improving the fishery.

Public Service Co. of New Mexico has completed two years of data collection on succession of plant communities in relation to maintenance and construction of overhead transmission line rights-of-way in the semiarid Southwest (RP756). Preliminary analysis of the data indicates that within nine years of line construction, rights-of-way in a well-established, mature, grassland community (upper Sonoran life zone) should have reached their preconstruction state. Northern and southern desert shrub communities appear to require approximately seven years to return to their preconstruction state.

As part of an important series of projects being conducted by Westinghouse Electric Corp. and Pennsylvania State University on transmission line electromagnetic field effects, it has been found that the threshold for leaf-tip damage is about 22 kV/m for pointed leaves, such as grasses and pine needles. For rounded leaves, 80 kV/m (the maximum field available to the investigators) caused no damage (RP1064).

The beehive is a complex ecological community of interdependent members. It was therefore selected as the system to be used by Bioconcern to test for effects of electromagnetic fields. When beehives were placed under a segment of a 765-kV transmission line, the populations of hives that contained no metal grew normally, but those of conventional hives, which contain metal, did not. The preliminary work seems to confirm the hypothesis that reported detrimental biological effects may not be a direct effect of electromagnetic fields but could be caused by minishocks (RP934).

In regard to the beneficial uses of waste products, a workshop and technical planning study with the Tennessee Valley Authority on waste heat utilization will be completed later in 1978. Future research in this area, such as modeling studies of waste heat utilization systems and the feasibility of pilot-scale research, will be based on this effort. Projects related to fossil fuel combustion product utilization will be implemented this year, including one on structural fills using power plant ash.

In the near future, emphasis will be shifted from ecological effects of power plant cooling systems to ecological effects of fossil fuel utilization. This year several projects on microcosm development and application will be implemented. Systems developed in this project area will be useful in generating a data base for predicting ecological effects of fossil fuel combustion by-products.

Studies of lake acidification in the Adirondack Mountains will be complemented by experimental programs conducted on site to evaluate effects on specific biological components of three lakes and watersheds in New York State. A major effort will be the calibration of a network of watersheds in cooperation with federal agencies, such as the U.S. Forest Service. An important problem in assessing ecological effects is the lack of long-term data sets. The calibration of this network of watersheds across the nation would provide a mechanism both for the collection of long-term data on aquatic and terrestrial systems and for the implementation of experimental field programs in various regions. Also, during 1978 a data base will be developed on acidic deposition in the eastern United States. *Program Manager: Harry Kornberg*

HEALTH EFFECTS AND BIOMEDICAL STUDIES PROGRAM

A critical review of existing knowledge on the health effects of sulfur oxides has been published (EA-316). A similar critical review by Greenfield, Attaway & Tyler, Inc., on oxides of nitrogen is also available (EA-668). Using these reviews and other available data, EPRI, in cooperation with EPA and DOE, commissioned the National Academy of Sciences and a panel of senior authorities in the field of air pollution health effects research to assess the unmet health research needs in fossil fuel combustion (RP809).

Since interpretations of the Community Health and Environmental Surveillance System (CHESS) studies by EPA have been cited as supporting data for present national ambient air quality standards, a reanalysis of some of these data has been undertaken to assess the validity of the CHESS conclusions. A critical analysis commissioned by EPRI of the original data tapes used by EPA failed to confirm the EPA claim that a positive correlation exists between levels of sulfate and the incidence of asthma attacks in the study population (EA-450). Further studies on other CHESS data sets are under way and will become available later.

The greatest efforts during the past year have been in the field of animal toxicology. In an integrated series of projects, five contractors have initiated long-term studies on various aspects of toxicity of fossil fuel combustion products. Each addresses several aspects with different methodologies.

A project at Battelle, Columbus Laboratories uses in vitro test systems to assess the toxicity of various types of fly ash (RP937). An interdisciplinary project at Massachusetts Institute of Technology involves burning various types of coals under simulated boiler conditions and analyzing the structural composition of the particulates emitted (RP1112-3). The relative irritant potency is then analyzed in a standardized model of animal respiratory mechanics. In another major animal toxicology study, at the University of California at Irvine, the effects of pollutant combinations, including both gaseous and particulate species, are being examined, and new testing methods to assess changes in pulmonary function are being developed (RP1112-1). These tests can later be adapted for humans. In order to better understand permanent pulmonary impairment, the project is also examining the effects of fossil fuel products on lung development in young animals.

A fourth major toxicology program, being conducted by the University of California at Davis, is examining chronic exposure of animals, including primates, to various pollutants (RP1112-2). These animals will be used in a series of morphological, pathologic, physiologic, and clinical studies to identify mechanisms by which specific pollutants may exert effects on health or functioning. The fifth animal toxicology program, at New York University Institute of Environmental Medicine, is examining health effects of sulfites, about which little is known (RP1157). Together, these animal toxicology programs will provide a basis for controlled human exposure studies in the future.

In collaboration with the National Institute of Environmental Health Sciences, EPRI is supporting a large ongoing epidemiologic study that evaluates human health and pulmonary function in relation to air pollution. This study, conducted by a group from the Harvard School of Public Health, will extend over a nine-year period and follow groups of adults and children in six communities that have varying degrees of air pollution (RP1001). Preliminary information from the first two years of this study indicates pulmonary function impairment in children who live in cities with higher levels of air pollution.

In regard to the increasingly important issue of effects from high-voltage transmission lines, the major project is being undertaken by Battelle, Pacific Northwest Laboratories (RP799). It involves the long-term exposure to electromagnetic fields of Hanford miniature swine, from conception through reproduction of offspring. Facilities have been constructed, and actual exposures are expected to begin in the spring. As a result of the EPRI project, DOE is now supporting a parallel project at Battelle in which laboratory animals will be exposed to electromagnetic fields and subsequently studied. Experiments in the United States and USSR that have shown positive effects are being reproduced at Battelle. So far, these positive results have not been confirmed, but efforts are being continued and extended.

Since the industry expects to increase the use of direct current for long-distance transmission of bulk electricity, it is necessary to determine whether dc fields will cause biological problems. It is anticipated that research on this subject will be cosponsored with DOE. Additional research needs include clinical studies of a larger number of transmission line workers. This will not be initiated until after the personnel field meters become available and are field-tested. Such meters are being developed by General Electric Co. (RP68). The parts played by minishock and hair stimulation in causing effects ascribed to electromagnetic fields need to be clarified. It is likely that the let-go current of 5 mA can be increased; innovative research is needed to develop new data. Research is also needed to determine whether pole-top resuscitation of shocked electrical workers is feasible.

