Reliability: How and How Much?

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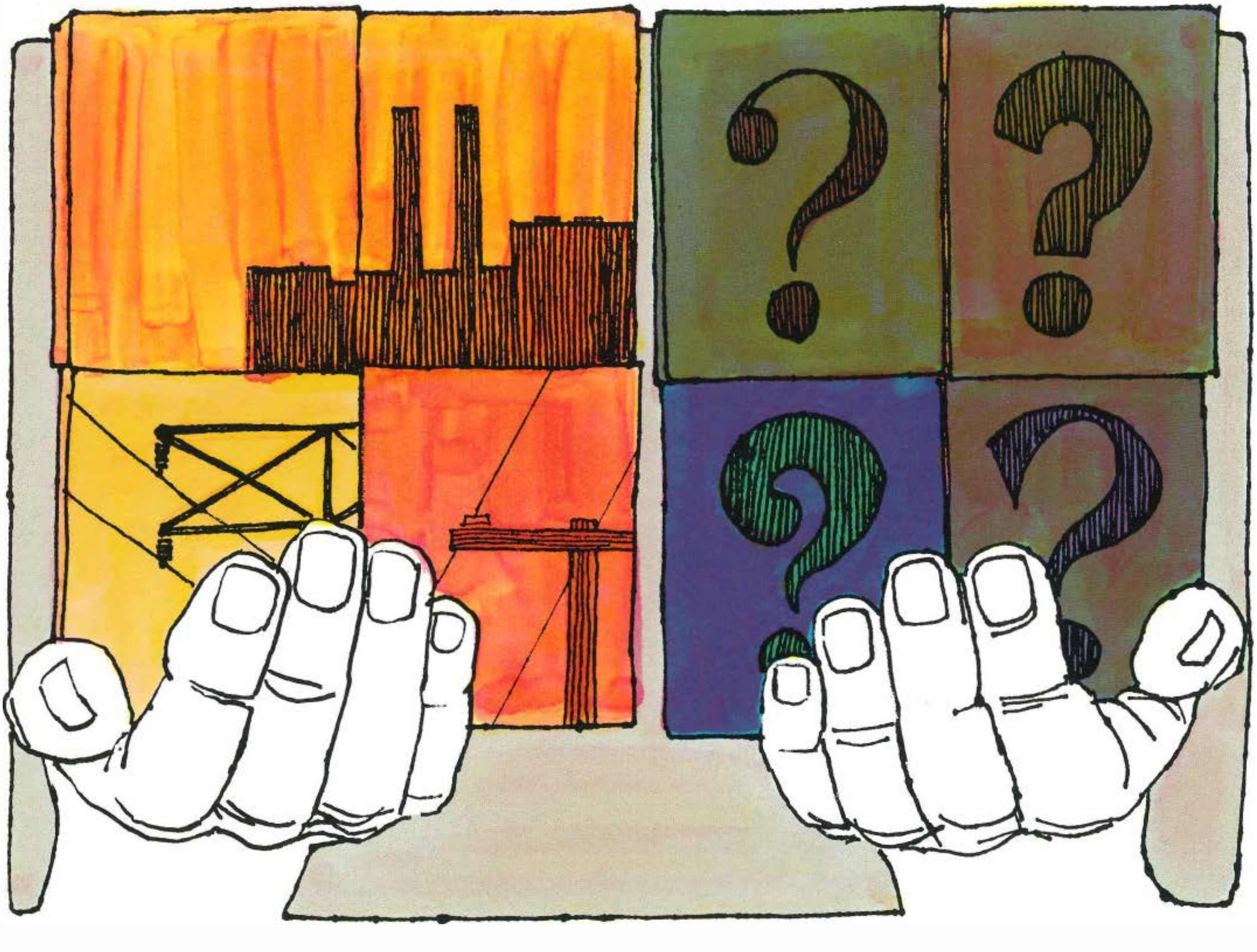

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Cover: The utility planner balances the selection of future system additions against the requirement for reasonable certainty of system performance. Reliability defines the balance.

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Reliability Assessment: Art or Science?

What is electric system reliability? How is it measured? What is its value to a utility and its customers? How much should a utility spend to achieve it? These questions always arise when the subject of reliability is discussed. There are no simple answers. Electric system reliability is a complex subject—not only technically but also financially and emotionally.

The subject of reliability has assumed ever-increasing importance in recent years. People have become more dependent on electricity and more concerned with the quality and certainty of the service they receive. However, the level of reliability of electric service that should be provided—to a single customer, a class of customers, or a geographic area—is a question that has never been answered precisely.

One consideration that comes to mind in any system reliability analysis is the frequency of interruptions. What is an acceptable frequency? Even this single question requires analyzing many factors: where interruptions occur on the system, when they occur (day or night, summer or winter), why they occur, how many customers are affected, how long they are without service, the consequences for the utility and its customers, and so on. For example, the loss of service to 100,000 customers, one at a time, is quite different from the loss of service to 100,000 customers at one time because of one interruption.

To evaluate the impact of a potential interruption on one customer, a small neighborhood, a community, or an entire region is extremely difficult. No one can predict a customer's emotional response to each and every type of power failure, nor assign an exact dollar value to all direct and indirect social costs of power interruptions. Such factors as public safety, customer inconvenience, plant shutdown, and loss of wages must all be evaluated.

The question ultimately becomes, "How much reliability is enough?" This question is nearly imponderable, and in the final analysis, the answer must be based on experience and the astute application of value judgments. At best, this is an art, not a science.

Some qualitative measures of system reliability are well known, such as percent generation reserve and redundancy in transmission. Using probability methods, these measures can be made quantitative. Reliability measures such as how often, how long, and how many customers will be interrupted can be computed. These are the subject of this month's first article, "Reliability Measures for System Planning." Even a cursory reading will introduce you to a number of new and meaningful terms.

At EPRI we give high priority to power system reliability methods research. The results will be useful for utilities to more accurately evaluate their own reliability criteria and to plan reliability levels that are acceptable to *their* customers, *their* regulatory bodies, and *themselves.* Utility managers will thus be better equipped to justify their planned expansions in generation, transmission, or distribution.

There is an important distinction to be made between EPRI and utility responsibilities. EPRI's objective is only to develop useful system planning tools, including some new definitions of terms and concepts. But EPRI cannot define reliability levels or standards for utilities. That must remain an individual utility responsibility. We hope, however, that our research efforts will bring reliability assessment closer to being a science than an art.

R G Steiner

R. G. Steiner, Director
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Authors and Articles

Measurement. It's the obvious way to compare solutions to an engineering problem. But it has a more fundamental role in science and R&D, where it helps to identify and define the problem itself. Both roles of measurement are evident in the *Journal*'s feature articles this month.

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Power system reliability was once a totally subjective quality—good in Edison's opinion simply because his dynamo worked and equally good in the public's opinion because incandescent bulbs outshined oil and gas lamps. But with the extension of utility networks came load variety, design complexity, and a need to evaluate alternative systems years in advance. Equipment cost is an obvious distinction, but what kind of reliability does it buy, and how much? Reliability has thus taken on a context of objectivity and measurement.

Still largely qualitative, however, today's "Reliability Measures for System Planning" (page 6) are surveyed by Murty Bhavaraju, who shapes EPRI's efforts to make reliability assessments more precise and eventually quantitative.

Bhavaraju comes to the task well equipped: eight years with Public Service Electric & Gas Co. in New Jersey, most recently as a principal engineer responsible for reliability and operations research methods applied to capacity and transmission planning. Now on loan for 18 months to EPRI's Electrical Systems Division, he is a project manager in the Power System Planning and Operations Program. He is a senior member of IEEE; a member of its Power Engineering Society, Reliability Group, and Probability Methods Subcommittee; and chairman of a working group on the use of performance records to optimize system designs.

After his 1961 graduation from Andhra University in Waltair, India, Bhavaraju earned an advanced degree at the Indian Institute of Science in 1963. In 1967 and 1969 he added MS and PhD degrees from the University of Saskatchewan in Canada.

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Taking the measure of sulfates and other air pollutants across nearly a third of the United States is the main objective of the three-year, $6 million Sulfate Regional Experiment, reviewed in "SURE Takes to the Air" (page 14) by *Journal* staff writer Stan Terra. The SURE monitoring effort, using 54 ground stations and five aircraft, is yielding data from the most comprehensive measurements yet made of the concentrations and transport patterns of sulfates and other man-made sulfur-derived emissions.

The principal source for this article was the project's technical manager, Glenn Hilst, who since 1970 has concentrated on advanced research and applications in micrometeorology and atmospheric chemistry. Before joining EPRI in 1977, Hilst was chief scientist with Travelers Research Center of New England and was responsible for developing a research program in atmospheric transport and chemistry for industrial and regional air quality applications. Earlier, he and a colleague at Aeronautical Research Associates in Princeton, New Jersey, developed the first invariant, coupled diffusion and chemistry models for atmospheric research—models that defined needs for theoretical and experimental research into such pollution components as sulfates and oxidants. Hilst holds a doctorate in meteorology from the University of Chicago.

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Nuclear fuel reprocessing is a subject that carries an urgent question—should we or shouldn't we—and the answer is elusive when sought through conventional processes. Too often discussion leads away from evaluation and into advocacy and argument. But the same question yields to structured decision analysis, given the validity of the estimates used to measure causes and effects that flow from the basic alternatives.

In "The Reprocessing Decision" (page 18), Carolyn Heising deals with three alternatives: permit, prohibit, or delay. The article summarizes her work of three years (the last year sponsored by EPRI as RP620-24) on a Stanford University PhD thesis completed just last July, *The Reprocessing Decision: A Study in Policy Making Under Uncertainty.* Heising's effort also won the first annual student paper award from the Institute of Nuclear Materials Management.