The first contract in the area of controlled human clinical exposures has been awarded to Rancho Los Amigos Hospital in Los Angeles (RP1125). These studies will assess the effects on both low-risk (healthy) and high-risk (asthmatic) subjects of various sulfur oxides, nitrogen oxides, and trace metals. Specific compounds studied will be selected in cooperation with the Air Quality Control Program of EPRI's Fossil Fuel and Advanced Systems Division and will also be based on data obtained from the previously described animal toxicology programs as these become available. A second major human clinical exposure study is being proposed for initiation in August 1978 (ES3535). This study will examine some pollutants not being considered in the study at Rancho Los Amigos Hospital and will use some new sophisticated cardiopulmonary function tests developed by these investigators. As relevant compounds are identified in the animal toxicology program, other controlled human exposure studies will be initiated to extrapolate the animal data to humans.

The in vitro animal studies on the toxicity of fossil fuel particulates under way at Battelle, Columbus Laboratories (RP1315) will be extended into in vivo studies on stress in animal models. These studies should cover the effects of air pollutants on more sensitive segments of the population, such as those with underlying cardiopulmonary disease.

A major undertaking of an ongoing epidemiologic study (RP1001) will be an attempt to assess the actual effects of the pollutants on the health and functioning of real-world populations. The study, cofunded with the National Institute of Environmental Health Sciences, will continue for another six years. Using information derived from this study, an epidemiologic study will be designed during the next two years that will be able to focus closely on those pollutants shown to be of most concern to human health and on those parameters of health and functioning that have been shown to be most affected. This study, which is expected to be launched by 1980, will probably have the joint participation of EPRI, federal agencies, and perhaps other private research groups or foundations. Such a carefully designed study could produce definitive information for use in the formulation of realistic ambient and emission air quality standards.

Research designated as integrated assessment, which serves to integrate both health effects and economic aspects, is carried out within the Health Effects and Biomedical Studies Program.

The objectives of this work are to estimate the aggregate environmental impacts associated with alternative technologies, energy systems, and scenarios, and to develop environmental socioeconomic impact assessment tools. Work has been launched in a wide variety of program areas, including the estimation of environmental damage from coal-burning power plants; estimation of the relative importance of visibility reduction; estimation of the environmental damage associated with solar technologies; development of better socioeconomic impact assessment tools; and estimation of the environmental and social costs of an electricity shortage.

Results are expected shortly for the first three of these topics. Mathtech, Inc., is developing a framework for evaluating the environmental damage associated with coal-burning power plants (RP755-1). The results will facilitate a cost-benefit analysis of emissions control for power plants. Researchers at the University of Wyoming have refined and applied two approaches for estimating the relative value that residents attach to visibility in the Southwest (RP755-2). Woodward-Clyde Consultants has developed and applied a decision theory methodology that will evaluate the environmental impacts of and help determine optimal sites for two solar technologies, solar central receiving and wind power (RP551).

In the near future, projects will be initiated to assess the environmental impacts of energy storage technologies and to evaluate and contribute to the development of integrated environmental assessment models. *Program Manager: James McCarroll*

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

ELECTRICAL SYSTEMS

A dynamic model for computer control of the extrusion of solid dielectric cable

EL-605 State-of-the-Art Report (RP7829)

This report by Analytical Services Co. documents work performed toward the development of a computer control system for the General Cable Corp. Bayonne Laboratory extruder system, constructed as part of a joint EPRI–ERDA project. After preliminary operation of the extruder, it was determined that computer control was not essential to meeting program objectives, so further development was suspended. The purpose of this report is to document work completed, for future reference, if it appears desirable to proceed with the development of such a computer control system.

The report reviews the state of the art in mathematical modeling and control of extrusion processes, defines the problem of extruder control, describes a control design methodology, and formulates the necessary dynamic model for control system design. *EPRI Project Manager: Felipe Garcia*

The development of a high-voltage dc cable

EL-606 Final Report (RP7818)

It has long been recognized that there are certain advantages in the use of HVDC systems to transport large amounts of power across long distances. Compared with ac power cables of the high-pressure, oil-filled type in widespread use today, there is less dielectric loss and no skin-effect loss in the dc cable. Dc cables can be used to connect frequency-dissimilar ac systems and are practical in situations where reactor compensation of ac systems is not feasible, as in long submarine lengths. In recent years there has been increasing interest in determining whether HVDC systems might provide technical or economical alternatives to extra-high voltage ac transmission.

This report outlines the scope of an investigation by The Okonite Co. into the theory of HVDC cable design. Research was primarily in three areas: the study of various dielectrics as possible candidates for future HVDC cable insulations; dc voltage evaluation of existing dielectrics; and development of a method for determining the stress distribution in a dc cable. *EPRI Project Manager: Felipe Garcia*

Model study of electric field effects in substations

EL-632 Final Report, Vols. 1 and 2 (RP753)

Energized scale models of EHV and UHV substations can be used as design tools to determine the electric field distribution in and around the substation. To prove the method, an energized scale model of the Bixby Road 345-kV substation of Columbus and Southern Ohio Electric Co. was designed and built by Ohio State University in order to compare the electric field distribution of the original substation with that of the substation model.

Volume 1 reviews instrumentation and modeling problems and their solutions, reports on calibration and verification tests, and discusses the accuracy of the model measurements. Comparison of corresponding test points shows that the agreement between substation and model measurements is good: the mean of absolute values of errors is about 4.6%. In the course of the study, the electric field strength of the model was mapped for the base case and the effects of a wide range of modifications included changes of equipment (circuit breakers), switching operations, position (height and spacing) of buses, position of ground wires, transmission line sag, and phasing of bays; application of shielding wire mesh; introduction of masts of different heights; and changes in the layout of the substation. The feasibility of short-circuit (charging) current measurements on model vehicles has also been proven.

This modeling technique is detailed in Volume 2. Any utility having a need to determine the electric field distribution in or around substations will find this technology to be a useful design tool. *EPRI Project Manager: Stig Nilsson*

Correction

In the March 1978 issue, page 58, *Cable Neutral Corrosion, Phase II,* was listed as EL-622. This should have been listed as Vol. 2 of EL-619.

ENERGY ANALYSIS AND ENVIRONMENT

Solar energy and the heat pump in a northern climate

EA-407 Final Report (RP385)

The Alumni House–Conference Center (AHCC) on the campus of the State University of New York at Albany combines 213 m^2 (2300 ft^2) of copper solar panels with a water-to-water heat pump, an air-to-water heat pump, an electric boiler, and two 24-m^3 (8000-gal) storage tanks. The building is instrumented to provide data for the time-variant electric power demands, the impact of meteorologic variables, peak storage capabilities, the efficiency of the solar panels, coefficient of performance (COP) of the heat pumps, and the heating system performance factor. Computer simulations of the heat budget of the AHCC have been prepared and verified. A series of economic analyses provide return-on-investment data by comparing the air-source heat pump with the solar-assisted water-to-water heat pump and using a base case of electric heating peak shaving. Incremental costs are included, but the peak shaving capability was not tested.

Computer analysis, unverified, indicates that the air-source heat pump has a higher COP than the solar-assisted water-to-water heat pump. The solar system, however, provides 33% of the heating load of the AHCC during peak winter operating conditions. *EPRI Project Manager: Larry Williams*

Dynamic models of the industrial demand for energy

EA-580 Interim Report (RP683-1)

This interim report, prepared by Economics Research Group Ltd., represents an element of EPRI's Demand and Conservation Program effort in econometric approaches (based on aggregate time series) to long-range forecasting of industrial consumption of electricity and fossil fuels. Previous EPRI research on this topic (RP433, "Forecasting the Industrial Demand for Energy"; and in-house research) has resulted in static models that do not adequately deal with the problem of time lags in adjusting inputs of energy, capital stock, and other factors of production to new optimal levels that reflect the new costs of using these factors. The research detailed in this report represents important methodological contributions to the problem of building dynamic models of industrial energy demand. *EPRI Project Manager: Larry Williams*

Long-term residential load forecasting

EA-584 Final Report, Vols. 1 and 2 (RP943-1)

The main objective of this joint study by the University of California at San Diego and Econometric Research Associates was to isolate and evaluate the importance of various factors, many of which are household characteristics and weather conditions, that determine the demand for electricity at different times of day. A second purpose was to investigate in detail one of the factors—prices—which was feasible because half the households in the sample were subjected to time-of-day pricing.

Substantial differences between the load curves of the experimental and control groups were found. Households in the experimental group significantly decreased electricity usage when its price was high by shifting some consumption into the evening. The importance of certain appliances in shifting the load curve is also clearly brought out. For example, households with a dishwasher or electric heating appeared to change the timing of use of these appliances under peak load pricing. Other appliances were also important in determining the load curve for both groups. Swimming pool pumps and air conditioning, for instance, were important determinants in the summer; whereas in the winter, electric heating and dishwashers substantially increased consumption levels.

Volume 2, the statistical appendix, contains the regression results and is available on request from the project manager. *EPRI Project Manager: Anthony Lawrence*

An overview of the economic theory of uncertainty and its implications for energy supply

EA-586-SR Special Report (RP869)

This is an excerpt from the interim report of a study on the effects of risk on prices and quantities of energy supply. It is an overview of economic theory of uncertainty and summarizes much of the economics literature of the past 10–15 years on risk and uncertainty.

The report, by MicroEconomic Associates, reviews the economic principles of risk bearing, which include such topics as the measurement of risk, the institutional structures by which risks are shared in the economy, activities that reduce risk, and market mechanisms that provide incentives for risk reduction. It also examines the effects of uncertainty on the price and quantity decisions of firms, the sources of risk, the characteristics of risk, the producer's attitudes toward risk, and the effects of market structure and regulation on decision making. *EPRI Project Manager: A. N. Halter*

NUCLEAR POWER

Sources of radioiodine at boiling water reactors

NP-495 Final Report (RP274-1)

This report by Science Applications, Inc., determines specific components in operating BWRs that have a potential for being emission sources of radioactive iodine. The relative magnitudes of these specific releases in terms of the chemical forms of the radioiodine and the resultant annual averages from major components are established. Two models are developed: one generalizes data for broad industry use for predictive purposes, and the second determines the behavior of the iodine during transport through plant ventilation systems.

Conclusions of this study indicate the following: most radioiodine emanating from plants is from a few major areas; in most cases these releases are locally treatable; the interaction with surfaces is an important phenomenon in the behavior of the iodine; and the chemical form in the plant varies according to the circumstances of release. The models developed provide an improved method for predicting releases of radioiodine from plants in the future.

Data on other important radionuclides that were measured in this study are given in the appendixes. Detailed analyses of these radionuclides are to be provided in a separate report. Similar analyses for radioiodine and other radionuclides for operating PWRs are also to be given in a separate report. *EPRI Project Manager: Henry Till*

Transient deformation properties of Zircaloy for LOCA simulation

NP-526 Final Report, Vols. 1, 2, and 3 (RP251-1)

Battelle, Pacific Northwest Laboratories used analytic techniques to determine and compare the creep–creep rupture anisotropic properties of Zircaloy with ramp pressure and ramp temperature test results. Tests were performed for the temperature range 600–2200°F (589–1477 K), with emphasis on the 800–2000°F (700–1366 K) temperature levels in low-pressure air and in a 101-kPa mixture of 20% oxygen, 80% argon. Stress levels of 60–95% of the ultimate tensile stress were used for most of the tests at each of the temperature levels tested, with selected tests performed as low as 30% of the ultimate tensile stress. Biaxial and uniaxial testing modes were used to evaluate the anisotropic deformation behavior. The combination of test results and predictive analysis techniques that were developed as part of this program makes it possible to predict the transient deformation of reactor fuel cladding during simulated LOCA conditions. Results include creep–creep rupture strain numeric constitutive relationships out to 120 seconds, computer codes, and ramp test data. *EPRI Project Manager: J. T. A. Roberts*

A rapid hot-water depressurization experiment

NP-527 Interim Report (RP687-1)

An apparatus has been constructed by the University of Kentucky for the purpose of studying the early response of water to very sudden depressurization from both BWR and PWR conditions. The apparatus incorporates a novel opening device that achieves extraordinarily rapid removal of pressure from the water—up to $\sim 1.58 \times 10^8$ kPa/s, resulting in 80% depressurization in as little as 100 μs.

The present configuration of the container is a straight, 12.7-mm-ID (0.5-in) pipe with a full cross-sectional opening. Later experiments are to involve reduced cross-sectional openings, slower opening rates, and the construction of a 50.8-mm-ID (2-in) pipe to determine whether dimensional scaling influences the results.

The early results of these experiments reveal that the pressure initially undershoots the saturation pressure dramatically. Under PWR conditions it almost reaches the "spinodal line," or locus of limiting liquid superheat states.