Heising graduated from the University of California at San Diego in 1974 with high honors in physics. Thereafter a Stanford graduate student in mechanical engineering (nuclear), she worked during successive summers at Lawrence Livermore Laboratory, Brookhaven National Laboratory, and EPRI, where she was a 1978 research assistant in the Nuclear Systems and Materials Department. She recently began postdoctoral work under Norman Rasmussen at the Massachusetts Institute of Technology.

■

If litigation may be said to bind adversary parties by exact prescriptions, then mediation potentially yields something more qualitative but equally final—the resolution of conflicting attitudes and values. Mediation is the business of a new member of EPRI's Advisory Council, and he discusses it in Stan Terra's article, "John Busterud: It's Better to Mediate" (page 23).

■

To look at an unusual heating and cooling concept, the *Journal* goes outside EPRI and into Oak Ridge National Laboratory for a "House on Ice" (page 26). The concept is the annual cycle energy system (ACES), which is essentially an insulated water/ice bin that is seasonally frozen and thawed by a heat pump for space heat, hot water, and air conditioning.

Early performance measurements indicate that ACES can save as much as 70% of the source energy used by conventional systems over the course of a year. But is it commercially feasible? *Journal* staff writer Nadine Lihach collected perspectives from both Oak Ridge and EPRI, including comments from Harry C. Fischer, the engineer-inventor-consultant to whom the ACES concept is attributed.

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One hundred years is a precise measure. It's also a ceremonial one in next year's Centennial of Light celebration, which commemorates the lighting of Edison's incandescent lamp on October 21, 1879.

"Update: Edison Centennial Symposium" (page 29) details the program of a 2½-day San Francisco conference being cosponsored by EPRI and the Thomas Alva Edison Foundation to illuminate the theme of science, technology, and the human prospect. Symposium dates are April 1–4, and registration information is now available.

Bhavaraju

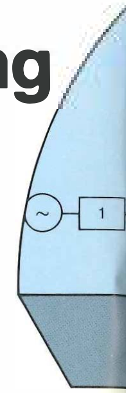
Hilst

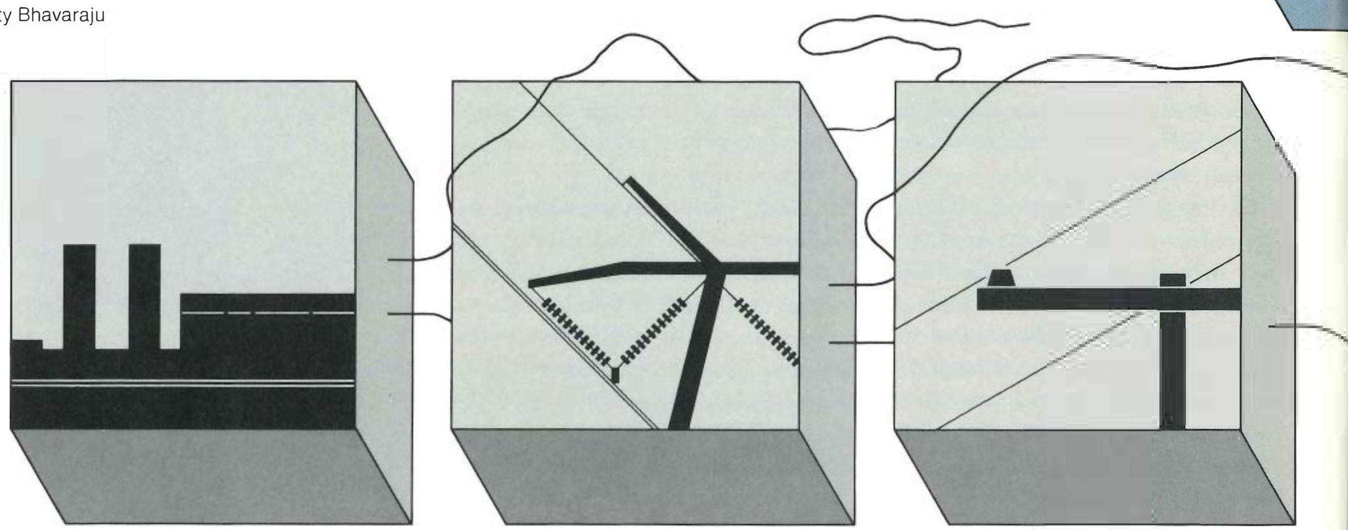
Heising

Reliability Measures for System Planning

The best-planned electricity service carries some likelihood of interruption because of outages of generators, transmission lines, or distribution feeders. How often, how long, and how extensive these occurrences—all are yardsticks to measure system reliability, and all must be evaluated if investments in new facilities are to be wisely planned.

by Murty Bhavaraju





You flick the switch. The light comes on. So do the TV, the air conditioner, the stove. It almost never happens otherwise. You'd say the electricity supply is very reliable.

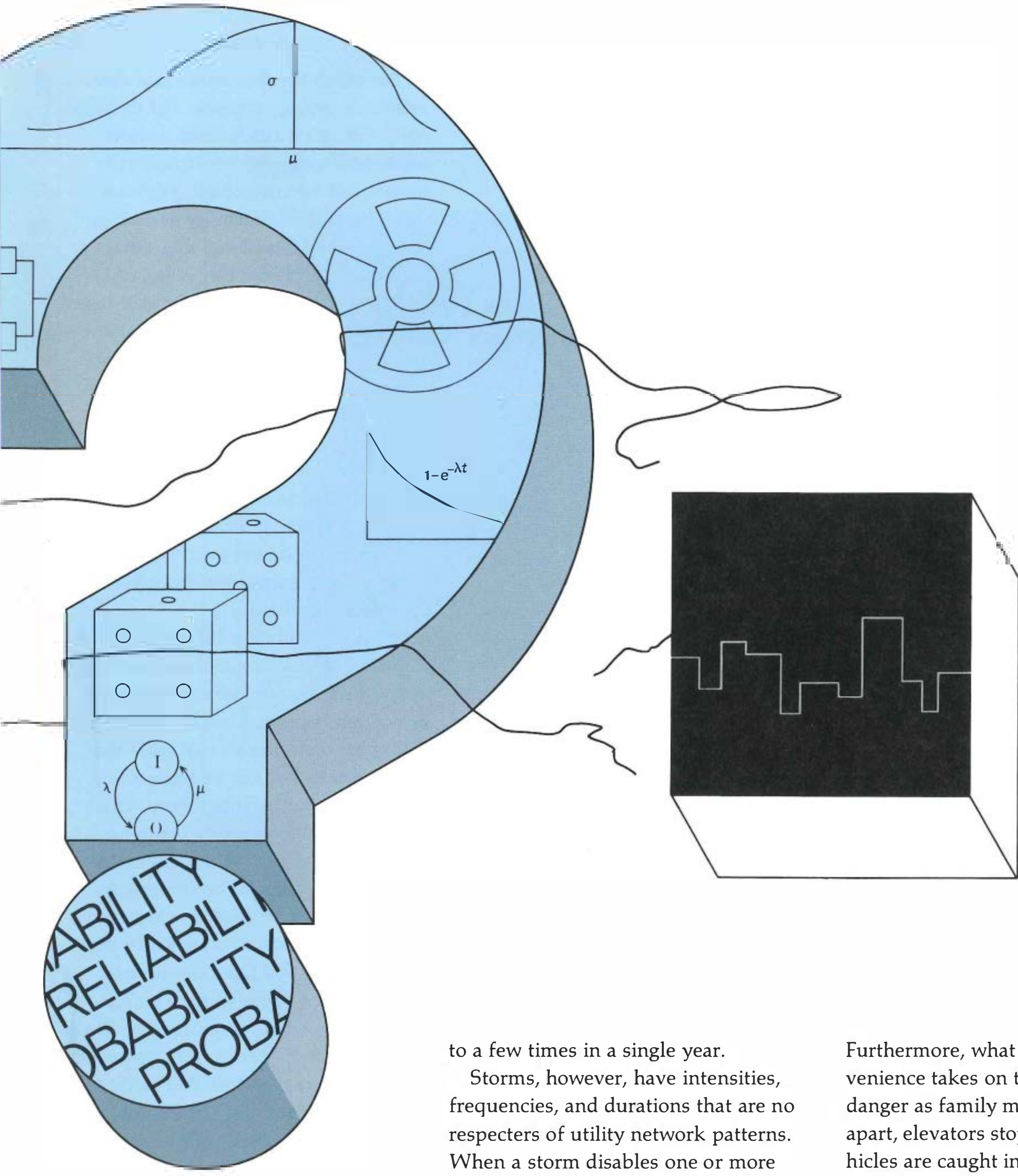
Even so, power failures do occur sometimes. And it's typical that 90% of them originate well out in the distribution system, close to where people live and work, while only 10% originate in the bulk power system—in power plants or along transmission lines. Some observers of utility service are therefore quick to argue that distribution reliability is inadequate, or that the other segments are too reliable. Why is this so, they ask, urging that utilities should spend less on generation and transmission facilities.

But the problem isn't simply one of where an interruption originates, or even how often. The difference is more a matter of how long an interruption lasts and how wide an area is affected—that is, how many customers simultaneously and with what consequences in their lives.

Murty Bhavaraju is a principal engineer in system planning for New Jersey's Public Service Electric & Gas Co. On loan to EPRI's Electrical Systems Division for 18 months, he is a project manager in the Power System Planning and Operations Program.

What if . . .?

If a storm takes out a nearby power line—what utilities call a distribution feeder—you and your neighbors face a short interruption in service. The extent of the inconvenience depends on the time of day. At the very least, there are a few clocks to reset, and if you own a store, you may lose some business.



If you run a factory, you may lose some production. For some kinds of business, say a chemical processing plant or a computer center, the loss may continue even after power is restored. If you work for one of these, you may lose some time and wages. Such an incident happens from once in every few years to a few times in a single year.