Following nucleation, the pressure rapidly recovers to within about 70% of the saturation pressure. From experiments made to date, it appears that the very sudden pressure excursions do not accompany this recovery. *EPRI Project Manager: Bal Raj Sehgal*

Study of transuranium concentration levels in solid radioactive waste from commercial power reactors

NP-631 Interim Report (RP613)

This interim report by Science Applications, Inc., presents the results of isotopic assays of the waste sources in operating nuclear reactors, with particular emphasis on the transuranic elements. This report provides a description of the radwaste systems from which the samples were taken, a description of the analytic procedures, and the results of comparative testing conducted by several laboratories. Samples were acquired from seven operating reactors over periods of up to two years.

Although the primary purpose of this phase was data acquisition, some preliminary analysis of results is included to suggest how the concentration of transuranic elements may be estimated from other isotopes that are more easily measured. *EPRI Project Manager: Melvin Lapides*

Plutonia fuel study

NP-637 Final Report (RP396)

The EPRI plutonia fuel study was conducted by Battelle, Pacific Northwest Laboratories to investigate the in-reactor densification characteristics of mixed-oxide fuels and to determine the extent of thermal and irradiation-induced uranium-plutonium homogenization in mechanically blended mixed oxides for thermal reactors. Also, the densification behavior of the mixed-oxide fuels was compared with the behavior of UO_2 fuels irradiated under similar conditions.

Sintered mixed-oxide pellet fuel types incorporating a wide range of microstructural features were produced, thoroughly characterized, and irradiated over a wide range of conditions. Detailed pre- and postirradiation characterization was performed on the different fuel types in order to evaluate the effects of pellet density, microstructural features, PuO_2 particle size, PuO_2 concentration, fission rate, fuel temperature, and burnup. *EPRI Project Manager: Howard Ocken*

Progress in the development of a reactivity capability in the SAM–CE system for validating fuel management codes

NP-638 Interim Report (RP972-1)

Mathematical Applications Group, Inc., expanded the SAM–CE Monte Carlo system (for three-dimensional neutron, gamma ray, and electron transport) to include a reactivity capability. The implemented code modifications have effected the following improvements: Doppler broadening of ENDF/B-IV–based nuclear data (including fission); probability table representation for the unresolved resonance range; use of thermal scattering law data for the moderator; free-gas model in the absence of thermal scattering law data; generalization of the nuclear-element data tape structure to facilitate data management; generalization of data management routines; extension of the SAM–CE complex combinatorial geometry capability to facilitate treatment of hexagonal lattices; simultaneous use of four different eigenvalue estimators; estimation of the eigenfunction in user-prescribed spatial domains; and variance reduction via stratification of source (position, energy, direction) and absorption (based on a quota sampling technique), as well as optional suppression of absorption.

The new coding has undergone extensive testing, both specific (via drivers and idealized data) and integral (via comparison with previous computations). Base data have been examined for internal consistency and checked for reasonableness.

A documented TRX-1 benchmark calculation has been performed. Agreement with other calculations, as well as with experiments, has served to validate the reactivity mode of SAM–CE. Further refinement of the cross-section data processing component of SAM–CE (i.e., SAM–X) is suggested. *EPRI Project Manager: Frank Rahn*

Assessment of technologies essential to the application of advanced systems for process control

NP-640 Final Report (TPS75-625-1,2,3)

This report assesses the adequacy of certain underlying technologies that may be required for the successful design and implementation of advanced computer-supported control rooms. The assessment is based on the answers provided by Babcock & Wilcox Co., General Electric Co., and the Institutt for Atomenergi to a detailed set of technical questions developed by EPRI (the questions and answers are documented in the appendixes to the report). Among the technical areas addressed are: definition and justification of functional and design requirements; information assimilation techniques; operability; validation; reliability; and maintenance capabilities. The report discusses the need for techniques to evaluate the impact of different design alternatives on operator performance, the increasing importance of software validation to ensure adequate availability, and the role of utility personnel in the support of these systems. *EPRI Project Manager: A. B. Long*

EPRI ductile fracture research review document

NP-701-SR Special Report

This report describes the ductile fracture research sponsored by EPRI. The need for such research is related to the need to accurately define the effect of flaws (either real or hypothetical) on the burst-resistance of nuclear pressure vessels, particularly the reactor vessel. Current analytic tools cannot accurately predict this behavior at or near operating conditions because they assume the vessels to be fabricated with brittle, elastic materials, which is not the case. Therefore, the general goal of the ductile research is to develop analytic tools that are capable of dealing with the tough, ductile materials characteristic of the reactor vessel. The three projects (five individual contractors) have separate but complementary objectives, all of which add to the development and use of such a tool. The five contractors are Battelle Memorial Institute; General Electric Co.; Lawrence Livermore Laboratories; Science Applications, Inc.; and SRI International.

The general strategy for developing an analytic tool is to: develop or select a basic theory that describes or predicts the ductile fracture process in its entirety; develop a suitable means of implementing such a basic theory in the analysis of ductile failure in structures; conduct appropriate ductile fracture experiments to obtain the proper inputs and verify the predictive capability of the analytic means developed; and apply this technology to the prediction of the behavior of flawed pressure vessels. *EPRI Project Manager: Theodore Marston*

FOSSIL FUEL AND ADVANCED SYSTEMS

A study of brine treatment

ER-476 Final Report (RP791-1)

The objective of this project by Lawrence Berkeley Laboratory was to collect, from a literature search, information pertinent to the treatment of geothermal brines and then to evaluate and summarize this information for use by the electric utility and geothermal industries.

The information used for this study was screened from the geothermal, oil and gas, waste water disposal, and boiler water treatment industries. The current state of knowledge and methodology concerning the treatment of geothermal brines to control scaling and corrosion in geothermal electric power production was assessed on the basis of this information. Currently, geothermal scale in pipes and wells is removed by physical or chemical methods. There is a growing effort to develop methods to control scale formation for both fresh and spent brines, including pH adjustment and application of an electric potential for fresh fluids and coagulation to treat spent fluids. Current methods of corrosion control center on planned replacement of piping and other plant components, with efforts focused primarily on development of materials with improved corrosion resistance. Recommendations for additional work to improve brine treatment include: chemical and physical characterization of brine and scale compositions; basic data on the mechanism of scale formation and the effects of inhibitors; development of instrumentation to monitor geothermal brine constituents; correlation of laboratory results with field test data; and screening of available commercial inhibitors for application to geothermal brines.

An annotated bibliography of the reference material used in this study is contained in this report. *EPRI Project Manager: Phillip La Mori*

Thermodynamic phase stability diagrams for the analysis of corrosion reactions in coal gasification/combustion atmospheres

FP-539 Topical Report (RP716-1)

This is a review by Lockheed Palo Alto Research Laboratories of a thermodynamic approach to the analysis of the high-temperature corrosion behavior of complex alloys in mixed oxidants. The derivation and use of phase stability diagrams to interpret corrosion behavior is discussed. Diagrams are presented for Fe, Ni, Co, Cr, Al, and Mn in S–O, C–O, N–O, C–S, C–N, and S–N at 894, 1144, and 1366 K (1150, 1600, 2000°F). *EPRI Project Manager: Robert Jaffee*

Coil systems for measuring electrical conductivity in MHD combustion flows

AF-569 Final Report (RP843-1)

An instrument system for measuring electrical conductivity, σ, was tested in a copper-walled magnetohydrodynamic (MHD) combustion duct at Stanford University. These tests were preceded by simulation tests at Utah State University in an electrolyte-filled aluminum duct. The system consisted of an immersible two-coil magnetic-induction probe, a pneumatically actuated traversing apparatus, gas cooling, and signal conditioning and readout devices. Operation of the probe was based on the fact that sinusoidal power supplied to the primary coil creates a magnetic dipole field that induces eddy currents in the surrounding medium; the σ-dependent eddy-current magnitudes were detected and measured by the probe's secondary sensing coil.

After the influence of nearby highly conducting walls (10^5 mhos/m) was essentially eliminated, the system could measure $\sigma(\sim 10$ mhos/m) in electrolytes with a maximum error of 10%. However, the tests in a seeded MHD combustion flow at Stanford were not successfully completed because of complexities associated with the cooling and traversing apparatus and because of funding and facility-scheduling priorities.

Consequently, in an effort to simplify the measurement technique, a theoretical study was made of an instrument having the primary and secondary sensing coils embedded in an insulator wall adjacent to the conducting fluid. A two-coil system was tested, using a uniformly conducting electrolyte; the disagreement between theory and experiment was less than 15%. The theory predicts that extra sensing coils can be used to obtain a conductivity profile. Although it has not yet been tested in an MHD flow, the wall-mounted coil system is attractive because coil cooling would be simplified, traversing would be unnecessary, the technique is nonintrusive, and the measurement readout would be continuous. *EPRI Program Manager: Vance Cooper*

Evaluation of materials for use in letdown valves and coal feed pumps for coal liquefaction service

AF-579 Final Report (RP458-2 and RP779-13)

This report by Battelle, Columbus Laboratories on applications of advanced materials and fabrication technology to letdown valves for coal liquefaction service also contains a summary of an independent erosion evaluation conducted in support of an EPRI-sponsored program on coal slurry pumps. The report describes the test equipment, procedures used, and results of the erosion evaluations. *EPRI Project Manager: Howard Lebowitz*

Solvent-refined coal (SRC) process operation of pilot plant at Wilsonville, Alabama

AF-585 Annual Report (RP1234-1-2)

This report by Catalytic, Inc., presents operating conditions and results for the 6-t/d solvent-refined coal (SRC) pilot plant at Wilsonville, Alabama, for the last quarter of 1976. It also summarizes conditions and results for the entire year.

The first objective was correlation of the results from Wilsonville with the 50-t/d Ft. Lewis pilot plant operation. This correlation was established by processing Kentucky 9 and 14 coal during the first half of 1976. A second objective was to determine the effect of process variables on yield and quality when processing other coals. This was completed for Monterey (Illinois 6) and continued into 1977 for Amax Belle Ayr coal.

The effects on the operation of varying the boiling range of the process solvent and the dissolver volume are reported. Also reported are the effects of operating variables on the overall solvent inventory balance for the plant.

Filtration results show that the filter cake from Amax Belle Ayr coal has lower resistance, but is more compressible, than the filter cake from either the Kentucky 9 and 14 or the Monterey (Illinois 6) coal. Work with precoat materials that do not contain asbestos is described. Other improvements in the filtration system are discussed.

Results from testing of alternative methods for mineral residue separation, such as centrifuges and hydrocyclones, are described. Background information is reported on installing a system for preliminary evaluation of an antisolvent method to improve the mineral residue separation systems.

SRC containing less than 0.16% ash, 0.96% sulfur was produced from each coal processed during the year.

An SRC solidifier, which uses indirect cooling, was developed; and the capacity of the machine has been defined. Several alternative methods of solidification were also investigated. *EPRI Project Manager: Norman Stewart*

Perspectives on utility central station photovoltaic applications

ER-589-SR Special Report

This report develops nominal cost and performance goals for solar photovoltaic conversion devices intended for large-scale electric utility applications. The objective is to provide an improved basis for establishing R&D priorities for photovoltaic devices and conversion concepts. Comparisons are made among a number of generic power plant conceptual designs, with the aid of an array design parameter that is defined to include array-area–related costs, overall power plant efficiency, and average available insolation.

The analysis indicates that flat plate approaches without concentration or tracking have good prospects for commercial viability if device conversion efficiencies near 10% can be combined with installed-device costs under $\$20/m^2$ ($\$2/ft^2$) and device lifetimes in excess of 20 years. Thin-film approaches have potential for achieving these cost and performance goals because of low material content and potentially low fabrication costs.

Very high efficiency devices coupled with concentrations in excess of about 100:1 represent a viable alternative if sufficiently high conversion efficiencies (25% or more) can be achieved. Such devices are likely to be expensive, but high concentration may make their costs acceptable. Several device types and converter approaches exist or have been proposed that have potential for reaching these efficiencies. In contrast to flat plate approaches, however, high-concentration approaches may have the disadvantage of requiring active cooling.

Approaches employing low to medium concentration appear to have limited potential for large-scale applications. Required efficiencies are likely to be comparable to those needed for high-concentration approaches, but the concentration ratios are not likely to be high enough to make the photovoltaic device costs tolerable. *EPRI Project Manager: Edgar DeMeo*

Modeling and analysis of moving-bed coal gasifiers

AF-590 Final Report, Vols. 1 and 2 (TPS76-653 and RP986-1)

Moving-bed coal gasification reactors are countercurrent devices in which a coal bed moves downward by gravity flow through an upward-flowing gas stream. Steam and oxygen (or air) are fed at the bottom to provide reactants for the combustion and gasification reactions. The pressurized Lurgi gasifier is commercially proven, while other moving-bed gasifiers, including a potentially high-throughput and high-temperature reactor that produces liquid slag, are under development.