Storms, however, have intensities, frequencies, and durations that are no respecters of utility network patterns. When a storm disables one or more lines along a major transmission corridor, a whole chain of events can be triggered, which may culminate in a systemwide blackout.

Everything comes to a standstill for hours over several square miles. This total upset of the urban metabolism means severe economic costs to businesses, governments, and individuals. Furthermore, what begins as an inconvenience takes on the proportions of danger as family members are stranded apart, elevators stop, emergency vehicles are caught in traffic jams, heating (or air conditioning) systems no longer work, food supplies spoil, and looters terrorize entire districts.

In short, the physical effects of an area blackout are more severe than those of a local outage, and our reactions—like the above description—are often extreme. What would it cost to reduce these effects, or to cut the chances of their occurrence? How do utilities measure reliability of service? Is it entirely a matter of how many power lines and power plants? Even if that is so, how many should there be and where?

The answers lie in the judgments and practices that make up reliability assessment. Some are highly structured on the basis of long experience and some are quantitative, but in the sense of absolute measurement, none is a true yardstick.

Reliability without yardsticks

Reliability must begin with a very long view of generation and transmission needs on a utility system. Trends in overall load growth for several years and the load pattern from one season to the next are inputs to the system planning problem. At this stage our concern with reliability is not in the dynamic context of system disturbances or blackouts but in the functionally normal context of gradually growing demand that must be met.

Utility planning thus begins with alternative forecasts of the future and seeks to schedule the sequence of system additions that will best serve the entire range of possibilities. The problem is overwhelmingly economic—plant capacities and their costs, transmission facility and right-of-way costs, fuel availabilities and price escalations, inflationary factors and interest rates, and expectations of rate changes.

Even in resolving these long-term system uncertainties, a very important consideration is reliability. Generally, the higher the generating capacity and the more transmission lines in a particular system, the more reliable the system is. Delays in adding needed generation or transmission facilities result in lower reliability.

Generation Planning In generation planning, *percentage reserve* is a common term. It is the margin of installed capacity in excess of the expected peak load. The National Electric Reliability Council (NERC) defines *adequacy* as sufficient generating capability to meet the aggregate peak electric loads (MW) and energy requirements (MWh) of all customers at all times. How much reserve is sufficient? The percentage varies among systems, frequently being in the 20–30% range. Utilities establish their own values by means of several analytic tools, but with strong reliance on judgment gleaned from past experience.

Transmission Planning Two aspects of reliability must be recognized in transmission planning. In an essentially steady-state sense, reliability is the system's ability to meet demand, within the specified voltage limits and the ratings of transmission lines, during outages of some generating units and transmission lines. Subtly different is reliability in a dynamic sense, which is the ability to withstand a sudden outage in its first few seconds or minutes without causing additional loss of facilities—the cascading effects that may lead to widespread blackout. NERC uses the term *reliability* to describe this dynamic aspect.

The term *security* is more familiar to utility operating personnel. They use this term for both the steady-state and the dynamic sense to denote system reliability in actual operation, in contrast to its assessment in planning.

State-of-the-art transmission planning addresses both facility outages and sudden system disturbances. Selected circumstances are mathematically simulated by computer to determine whether the resulting modeled transmission performance (voltage levels, line loadings, and the like) will be within acceptable limits. The outages and disturbances chosen for simulation are based on experience and judgment. Sufficient transmission is then planned to maintain system performance despite occurrence of the more likely outages (e.g., failure of a single line). However, some degradation of system performance may be tolerated for less likely circumstances, such as multiple line outages or the loss of an entire power plant. The goal of this approach is to reduce the chances of widespread blackout, but if it occurs, to limit its impact in terms of population affected and time to restore service.

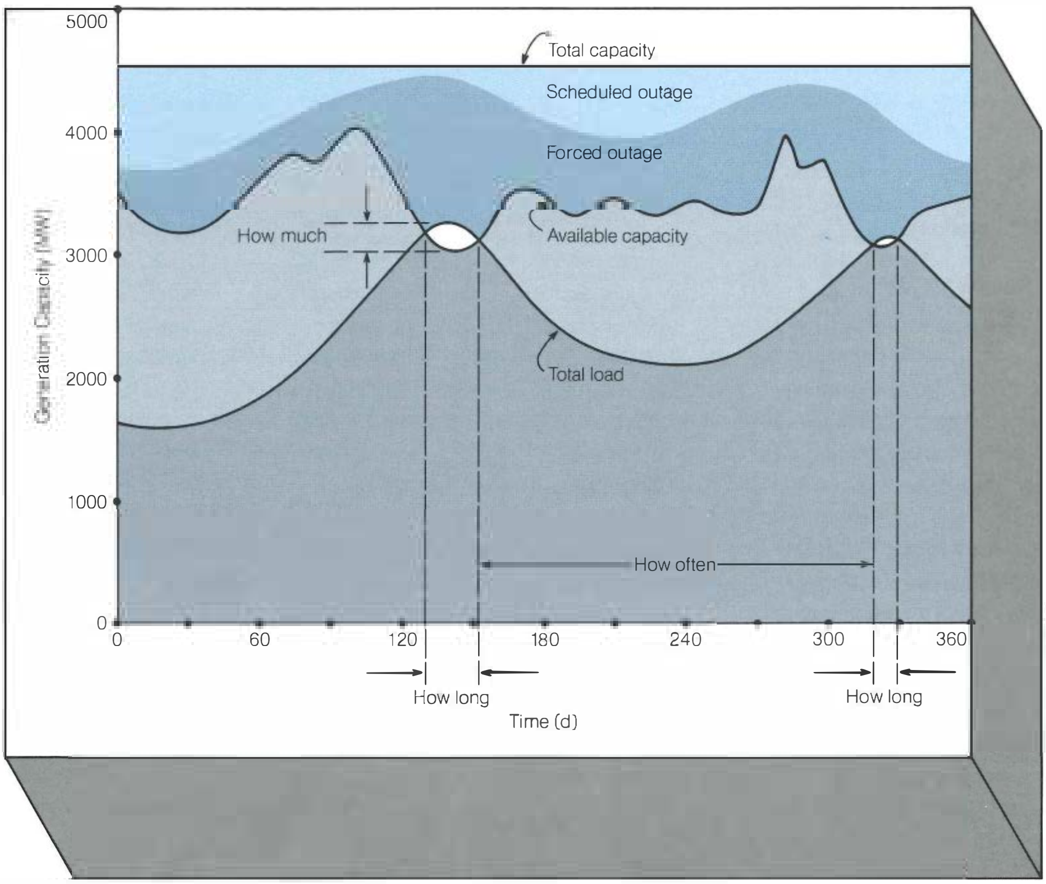
Reliability with yardsticks

So far, reliability definitions and assessments are only qualitative, and they do not produce yardsticks such as how often, how long, and how many customers will be interrupted. Without these yardsticks, reliability evaluation has to depend heavily on experience and judgment. Reliability levels of alternative plans with different equipment sizes or equipment reliabilities cannot be compared accurately; the effect of changing load patterns on system reliability cannot be accurately assessed. Without yardsticks of reliability, it is difficult to accommodate these complexities and uncertainties in the planning process. It is also difficult to quantify and communicate the conclusions: why new facilities are needed and when they must be added.

What the planner must do is turn to statistical approaches that use probability—the chance that something will or will not happen. Most of the factors that affect customer service reliability are uncertain, but can be accounted for by using probability theory. This doesn't mean deliberately planning to take chances in meeting electricity demand. It does mean attempting to recognize and give relative weights to different circumstances. Most obvious are the equipment failures with immediate effects: a boiler tube leak, a severed line, a faulty transformer, or the overload that may arise from demands that are higher than installed facility ratings. There are planned circumstances to be met, too, such as scheduled removal of a generator or a line from service for maintenance. Each of these circumstances can have different effects on the reliability of the system, depending on its relative importance in that system.

Three fundamental yardsticks

The academic definition of reliability is the probability that a mechanism—a



Yardsticks of generation reliability become evident in these patterns of planned system capacity and expected total load over a year's time. Allowances for foreseeable outage (both scheduled and forced) are compensated by reserve capacity so that available capacity is nearly always sufficient. Crossovers of total load and available capacity measure the frequency of possible service interruptions (how often), their duration (how long), and their magnitude (how much)—all contributing to the assessment and evaluation of system reliability. The reliability of actual service to customers is predictably much higher because emergency power can be purchased from neighboring utilities.

SYSTEM RELIABILITY

	Steady-State Aspect			Dynamic Aspect
Subsystem	Generation	Transmission	Distribution	Bulk power (generation and transmission)
Typical Failure Causes	Generator outages	Line or transformer outages	Line or transformer outages	Multiple line outages in a short time
	Unexpected load	Unexpected load	Unexpected load	Protection system failure
Resulting Conditions	Generation deficiency	Line overload	Line overload	Cascading outages
	Energy deficiency	Low bus voltage	Low bus voltage	Instability
Service Consequences	System voltage reduction	Low voltage (areawide)	Low voltage (local)	System blackout
	Systemwide load reduction (selective customer interruptions)	Areawide load reduction (selective customer interruptions)	Local load reduction (customer interruptions)	

part, a component, an assembly, or even an entire system—will perform its intended function for the intended period of time under stated conditions. As a practical matter, however, because malfunction is what must be dealt with, the failure analyst usually turns the definition around and measures the probability of malfunction or outage instead.

This definition has been used in the aerospace industry, where the intended period of time is a few hours to a few days. In power systems, however, the concern is how well customers are served year after year, and a probability measure alone is an inadequate yardstick.

How often (time to failure) and how long (time to repair) have a tangible significance in electric utility performance. If a component or system fails once in 90 days and takes 10 days to repair, the probability of outage is 10% (10 divided by [10 + 90]). If it fails once in 90 weeks (nearly two years) and takes 10 weeks to repair, the outage probability is still 10%. But what a difference in practical significance: a single outage seven times longer.

Another yardstick must be devised, one that enables the planner to evaluate a component or system that is neither completely failed nor perfectly working. The magnitude of a problem needs to be measured. For example, how much overload on a line, how low a voltage at a customer terminal, how much load interrupted, and ultimately, how many customers interrupted. All these eventualities have magnitude, or extent, in addition to the yardsticks of how often and how long.

The term *quantitative reliability* is coming into use, meaning reliability assessment based on probability theory. Utility system planners refer to the yardsticks themselves as reliability measures or indexes.

Power system segments

Given an index, where do we make the measurements? What are the meaningful functional groupings in a power system? Two are commonly defined in planning—the system component and the subsystem.

The combination of a boiler or reactor, a turbine, and a generator forms a generating unit, which is a system component. The combination of towers or poles, conductors, and insulators forms a transmission or distribution line, which is another system component. Other system components are transformers, circuit breakers, capacitors, and so on.

Different system components together form a subsystem. Thus, system generating capacity (a subsystem) refers to all the generating units of one utility. Transmission and distribution subsystems each consist of lines, transformers, breakers, and so on. These three subsystems (generation, transmission, distribution) form a power system.

Component reliability

The reliability of a system component can be expressed as the probability of its being able to serve (to generate or to carry load) when called upon to do so. There are many influences at work. System components fail, they are repaired, they fail again—the cycle repeats. In addition, they must be maintained, which involves such jobs as turbine overhaul (weeks) and insulator cleaning (hours). There are yet other outages, such as nuclear unit refueling or clearances for new construction.

Availability is the percentage of time that a component is neither forced nor scheduled out of service. Component availability is estimated from the outage records kept by most utilities. These availability data are essential in evaluating subsystem reliability.

Subsystem reliability

Generation Probability methods for generation planning were introduced more than 30 years ago. A common reliability index is loss-of-load expectation (better known as loss-of-load probability), which is the expected number of days per year during which system load may exceed available generating capacity within the system.

Computation methods exist, are well documented, and are well developed for establishing this index of generating capacity adequacy. Limitations because of transmission configuration are not usually recognized, but emergency power from interconnections with neighboring utilities is taken into account. Suggestions have been made to refine the measure of loss of load by recognizing such additional indexes as frequency of occurrence, duration, and magnitude of lost load or lost energy.

Transmission Applied to transmission subsystems, probability methods are so far of limited use. Loss-of-load indexes can be calculated for each substation and for the entire subsystem in a steady-state sense, but such determinations are only a partial answer.

Some utilities have started using steady-state methods in transmission planning on an experimental basis. There are several reasons for their hesitancy.

- The dynamic aspects of transmission system reliability have not been addressed.

- Definition of system failure and its interpretation in system planning are not resolved.

- Transmission system component outage data are not adequate.

Distribution In distribution subsystems there is yet another approach for evaluating reliability. Probability methods have had only limited application. The definition of reliability in a distribution subsystem is conceptually more simple than in a bulk power system. It directly involves interruptions of customer service, and simple measures can be defined: the frequency of customer interruptions (how often), the magnitude (how many), and the time to restore service (how long).

For systems already in place, the approach is to measure the reliability actually experienced by various customers and to improve it, where needed, with better equipment, better maintenance practices, or system reinforcements. Empirical data from this practice become the basis for future planning and design.

Relative or absolute reliability?

Reliability evaluations for generation, transmission, and distribution subsystems are performed separately by most utilities. As described above, the methods are different and the indexes, even when quantitative, are necessarily relative, not absolute. For example, the calculations are based on mathematical models that only approximate system or subsystem behavior, as well as on component outage data that are extrapolated into future years.

Such models are not perfect; in the trade-off between tractability and accuracy, some factors must be ignored. Accuracy may suffer because desired data simply do not exist. Or accuracy may be compromised intentionally because all possible system states cannot be considered, all the complex system responses cannot be modeled, or in long-range planning, the uncertainties of construction times and costs cannot easily be accounted for.

Notwithstanding these imperfections, relative reliability indexes are serviceable, with due caution and judgment, for evaluating alternative solutions to a given problem. They are useful in dealing with such basic planning concerns as component capability and reliability, load patterns, and load forecast uncertainty. For example, the loss-of-load probability calculated for a utility's generating capacity will increase if generating unit sizes are increased, unit forced-outage rates are projected at a higher figure, or the load forecast becomes more uncertain.

How much reliability?

The selection of reliability criteria by which to plan system facilities is clearly a matter of judgment. How much generation reserve, what level of loss-of-load probability, how many transmission lines—these questions are typical in system planning, and reliability criteria can provide the needed answers.

Reviewing criteria in light of experience serves either to validate them or to signal a need for change. For example, a periodic question might be: "Why did you select a loss-of-load probability of 1 day in 10 years for planning your generation reserve?"

And a system planner's reply might run like this: "We calculated the loss-of-load probability for our system for the last few years. We got a number around 0.1 day per year, that's 1 day in 10 years.

"Then we questioned ourselves. Are we satisfied with system performance over those years? Were there too many emergencies, such as voltage reductions? Too many close calls? Too many load curtailments? On the other hand, did it appear that reliability was unnecessarily high? The answer was no to all questions.

"So we accepted the level of 1 day in 10 years for our future planning. We know the index itself is relative, but it is sensitive to the factors that could affect reliability."

This is an intuitive approach, which is used when no other is available. Is there a better approach? How often can customers tolerate interruptions? It would be ideal if electricity service was never interrupted. But never, which is the same as 100% reliability, would also cost much more if indeed it could be attained, and utility rates would skyrocket.

This balance between the cost of consequences and the cost of greater reliability (to preclude them) is central in a utility planner's thinking. And here is a serious difficulty. The planner can price out the equipment for various levels of

RELIABILITY RESEARCH AT EPRI

Power system reliability R&D has high priority in the Power System Planning and Operations Program of EPRI's Electrical Systems Division. This work is organized into four areas of investigation: component outage data, reliability indexes, reliability evaluation models, and reliability benefits.

Component outage data

There is a need for uniform definitions and procedures in the collection and analysis of outage data. Generator outage data, compiled by EEI for several years, are now becoming a responsibility of NERC. Generator outage definitions are being revised by the IEEE Task Force on Power Plant Productivity Definitions (formerly an ad hoc group formed by the ANSI Steering Committee on Power Plant Data Systems). Transmission component outage definitions require a similar effort to achieve the same level of consistency among utilities.

A project on bulk transmission system component outage definitions (RP1283) was begun last June and is reviewing activities of EEI, IEEE, and several utilities and power pools in an effort to develop a uniform basis for data collection. Special attention will be given to multiple outages, those that either stem from a common cause or are triggered by an initial outage. It is evident that these outages have more severe effects on system reliability than do independent outages.

A project on component outage data analysis methods (RP1468) begins in 1979 with the objective of developing ways to analyze outage data and thereby forecast outage and repair rates. (In this study, *component* refers to a system component, such as a generating unit, transmission line, transformer, or circuit breaker.) The project will address pooling of data to increase the base, confidence levels, different component exposures to failure (functions of operating time, line length, weather, for example), problems of overlapping outages, and adjustments to reduce the effects of anomalous data on outage rate forecasts.

Reliability indexes

Evaluation of existing indexes and development of new ones are dual objectives of research on reliability indexes for power systems begun last August (RP1353). The project gives highest consideration to indexes that:

- Respond to changes in basic parameters used in generation, transmission, and distribution planning
- Measure service quality from the viewpoint of the customer
- Permit quantification of reliability worth
- Aid clear communication with nontechnical audiences
- Can be computed with both present and future methods

The indexes considered in this effort are those that are primarily used for planning generation and transmission systems. Reliability indexes for distribution planning will be coordinated with a project on distribution reliability and risk analysis models initiated by the Distribution Program (RP1356).

Consideration of the customer's viewpoint on reliability is also being investigated by designs for evaluating the value of service reliability to consumers, a project of the Supply Program in EPRI's Energy Analysis and Environment Division (RP1104).

Reliability evaluation models

Projects are contemplated primarily for developing models to evaluate bulk system reliability. These models should:

- Permit transmission network analysis with different combinations of generator and/or line outage
- Identify unacceptable system conditions that result (e.g., line overloads, low station voltages) and their consequences for customers
- Accommodate weighting of consequences according to the probabilities of occurrence for various outage combinations
- Produce reliability indexes at specific system load points, in stated system areas, or for an entire system

Several considerations suggest some of the capabilities to be designed into these models. For example, load representation must recognize daily, weekly, and seasonal loads at different points and their correlation with total system load. Also, methods have been proposed for ranking outage contingencies (in terms of line overload effect) without having to simulate the network. Research must refine these methods and also include the effects of low-voltage conditions and outage probabilities as ranking factors. Common-cause and dependent multiple outages should also be included.

Provisions for network analysis will depend on the precision to be required in model applications. Both dc and ac load flow solutions are foreseen for evaluations of transmission system adequacy. For evaluation of reliability in a dynamic sense, network analysis must deal with system stability under selected fault or short-circuit conditions. The models must therefore simulate realistic responses, such as cascading, protective system actions, and load shedding as dictated by various operating policies.

Synthesizing these several model capabilities into a single model would enable bulk power system reliability indexes to be determined. Research toward this objective will have to address the form of these indexes, how steady-state and dynamic variants can be related, and how the results can be applied in system planning.

Reliability benefits

Research into reliability benefits is yet to be developed by the Power System Planning and Operations Program. Some inputs are expected to flow from work in EPRI's Supply Program (RP1104 on designs for evaluating the value of service reliability to consumers) and Health Effects Program (RP1374 on the environmental and socioeconomic consequences of a shortage in installed generating capacity), as well as from DOE's project on the development of the conceptual framework needed to establish a viable theory for large-scale system effectiveness analysis (EC-77-R-01-5008).