The composition and temperature of the product gas and the amount of unburned carbon in the ash largely determine the thermal efficiency of the process. The maximum temperature in the reactor determines the physical state of the ash (dry powder, clinker, slag), and hence the operability of a given reactor configuration. Composition and temperature depend on the properties of the coal being processed and on such operating parameters as feed rates, feed temperature, and reactor pressure.

The University of Delaware has developed a steady-state simulation model of a moving-bed gasifier. The model describes the complex physical and chemical processes taking place in the multiphase moving bed, using fundamental principles such as mass and energy balances, information about rates of chemical reaction and physical transport processes, and thermodynamic relations. The model has been compared with available plant data for Lurgi gasifiers and shows good agreement. The use of such a model enables the exploration and prediction of feasible and economically attractive ranges of design and operation in terms of the properties of the coal to be gasified. *EPRI Project Manager: Linda Atherton*

Laser fusion power balance measurements (particle transmission diagnostics)

ER-591 Final Report (RP647-1)

Lockheed Missiles & Space Co., Inc., had as its objective the development of the particle transmission technique for the measurement of density in plasmas encountered in inertial-confinement fusion. In this technique the implosion region is illuminated by a pulsed and tightly focused beam of charged particles. A configuration of electric and magnetic fields then provides a time-energy analysis of the transmitted beam, and the value of $\int \rho dr$ along the particle track is determined from the loss of energy.

The 50-GW Nd-glass laser at the Lockheed Palo Alto Research Laboratory was employed to produce inertially confined plasmas, and the 3-MV Van de Graaff accelerator was used as the source of the diagnostic proton beam. The overall system is conveniently divided into three basic subsystems: the particle beam control system delivers a pulsed, monochromatic, and tightly focused beam of protons at the target spot; the time-energy analysis system (TEAS) analyzes the transmitted beam in time and energy coordinates; and the laser timing and synchronization system coordinates the interaction of the particle and laser beams. These three subsystems were completed in December 1976, and tests of the combined system were carried out over the next several months. The results of these tests have indicated that the particle transmission technique is a feasible approach to density measurement in inertially confined plasmas. Adequate solutions to the problems of background, temporal synchronization, and spatial overlap are demonstrated in this report. Further attention should be devoted to the problem of beam luminosity and to direct experimental verification of the time-resolution capability of the TEAS. The study of dE/dx, a problem of considerable importance to current fusion research in inertially confined plasmas, offers the best immediate practical application for the system assembled under this contract and is recommended as a follow-on effort. *EPRI Project Manager: F. Robert Scott*

System definition study—phase 1 of individual load center, solar heating and cooling residential project

ER-594 Final Report (RP549-1)

A study was carried out by Arthur D. Little, Inc., to determine preferred systems for residential solar and load management heating, cooling, and domestic hot water systems in the Northeast and Southwest regions of the United States. The program (1) developed a methodology for relating the performance of solar and load management heating and cooling systems to utility power generation, costs of supply, and weather characteristics; (2) identified preferred systems in the service areas of two utilities—Long Island Lighting Co. (LILCO) and Public Service Co. of New Mexico (PNM); (3) developed preliminary designs for five experimental systems in both the LILCO and PNM service areas, with the intent of maximizing the acquisition of experimental information on systems compatible with utility operations; and (4) developed instrumentation and test and evaluation plans for the experiments. The methodology provides a means of determining systems that on a life-cycle cost basis, minimize the total cost of meeting the energy needs for a specific application—including investments in generating capacity at the power plant, fuel costs, and investments at the point of use for energy conservation and HVAC equipment. The methodology was tested for 14 additional utilities throughout the United States. *EPRI Project Manager: John E. Cummings*

Combined-cycle power plant capital cost estimates

AF-610 Final Report (SOA77-402)

Capital cost estimates have been prepared by Bechtel Power Corp. for oil-fueled, high-efficiency combined gas turbine–steam turbine power plants in five regions of the United States: Great Lakes, Southwest, West (at two locations), Northeast, and Southeast. These plants are designed to burn liquid fuels, either distillate (kerosene and No. 2 distillate) or ash-bearing (blended residuals, crudes, and heavy residuals).

Plants have a nominal net combined electric power output of either 250 MW (for a single-unit installation) or 500 MW (for a two-unit installation consisting of two 250-MW units). All plants are designed to meet present environmental regulations and EPA New Source Performance Standards. In addition, one of the plants—located in the southern California metropolitan area (Los Angeles)—is designed to meet the special pollutant limitations in that area.

Capital costs for the 250-MW plant, expressed in 1976 dollars, range from \$306/kW (for a plant in the Southwest, burning distillate fuel) to \$417/kW (for a remote plant in the West, burning residual fuel). The costs in dollars per kilowatt for the 500-MW plants are about 5% lower. Cost estimates were based on information from recent and current construction projects for both conventional and combined-cycle plants and incorporate present criteria regarding releases to the environment. The costs also include an allowance for funds during construction and other owner costs.

Trends in future development of combined-cycle plants are also discussed. *EPRI Project Manager: Stanley Vejtasa*

Bench-scale coal liquefaction studies

AF-612 Final Report (RP779-2, -7, -10)

The results from three laboratory studies are included in this volume.

In the study by Battelle, Columbus Laboratories, viscosities of de-ashed and non-de-ashed solvent-refined coal were measured. Also measured were admixtures of these products with coal, as a function of temperature. Thirty weight percent mixtures of coal remained fluid in the case of western coals.

Suntech, Inc., conducted autoclave coal liquefaction experiments, including runs that show the effect of H_2S partial pressure, disposable catalysts, and solvent boiling range. H_2S partial pressure was shown to have a marked effect on product sulfur; disposable iron-rich catalysts were ineffective, though this may have been a result of the high pyrite in the feed coal; and solvent boiling range had a profound influence on coal conversion and yields.

The process of KVB, Inc., for splitting a feed oil into sulfur and nitrogen rich and lean fractions by selective oxidation and extraction was briefly tested on H-Coal distillates. The selective oxidation was not nearly as effective as it is for comparable petroleum feeds. *EPRI Project Manager: Howard Lebowitz*

Viscosity, suspended solids, and filtration studies of liquefied coals: phase I

AF-614 Final Report (RP459-1)

Johns-Manville Sales Corp. studied viscosity, vapor pressure, suspended solids characteristics, and filtration properties of several liquefied coals. Viscosities and vapor pressures were measured at temperatures up to approximately 370°C (700°F) with a Dynatrol viscosity instrument. The effects of solvent dilution and suspended solids on viscosity were also studied. Residual gases formed by holding samples of liquefied coal at elevated temperatures followed by cooling were analyzed on a gas chromatograph.