Findings from these projects may contribute to the formulation of structured methods that utilities can use to evaluate their own reliability criteria. In summary, the goal of present and future projects is to provide planning tools for more precise, quantitative reliability assessment, specifically including evaluation of costs and benefits. Their application should lead to system plans having the lowest revenue requirement consistent with the reliability desired by a utility, its regulatory commission, and its customers.

■

Two documents are suggested for the reader who wishes to study power system reliability issues and methodologies in greater detail.

Workshop Proceedings: Power System Reliability—Research Needs and Priorities. EPRI WS-77-60, October 1978.

Bibliography on the Application of Probability Methods in Power System Reliability Evaluation, 1971–77. IEEE committee report, Paper No. F78 073-9, IEEE Power Engineering Society Summer Meeting, Los Angeles, July 1978.

electric system reliability but cannot set an accurate dollar value on every direct and indirect cost of an increased number of power failures. Especially evasive are the costs outside the wires, such as reduced public safety whenever critical municipal services falter or, in a longer term, the loss of jobs if industries move elsewhere, and the societal and economic ramifications of all these.

Cost-benefit evaluation

Better understanding of reliability in its various contexts will inevitably lead to more precision in its assessment during the planning and design processes. The goal is to make more accurate evaluations of the costs and benefits of reliability.

Simplistically, the cost of raising reliability to a particular level is the capital and operating cost of equipment required to achieve that higher level. And the benefit is the reduction in cost of all consequences that flow from interruptions. The reliability level is ideal when the incremental cost to attain it is less than the reduction in the cost of all consequences.

The Cost of Service Since the 1960s every aspect of electric utility service has become markedly more expensive. Capital is difficult to raise and interest charges are up; construction and fuel costs have risen sharply; conservation and environmental compliance have added their own cost elements to system and component design.

At the same time, some observers and regulatory bodies have called for higher reliability levels, while others have questioned the reasonableness of the expense to meet those levels. The result is uncertainty for system planners, and uncertainty itself forces costs up.

In this circumstance, more astute evaluation of the need for new facilities implies the need for more astute evaluation of the reliability criteria that govern their exact nature, their scope, and thus their cost.

The Cost of Interruption Despite the motivation to improve reliability, cost-benefit evaluation methods for evaluating benefits continue to be somewhat oversimplified. So far, the approach is to use reliability indexes to calculate unserved energy (the kilowatthours lost by utility customers during power failures) and assign it a dollar value. Not only are relative reliability indexes unsuited to such precise use but the dollar values for unserved energy and their derivation are questionable.

For example, the value of unserved energy has been based on empirical relationships between gross national product or industry wages and the corresponding electric energy consumption. Or it has been drawn from limited surveys of industrial and commercial customers. These measures may be relevant for independent, essentially local power interruptions, but they are tenuous for areawide blackouts.

Moreover, for neither case do they consider the customer's value perceptions, one of the most important factors in reliability benefit evaluation. Customer reaction is a complex but intimate function of power failure frequency, extent, and duration, not to mention time of day, season, and so on. Dependence on electricity also has a bearing, and it is predictably extreme when customers are either very isolated or very congested. These value perceptions require thoughtful research from a number of viewpoints, with economics, sociology, and psychology among them.

The Reliability Link If we succeed in relating customer value perception to utility system reliability (or the lack of it) and in quantifying all the costs of unreliability, we will have solved part of the problem of making truly rational cost-benefit evaluations of reliability. Solving the remainder will require a set of measures of absolute reliability. The state of the art in reliability assessment does not permit the derivation of such measures. Until absolute indexes are at hand, the reliability cost-benefit question must remain open. ■

SURE Takes to the Air

The air-sampling phase of the Sulfate Regional Experiment is now completed and some early, partial results are in.

Technician Sandy McDonald checks on-board air collection and meteorological instruments before flight.

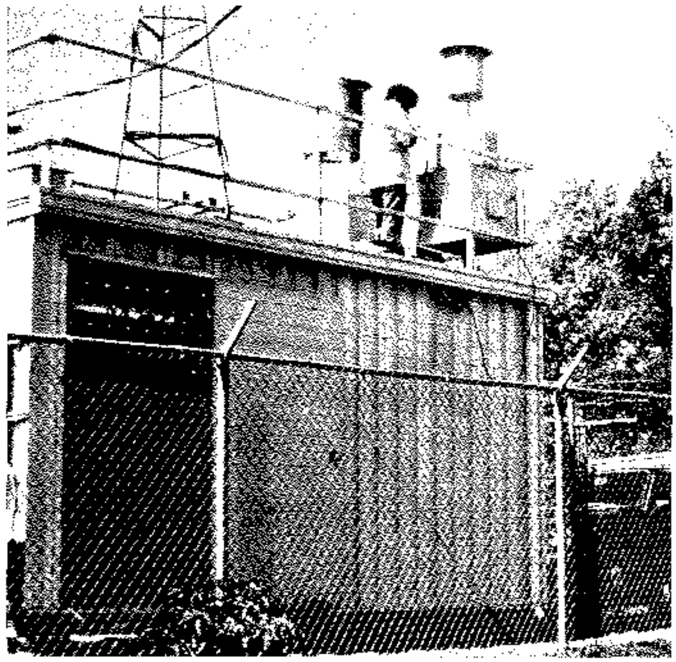
Pilot Kirk McQuown guides a twin-engine Beechcraft in a graceful spiral over Duncan Falls, Ohio, climbing to 10,000 feet, then reverses the maneuver, descending to within 50 feet of the ground.

During the climb and descent, technician Sandy McDonald monitors special instruments on board that collect and measure air samples and record meteorological conditions. At Duncan Falls an instrumented ground station is also collecting and measuring ambient air samples.

From July 1977 until October of this year, 5 aircraft and 54 ground stations in an area extending from eastern Kansas to the Atlantic coast and from mid-Alabama to southeastern Canada have been engaged in the data collection phase of a three-year, $6 million scientific effort to determine the concentration and transport characteristics of sulfates in the northeastern United States. This region was chosen because of its potential for high concentration of sulfur oxides.

Funded by the electric utility industry through EPRI, the comprehensive, meticulously planned project—known as the Sulfate Regional Experiment (SURE)—was prompted by the utility industry's concern over what contribution its coal-burning power plants are making to the sulfate content of the ambient air. This concern has been heightened by the anticipated increase in the use of coal for power plant fuel, as mandated by national policy, and the higher levels of sulfur oxides that would be emitted. It is known that one source of sulfates is from a transformation of sulfur dioxide (SO_2) in the atmosphere, but it is not clearly understood how this process occurs and in what proportion.

The Environmental Protection Agency (EPA) has cited inhalation toxicology studies that indicate sulfates are potentially hazardous to health. (EPRI has studies under way to determine the



SURE Class I monitoring station in Philo, Ohio. The device on the roof resembling a stovepipe collects respirable-size particles from the atmosphere on filters, which are replaced every three hours throughout the day. The metal building contains gas monitors, calibrators, pumps, and telemetering equipment for data storage and transmission via telephone lines to ERT laboratories for analysis.

validity of this indication.) Lacking conclusive evidence linking specific sulfate levels to incidence of respiratory disease, EPA has not yet issued a national sulfate standard. Until it can be established that there is a definite relationship between levels of SO_2 and concentrations of sulfates, it cannot be known by what extent we need to control SO_2 emissions to reduce ambient sulfate concentrations. SURE is designed to produce the data that will aid in determining this, among other objectives.

George Hidy of Environmental Research & Technology, Inc. (ERT), who is coordinating the SURE project for EPRI, says, "EPA is looking toward 1980 as the probable time it will issue a national standard. And there is no doubt that the SURE data will be taken into account."

Fifty-four SURE monitoring stations carefully sited in 22 states and Canada have collected and recorded samples of ambient air from July 1977 to October 1978. Nine Class I stations operated continuously, and 45 Class II stations operated for 30-day periods during August and October 1977 and January, April, July, and October 1978.

Air sampling

The SURE data collection network and the 16 months of its operation give SURE the basis for the most extensive sulfate-monitoring effort thus far. The 54 ground stations operated by ERT were carefully sited to obtain the most representative ambient air samples. Nine of the stations (Class I) were instrumented to measure SO_2, ozone, nitric oxide, nitrogen dioxide, hydrocarbons, and total suspended particles, as well as dew point, temperature, and surface winds. These stations operated continuously from July 1977 through October 1978. The other 45 stations (Class II) measured only SO_2 and particulates for 30-day periods during August and October in 1977 and in January, April, July, and October of this year.

The stations were sited to capture meteorological events bearing on the movement of cold, dry continental polar air masses, the warm, moist maritime tropical air masses, and the various stages of transition between these extremes. They examined the regional differences between a densely populated coastal environment, an inland industrialized area, and regions on both sides of the Appalachian Mountains. The stations also provided time and space resolutions sufficient for investigating the behavior of ambient sulfates, nitrates, and other aerosol components in relation to variations in meteorology, seasons, and emissions.

The two SURE aircraft, operated by Meteorology Research, Inc. (MRI) and Research Triangle Institute (RTI) under the direction of Don Blumenthal, carried instruments for measuring emissions as well as recording meteorological conditions and aircraft position. (Three other aircraft that cooperated in SURE were flown for DOE as part of its MAP3S program.)

Emissions inventory

In their spiral flights over and downwind from selected Class I stations, the planes took a series of ambient air "core samples" 2 miles high and 50 miles wide. The air collection flights took place at sunrise and midday during the so-called intensive monitoring periods—August and October of 1977 and January, April, July, and October of 1978.

A rigorous quality control program has been in effect from the start of the SURE project, with frequent verification of instrument accuracy and data collection, processing, and analyzing procedures.