Mineral and chemical analyses were made of suspended solids. Particle size analyses were made of pyridine insolubles, using light-scanning electron microscopes and computerized particle size analysis techniques. Median particle sizes determined by these methods for several coals were approximately 0.5 μm, compared with average particle sizes of 1.6 to 8 μm as measured by particle counters. Photomicrographs made of filter cakes formed at 180–370°C (350–700°F) showed distinct differences in particle structure. Nearly all particles in filtrates were less than 0.2 μm.

A laboratory filter capable of operating at up to 2757 kPa and 370°C was designed and constructed. The effects of temperature, differential pressure, viscosity, solvent addition, and body feed addition on filtration rates were studied. Filtration rates differed widely for four coals studied. Theoretical calculations of filtration data were made to show average cake resistance, cake compressibility, constant rate cycle lengths for different filtration rates, and rotary drum pressure precoat filtration rates at different drum rotation speeds. *EPRI Project Manager: Norman Stewart*

Fusion applications of fast-discharging homopolar machines

ER-625 Topical Report (RP469)

In this report by the University of California's Los Alamos Scientific Laboratory, fast-discharging homopolar machines, with energy delivery times of 1 ms to 5 s, are described for applications to fusion reactors, including toroidal and linear theta pinches, toroidal *z*-pinches, imploding liners, and tokamaks. Typical circuits and machine designs are also described. *EPRI Project Manager: Noel Amherd*

Characteristics of solvent-refined coal: dual-register burner tests

FP-628 Final Report (RP1235-5)

This is the fourth and final report in a series dealing with efforts by Babcock & Wilcox Co. (B&W) to support EPRI's continuing program to evaluate the suitability of solvent-refined coal (SRC) for use by the electric utility industry. This latest work was performed in 1976 in direct support of the then-pending SRC combustion tests at Georgia Power's Plant Mitchell. Identification of retrofitting requirements for B&W E-type pulverizers and for the B&W dual-register burner were the principal purposes of this work. Changes in the pulverizer included lessening of the grinding pressure, slowing of the grinding elements, changing of the feeder controls, and operating with cold primary air. The dual-register burner was equipped with a water-cooled coal nozzle, and eddy circulations were minimized in the vicinity of the burner front. These changes were necessary to prevent agglomeration and melting of the SRC in this equipment. All objectives were satisfactorily met and the field tests at Plant Mitchell were permitted to proceed as planned. *EPRI Project Manager: Robert Carr*

Closed-cycle, high-temperature central receiver concept for solar electric power

ER-629 Final Report (RP377-1)

Conversion of solar energy to electric energy has assumed increasing significance because of increasing energy requirements and the potential resource and cost constraints of conventional fossil fuels. Energy conversion in conjunction with a turbine generator set is the subject of this report.

The technical feasibility of a high-temperature central receiver in a solar plant employing closed-cycle helium as a heat transport fluid was examined by Boeing Engineering and Construction in terms of system life, efficiency, cost, and technology requirements. These considerations have been implemented in the conceptual design of a receiver and its components for use in a solar plant of 100 MW of electrical power output. The rationale is provided that supports the configuration, equipment arrangement, and material choices. Thermal cycling tests simulating a 30-year lifetime of the receiver's heat exchangers at temperatures to 816°C (1500°F) and at 3447 kPa (500-psi) helium pressure confirmed the material choices. Preliminary design considerations are presented for a 1-MW (thermal) test receiver and for a 10-MW (electric) pilot plant.

The report also contains system–supporting-subsystem definition for employing the central receiver design in a solar plant. This includes conceptual design of several thermal energy storage devices and their integration into plant operation. *EPRI Project Manager: John E. Cummings*

Silicon photovoltaic cells in thermophotovoltaic conversion

ER-633 Interim Report (RP790-1)

A preliminary assessment of the feasibility of a solar-electric thermophotovoltaic (TPV) system has been performed by Stanford University. In concept, the proposed system uses concentrating mirrors focused on a TPV converter that operates at high power density and potentially high efficiency. Within the TPV converter, the concentrated sunlight heats a refractory radiator. A photovoltaic cell faces the radiator, receives incandescent radiation from it, and converts this radiation to electricity.

TPV conversion has several features that make it economically attractive. First, based on preliminary theoretical and experimental results, the achievable cell conversion efficiency is expected to be in the range of 30–50%. These high efficiencies may be attractive in light of high supporting structure cost estimates for proposed photovoltaic systems. Second, the system runs with a concentration ratio of 300 to 500 at the photocell, permitting the use of an expensive and sophisticated converter, which will be necessary to obtain high efficiency.

A numeric model of TPV conversion was developed both to assess TPV conversion and to facilitate an initial design of TPV photocells. Also, a facility for experimentally evaluating TPV photocells was designed and built. *EPRI Project Manager: Edgar DeMeo*

Brine chemistry and combined heat/mass transfer

ER-635 Interim Report, Vols. 1 and 2 (RP653-1)

The objective of this program by Battelle, Pacific Northwest Laboratories is to develop analytic tools and a supporting data base to predict effects of scaling and corrosion on the performance of geothermal power plants, and the subsequent plant degradation in electric output and maintenance expense. The program includes development of several computer programs, the geochemistry of scale formation, laboratory scaling kinetics studies, and analyses of the composition of several field-scale samples.

A computer code called EQUILIB has been developed to calculate pH at temperature, gas pressures, concentrations of brine components, and the amount of potential mineral precipitates at temperatures of 25–300°C. The code is supported by an extensive data base of chemical equilibrium constants and a tabulation of brine compositions from literature sources. Power plant computer models were developed for multistage flash or binary cycle–type geothermal power. These codes permit the user to input mineral scale thicknesses from more than 90 locations in the plant to calculate the effects of the scale on plant operating parameters and electric output.

A laboratory scaling kinetics program indicates $CaCO_3$ deposits almost instantaneously when brine flashing occurs, and data are presented on effects of temperature and salinity.

All this work is leading to the later development of a computer code called GEOSCALE, which will integrate the brine chemistry, scaling rates, and plant operation to predict geothermal plant performance using various geothermal resources. *EPRI Project Manager: Phillip La Mori*

A summary of the effects of important chemical variables upon the performance of lime/limestone wet scrubbing systems

FP-639 Interim Report (RP630-3)

This document was prepared by Radian Corp. to provide both current and prospective operators of lime/limestone wet scrubbing systems with a general summary of important chemical variables and their effects on the performance of these systems. This report is based on information derived from three primary sources: open literature, contacts with scrubbing system operators, and Radian experience. Three separate but related areas are discussed: scrubber performance, which includes both SO_2 removal and additive selection and utilization considerations; techniques for precipitating calcium- and sulfur-containing solids in a scale-free manner; and factors relating to the quality of the product sludge and its disposal.