A major objective of the SURE project is to compile an inventory of emissions from the various sources in the survey region for four major pollutants: sulfur oxides, nitrogen oxides, total emitted particulates, and hydrocarbons. Sources monitored have included fossil-fueled power plants; other industrial sources, such as oil refineries and chemical plants; nonmanufacturing commercial establishments; residences; and surface transportation. Correlations between emissions and such external factors as atmospheric temperature, wind velocity, cloud cover, and rain, as well as estimates of errors and uncertainties, are also being developed by GCA Corp., the contractor for this phase of SURE.

Early results

It appears from the data that coal combustion is the major source of particles in the upper Midwest. Transportation systems account for most of the hydrocarbon emissions, with oil refineries, tank farms, and chemical plants also significant contributors. Fuel combustion by stationary sources and surface transportation account for most of the nitrogen oxide emissions. Coal-fired electric power plants were found to contribute between 60 and 70% of total sulfur oxide emissions.

Some early, partial results from the SURE field work indicate the average levels of sulfate are less than 10 mg/m^3, but from time to time the Ohio valley and western Pennsylvania experience higher sulfate concentrations. Maximum sulfate values found in Ohio and Pennsylvania in summer tend to shift southwestward in winter. Winter SO_2 levels appear to be significantly higher but are generally located in the same geographic area as summer and fall levels. Patterns of maximum SO_2 concentration appear to coincide with sulfate levels in August, but there is a shift southward in sulfate concentration in fall and winter, not paralleled by SO_2 levels. There is evidence of a distinct seasonal difference between sulfate and nitrate, with nitrate levels highest in winter in the North.

Data from the aircraft samples indicate that sulfate is greater in the lower than in the upper layers of the atmosphere, while nitrate is uniformly mixed. Ozone shows a buildup near the ground by midday, and there is a vertical mixing of the haze layer. Sulfate and nitrate levels vary in summer and winter, sulfate levels being higher in summer than in winter; nitrate concentration is less than half that of sulfate in both seasons.

Time and space frequency distribution of sulfate based on three seasonal months for the SURE region indicate that sulfates in concentrations greater than 20 mg/m^3 occur in two-to-five-day episodes but generally are restricted to less than 15% of the region. The shift in occurrence of maximum sulfate concentrations southward during winter may be related to the incidence of moist, warm air from the Gulf of Mexico flowing northeastward in summer. In winter the penetration of intense fronts from Canada with cold, dry polar air moving beyond the Great Lakes prevents the warm, moist air from flowing northward over the areas of high emission density.

These results are of note because they suggest major seasonal differences in sulfate behavior. A strong summer maximum can be seen in the Northeast, while a more constant annual level is experienced in the South. This appears to be related partially to the shift in maximum sulfate concentrations southward in winter.

Sulfate model

In an effort to use the SURE data to explain the formation and variation of pollutant levels in relation to sources and meteorological variables, ERT is developing a mathematical model that will attempt to simulate the real world of sulfate formation. The task is to produce a model capable of predicting ambient sulfate concentrations as a function of various SO_2 emission sources, particularly electric power plants.

All the SURE data are expected to be analyzed and a final, interpretive report issued in early 1980.

Glenn Hilst, EPRI technical project manager for SURE, says he is confident "the SURE data will stand as the basis for regional air quality reference for many years to come."

Noting that SURE "demonstrates clearly how EPRI, its contractors, and participating utilities can work cooperatively with two government agencies—DOE and EPA—in a highly complex project," Ralph Perhac of EPRI's Environmental Assessment Department, who has overall responsibility for SURE, points out it is developing "the most complete and highest quality regional air quality data and current emissions inventory."

René Malès, director of EPRI's Energy Analysis and Environment Division, adds that SURE is the largest single environmental project undertaken by his division—"a measure of the utilities' concern." ■

Decision makers charged with formulating energy policy are confronted with some of the most complex, uncertain, and controversial issues of our times, particularly in the nuclear power area. In the United States, legislators must decide whether or not to permit the nuclear power industry to commercialize reprocessing technology that would separate out and recycle plutonium and unused uranium from the spent fuel. The decision makers must weigh not only the economic implications of closing the fuel cycle but also the risks to society that attend the introduction of such a technology. These risks must be compared with those associated with leaving the fuel cycle open.

The reprocessing decision is difficult for legislators because the potential consequences could be very positive or very negative and because the decision is not easily resolved in the customary legislative process. The charged atmosphere of the adversary political process leads only to greater confusion as advocates present ever more heated arguments. Therefore, an analysis that treats the decision from a logical, quantitative perspective could be of considerable value to the interested decision maker.

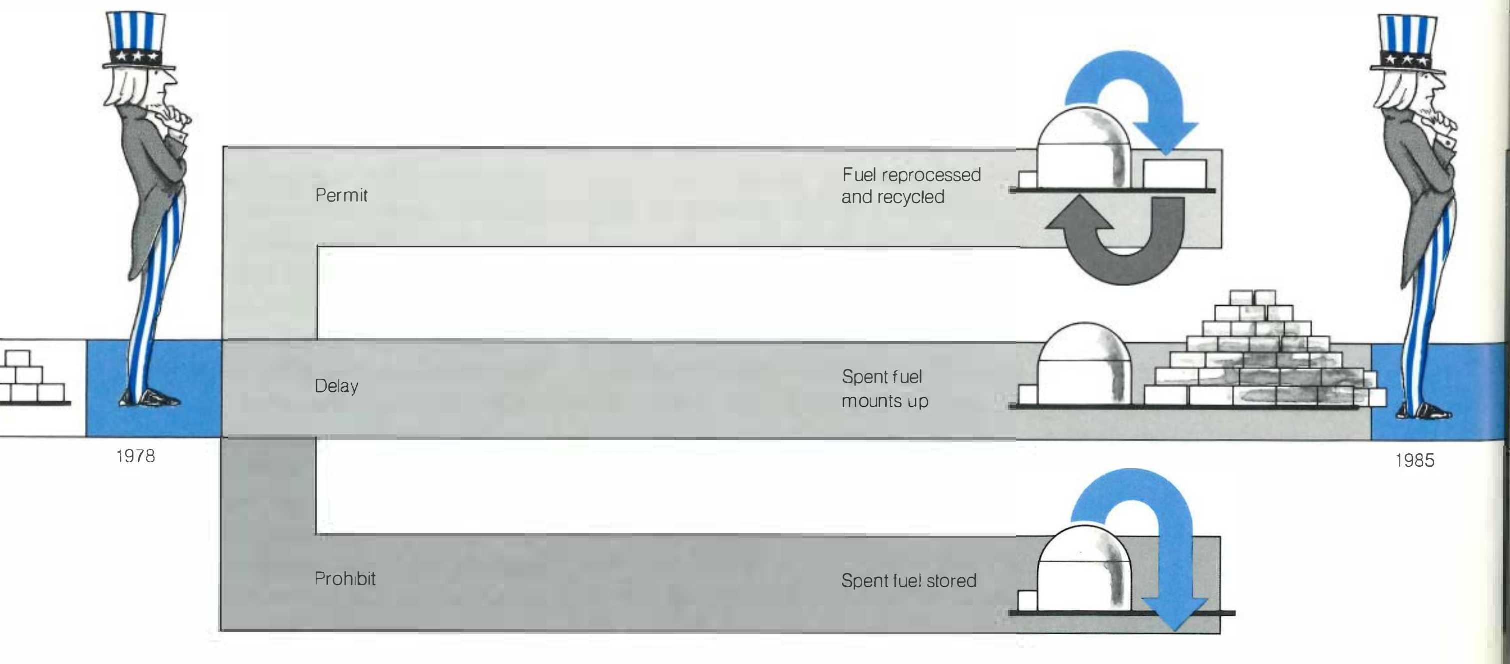
Bayesian decision analysis was used to examine reprocessing costs associated with risks and economic benefits. This method is well established and has been used to analyze many uncertain decision situations (*1*). Examples include applications in the NASA space program and in personal decisions, such as deciding

The Reprocessing Decision

by Carolyn D. Heising

Carolyn Heising is presently doing postdoctoral research at MIT. Her recent PhD dissertation at Stanford University, "The Reprocessing Decision: A Study in Policy Making Under Uncertainty," supported in part by EPRI, was the basis for this article.

Which of three paths should the United States pursue: permit, delay, or prohibit nuclear fuel reprocessing? Decision theory contrasts the economic benefits to the consumer with the technological risks associated with health, safety, sabotage, and proliferation.



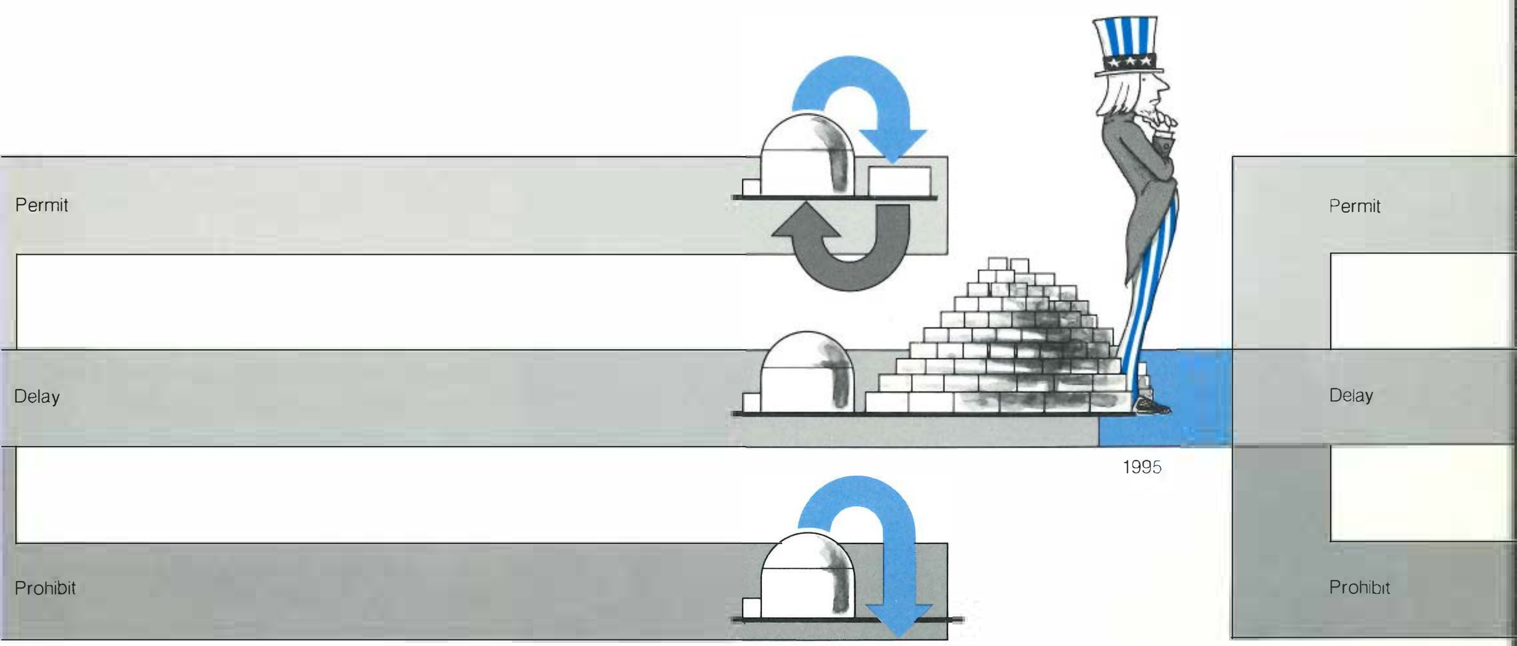
whether or not to undergo a medical operation. The method is unique because it permits a probabilistic description of important events that must be taken into account in coming to policy conclusions on reprocessing spent fuel, such as uranium supply and price, electricity demand, and the number of nuclear power plants needed to meet demand.

In decision analysis, important policy questions are modeled as event trees, each branch of which represents a future possible path the United States might follow. Smaller tributaries branching off from the main paths indicate possible futures with respect to economic prices, supply availabilities, and other uncertain parameters. Once the event tree is constructed, it becomes the analyst's task to assign probabilities to each branch. When probabilities have been estimated, the tree is folded back into a smaller tree with fewer branches until the expected values for each principal option have been completed. This done, the best decision becomes clear: the option exhibiting the largest positive expected value. Finally, the sensitivity of the outcome to the probability estimates is tested by using new sets of estimates to recalculate the expected values.

Three paths

With respect to the reprocessing decision, three options or paths are available for the United States to follow. These include the permit, delay, and prohibit paths. If the United States follows the permit path, the nuclear fuel cycle can be

The United States reprocessing decision. The United States must decide whether to permit, delay, or prohibit the reprocessing and recycling of nuclear spent fuel. To permit reprocessing would allow recycle as early as 1985; to delay the decision for a later administration to deal with means spent fuel would mount up at nuclear reactor sites; to prohibit would eliminate recycling and mandate permanent storage.



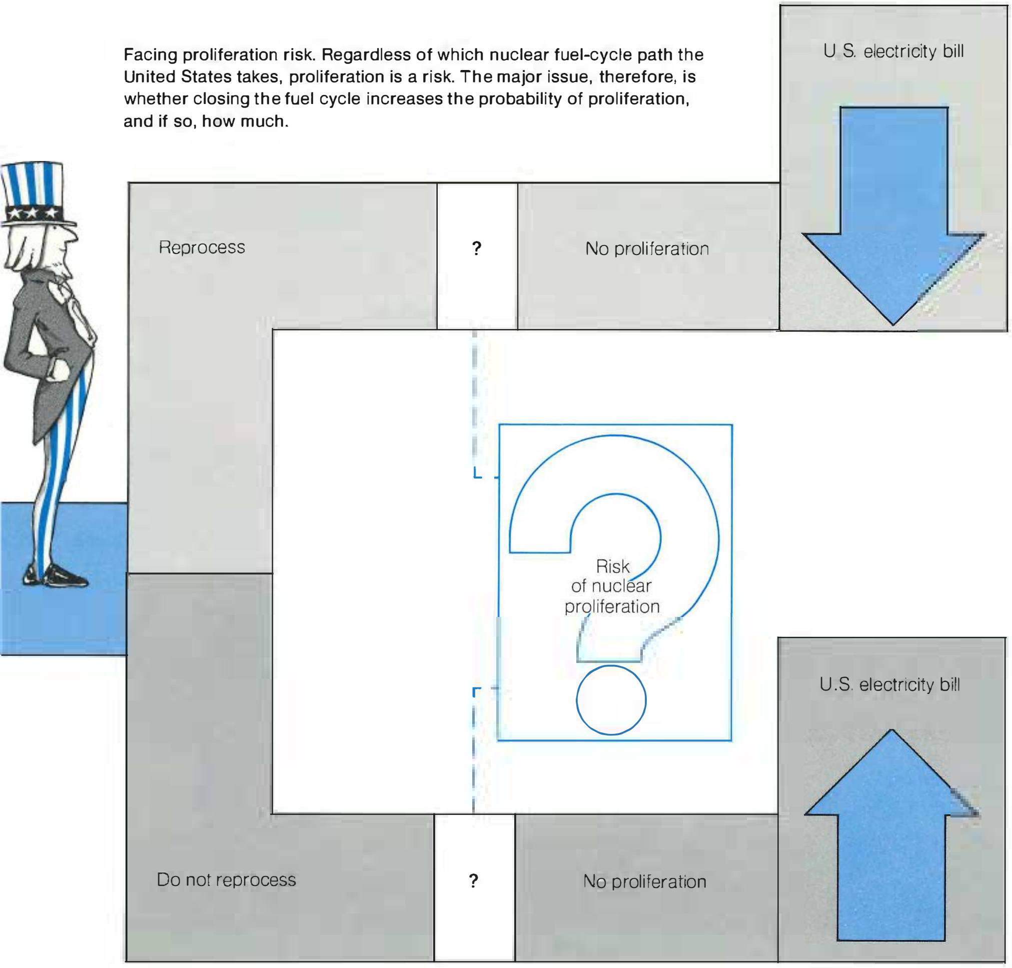
closed in the near future, which would allow uranium and plutonium to be recycled and help to conserve precious resources. To follow the delay path means the next administration will face the same decision at a later date, while spent fuel continues to mount at reactor sites across the country. The prohibit path would outlaw reprocessing and plutonium as a reactor fuel and would leave the country with no recourse but to throw away its spent fuel without the benefit of recycle. This would be accomplished by building temporary repositories for spent fuel assemblies, followed by permanent disposal in geologic formations.

The choice of which path the United States should follow depends on which can be expected to produce the greatest benefit to society. These benefits need not be only economic; they can also be measured in terms of risk reduction, cleaner air, or improved public health. To assess differences in benefits between options, it is necessary to identify the potential benefits of each option along with its risks. Once identified, these can be quantified and compared.

Quantifying benefits

The major economic benefit associated with reprocessing is the potential reduction in the consumer's electricity bill. The reprocessing decision can have an effect on electricity bills in two ways: by affecting fuel costs in the current generation of nuclear power plants (LWRs) and by affecting the future of advanced nuclear power systems, principally the breeder reactor (LMFBR). Engineering-economic computer models were designed to compute the potential differences in these effects implied by the three decision options of permit, delay, and prohibit. Because prohibition of reprocessing effectively eliminates the breeder, this option exhibited the largest cost penalty. The delay option was found to be the second most costly since delays in breeder commercialization result, and more expensive fuel must be used in the current generation of reactors. The permit option was found to be most economic because recycling and use of the breeder could start sooner, thereby conserving the more accessible (thus cheaper) uranium ore. It was found that the permit path would save the American consumer over $2.5 billion a year (at a 6% discount rate) in reduced electricity bills compared with the delay alternative.

Facing proliferation risk. Regardless of which nuclear fuel-cycle path the United States takes, proliferation is a risk. The major issue, therefore, is whether closing the fuel cycle increases the probability of proliferation, and if so, how much.



Technological risks

Technological risks are associated with all three decision options. Basically, there are three distinct categories of risk that are important in the nuclear fuel cycle:

- Health, environmental, and safety risks
- Nuclear theft and sabotage
- Nuclear weapons proliferation risks

Examples of the first category include occupational exposure to routine radiation emission and public consequences of accidents in fuel-cycle facilities. Safeguard risks, the second category, refer to acts that hypothetically might be directed against the fuel cycle by disgruntled employees and/or terrorist groups. These include disturbances at site locations, initiation of accidents by explosives, or theft of nuclear material. The third category, nuclear proliferation risk, refers to an illegal diversion of nuclear material from a facility by a national government bent on building crude nuclear explosives. Each of these categories of risk was examined and quantified for the decision options of permit (closed cycle), delay, and prohibit (open cycle).

Health, environment, and safety risks

The nuclear fuel cycle poses some measure of risk to the environment and to the health and safety of persons employed at or living near fuel cycle facilities. A review of recent studies indicated that while all three risks are small, the health risks outweigh the risks associated with safety. The major component of the health risk was routine occupational exposure to low-level radiation. It was found that the health risk to society was on the order of \$6,000 to \$80,000 a gigawatt-year and that the difference between open and closed cycles was negligible. In fact, closing the fuel cycle would lead to improvements in public health as a result of reduced uranium mining and milling (2).