It is concluded that although lime/limestone scrubbing systems tend to be somewhat simple mechanically, their chemical processes are very complex. And although many important variable effects and interactions have been documented, considerable gaps in our understanding of the chemistry of these systems still exist. *EPRI Project Manager: Thomas Morasky*

Economic studies of coal gasification combined-cycle systems for electric power generation

AF-642 Final Report (RP239-3)

This report presents the results of economic screening studies by Fluor Engineers and Constructors, Inc., for several current and advanced coal gasification processes coupled with combined-cycle power generation. The objective of these studies was to determine whether significant economic and/or environmental incentives exist for using such systems instead of the current practice of direct coal firing and stack gas cleanup.

The processes studied included the Lurgi dry ash gasifier, the British Gas Corp. slagger, and three entrained-bed processes offered by Combustion Engineering, Foster Wheeler, and Texaco. All these processes were integrated with combined-cycle plants based on advanced gas turbine technology (1316°C [2400°F] combustion outlet) estimated by Westinghouse to be available in the 1981–1985 time period.

The evaluations were based on complete grass roots facilities sized to conform to present electric utility practice of building units of approximately 1000 MW capacity.

The conclusions reached in the report are that several of the processes considered are potentially attractive and are, or can be, available for commercialization during the next decade. In particular, the entrained-bed processes appear to offer substantial environmental as well as economic advantages because of their simplicity and lack of by-products.

It is concluded that development emphasis should be placed on compression, power generation, and heat transfer equipment rather than on more gasification processes. *EPRI Project Manager: Michael Gluckman*

Proceedings: EPRI annual geothermal program, project review and workshops

ER-660-SR Special Report

EPRI sponsored a geothermal workshop in July 1977 at Warm Springs, Oregon. The purposes of the workshop were to: expose details of the EPRI Geothermal Program to the geothermal community; exchange information and ideas on projects and important issues among all segments of the geothermal industry; and gain insight and recommendations for future planning.

The participants included representatives from the utility industry, geothermal resource industry, suppliers, academic institutions, local and state governments, environmental groups, and DOE.

This report attempts to capture the main flow of ideas at the meeting. It is organized to include reports on individual EPRI and utility projects as well as results of workshop sessions on reservoir engineering, geothermal energy pricing concepts, and future directions of geothermal R&D. *Edited by Phillip La Mori and Vasel Roberts*

Solvent refining of Indiana V coal and North Dakota lignite

AF-666 Final Report (RP779-4)

Hydrocarbon Research, Inc., solvent-refined high-sulfur Indiana V coal in a bench-scale unit to determine operating conditions necessary to produce low-ash product with less than 0.9 wt% sulfur. Necessary background information was generated prior to recommending further processing of this coal at the Wilsonville solvent-refined coal pilot plant.

North Dakota lignite was processed in the same unit to determine its suitability for further study at the pilot plant level. Three sets of operating conditions with three different mixtures of carbon monoxide and hydrogen were evaluated. On the basis of these results, further testing of lignite at Wilsonville was deferred.

The report summarizes operability information and product distribution data; hydrogen, carbon monoxide, and water consumption; as well as elemental analyses of products and product fractions. *EPRI Project Manager: Norman Stewart*

SO_2 absorption in fluidized-bed combustion of coal—effect of limestone particle size

FP-667 Final Report (RP719-1)

Fluidized-bed combustion of coal with a limestone additive is a potential alternative to conventional methods of burning coal to produce electricity. In this method, SO_2 is removed from the combustion gas by means of its chemical combination with the limestone. A critical unknown at present is the quantity of limestone that will be required for adequate SO_2 removal. Data from other investigations have shown that adequate control of sulfur emissions requires from two to five times the amount of limestone theoretically equivalent to the sulfur in the coal. This excess limestone requirement represents added cost not only in terms of limestone purchased but also in terms of thermal losses and waste material disposal.

The objective of this investigation by Babcock & Wilcox Co. was to determine the influence of the limestone particle size on its utilization (SO_2 capture per pound) in a fluidized-bed combustion test unit ~1 × 1 m (3 × 3 ft). This unit contained a water-cooled tube bundle in and above the bed. The unit operated on a once-through basis, with no recycle of carryover particles to the bed. This report describes the test unit, test procedures, and results. Data tabulated in the report include flow rates to and from the unit; temperatures throughout the unit; concentrations of O_2, CO_2, SO_2, combustibles, NO_x and particulates in the freeboard (above the bed) and at the unit exit; chemical analyses and size distributions of solids entering and leaving the unit; and microanalytic examinations of bed material. An empirical equation was developed that relates SO_2 absorption to limestone particle size and to the calcium-sulfur ratio. *EPRI Project Manager: T. E. Lund*

State of the art of FGD sludge fixation

FP-671 Final Report (RP786-1)

Thirty-one fully operational flue gas cleaning electric utility lime/limestone and alkaline fly ash wet scrubbing systems were evaluated by Michael Baker, Jr., Inc., to determine the practical significance of FGD sludge fixation. Five commercial sludge fixation installations are in operation. Other disposal practices are widespread and acceptable. Nine installations use the wastes as landfill, through various types of processing, while 17 are using ponding for dewatering and ultimate disposal.

Of 16 vendor companies evaluated, only 2—IU Conversion Systems (IUCS) and Dravo Corp.—have fully demonstrated commercial capability. The other vendors have little or no FGD waste experience. Both IUCS and Dravo products exhibit lower permeability, greater strength, and overall improved physical, chemical, and engineering properties compared with untreated sludges. Dravo has one full-scale, 1650-MW facility; IUCS has four installations totaling 1818 MW.

Estimated 30-year levelized incremental sludge fixation revenue requirements are $6.90 and $2.50 per dry ton of sludge solids for wet disposal (ponding) and dry disposal (landfilling), respectively. These costs are not highly site-dependent and can be applied generally.

By-product recovery and utilization concepts were found to be technically feasible but not economically competitive at this time. The most promising concepts are use of fixed sludge as a construction material; production of by-product gypsum, with uses in agriculture and wallboard manufacturing; and mine reclamation. *EPRI Project Manager: Thomas Morasky*

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