Nuclear safeguards risk

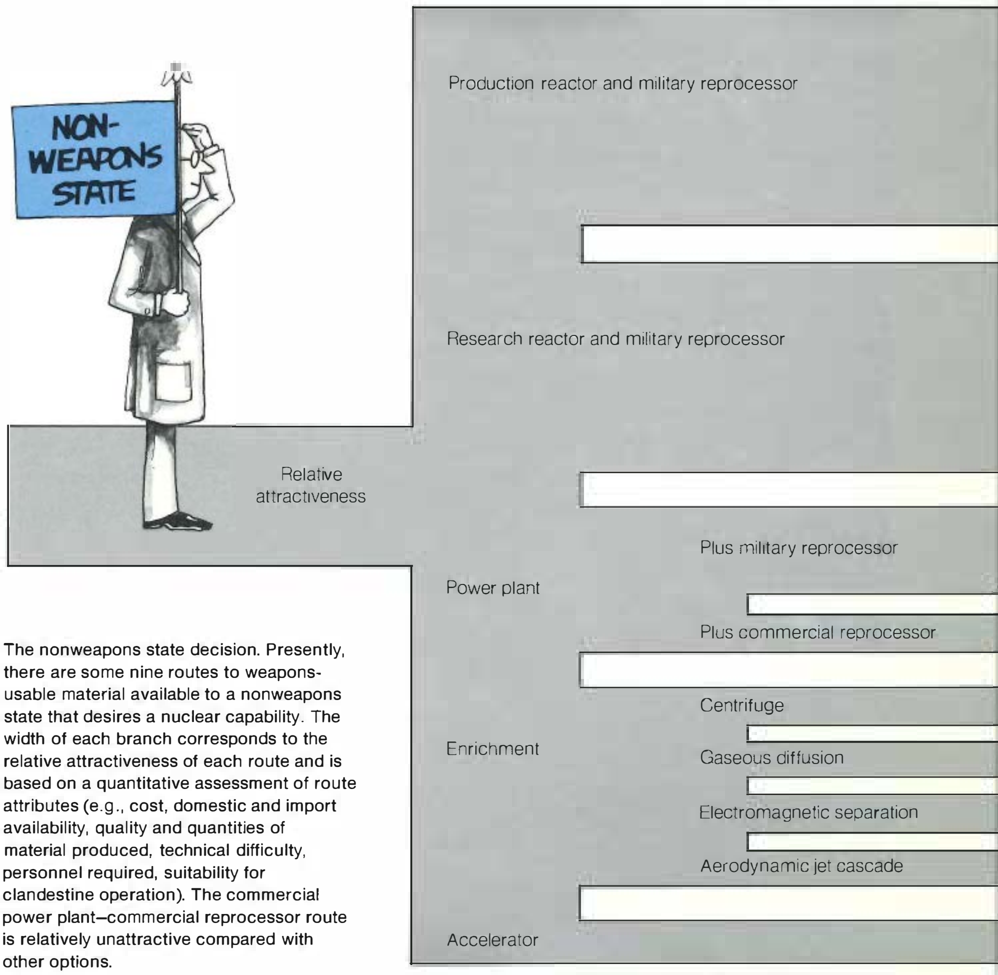
A safeguards assessment method was developed to compare the differences in social costs between the open and closed cycles for nuclear theft and sabotage. Facilities representing both cycles were examined for three categories of events: those that precede the act (e.g., access to technical information, organizing the attack), those that constitute the act (e.g., entry, overcoming security), and those that follow the act (e.g., dispersal of toxins, processing materials for explosives). Using the best available information on safeguard system reliability, facility layout, and the requirements for a successful intrusion, these events were assigned probabilities and arrayed sequentially into event trees to determine expected values.

It was found that the closed cycle represents the greater risk. However, the increase in the cost to society was found to be only on the order of \$250,000 a year (at a 6% discount rate), or about half a cent per family. Comparing this figure with the calculated benefits of a closed cycle (\$2.5 billion per year) yields a benefit-cost ratio of 10,000 to 1.

Nuclear proliferation risk

The third major area of social concern for which the open and closed cycles should be compared is the risk of nuclear proliferation. The analysis presumed that if the value to society from closing the nuclear fuel cycle (\$2.5 billion a year) exceeded the expected cost of increased nuclear proliferation under closed-cycle conditions, then it would be in the best interests of the United States to permit reprocessing. Getting to the expected cost required many assumptions, but mathematically it was obtained by multiplying the amount the United States would be willing to spend to thwart proliferation (v_p) by the increased likelihood of proliferation under closed-cycle conditions (Δ).

To elaborate, the value of nonproliferation (v_p) is interpreted as the dollar amount the United States would be



The nonweapons state decision. Presently, there are some nine routes to weapons-usable material available to a nonweapons state that desires a nuclear capability. The width of each branch corresponds to the relative attractiveness of each route and is based on a quantitative assessment of route attributes (e.g., cost, domestic and import availability, quality and quantities of material produced, technical difficulty, personnel required, suitability for clandestine operation). The commercial power plant–commercial reprocessor route is relatively unattractive compared with other options.

willing to pay per year to prevent a future event of proliferation from occurring. In short, the value v_p can be interpreted as an annual premium for insurance against the spread of nuclear weapons. And this value, in turn, depends on how society views the effects of proliferation, since they can be construed as either good or bad.

Some experts claim the probability of nuclear war decreases as the number of countries with atom bombs increases and point to such potential good effects as global equalization of wealth and a more lasting peace. Other experts think proliferation will have little effect on the world one way or the other. They believe nations will have adequate time to adjust to the emergence of new weapons states and point to past events of proliferation as evidence of such accommodation (e.g., reaction to India's emergence as a weapons state). However, the predominant opinion is that proliferation will result in regional nuclear war, possibly leading to an all-out nuclear confrontation between the superpowers. Therefore, from this viewpoint, the United States should be willing to pay substantial sums of money to help prevent future proliferation events.

Adopting this perspective and examining United States response to past events of proliferation, a nominal value of nonproliferation of $12 billion a year was considered an accurate reflection of how much the United States would be willing to pay. This figure corresponds to an annual 10% increase in the U.S. defense budget, or roughly $240 a year for a family of four.

Turning to the likelihood of proliferation, or more specifically, the difference in proliferation likelihood between closed and open fuel cycles (Δ), several questions must be asked. First, what influence does the United States have on decisions of nonweapons states to deploy reprocessing? And second, if a nonweapons state decides to proceed, does the existence of commercial reprocessing plants in that country affect the likelihood that it will be successful in constructing its first nuclear bomb? To answer these questions, alternative routes to nuclear material by a nonweapons state must be rated and compared with the commercial power plant reprocessor (*3–6*).

A nonweapons state's decision on which route to take will depend on several considerations, including weapons attainable from the material flow, the cost of each route, the number of technical people required to operate the technology, the level of support industry required, and the capability for clandestine operation to prevent other countries from applying sanctions. The quality of the material is also very important. All these considerations must be weighed by decision makers in the nonweapons state.

After comparing some nine currently available routes to weapons material, it was found that the commercial power reactor–commercial reprocessor route is comparatively unattractive to a nonweapons state. Specifically, given access to such a route, it is estimated that there is only a 3% likelihood that a nonweapons state would choose this route over some other (*7*). Therefore, by closing the nuclear fuel cycle, the United States would incur, at most, only a 3% greater chance of proliferation than if it decides to prohibit or delay reprocessing.

In summary, allowing nuclear fuel reprocessing to go forward in the United States can be expected to increase the costs to society by a maximum $360 million a year [$\Delta \times v_p = (0.03)(\$12 \times 10^9) = \$360 \times 10^6/\text{yr}$]. This is approximately one-seventh of the expected benefit (reduced electricity bills) to be derived by society from closing the fuel cycle. Thus, on the basis of this analysis, it appears that permitting reprocessing now is logically preferable to delaying or prohibiting the technology.

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John Busterud: It's Better to Mediate

A former national official spearheads a new effort to mediate rather than litigate environmental disputes.

Environmentalists, industrialists, and the public alike have suffered economically and socially from lengthy litigation over environmental disputes.

Large sums of money are ploughed into lobbying and legal services and are consumed by higher costs of development and construction resulting from long court-imposed delays. Industry and labor leaders view environmentalists as no-growth advocates, harmful to business and society, while environmentalists see their opponents as self-interested, short-sighted, and intransigent. The result often is polarization and stalemate.

A former public official with environmental credentials balanced by a sensitivity to the need for reasonable economic growth has formed an organization designed to resolve environmental disputes through fact finding, conciliation, and mediation. The organization is called, appropriately, Resolve. Its founder is John Busterud, whose background has been described as a distillate of the American dream—Yale Law School, Phi Beta Kappa, California State Assemblyman, chairman of the Council on Environmental Quality, Deputy Assistant Secretary of Defense, special adviser to the Aspen Institute for Humanistic Studies, and so on. In an informal interview with the *Journal* at Resolve's headquarters in a comfortable converted residence in downtown Palo Alto, California, Busterud, a recent addition to EPRI's Advisory Council, talked of Resolve's creation, its goals, and its activities.

When the Carter administration took office in January 1977, Busterud, a Republican and a Ford appointee to the chairmanship of the Council on Environmental Quality, saw it was time to move on. His work on the council, he explains, often involved him informally as a mediator in trying to resolve conflicts between environmentalists and energy producers, for instance, as well as between government agencies dealing with environmental issues.

"So when I began examining what I wanted to do then with my career," Busterud recalls, "I decided to focus on some kind of conflict resolution effort in the environmental field." A chance meeting with the chairman of Atlantic Richfield Co. (Arco) at an environmental conference in Washington, D.C., led to the seed money that got Resolve started. Robert O. Anderson was so impressed with the concept of mediation that he pledged $200,000 a year for five years from the Atlantic Richfield Foundation to launch Resolve in October 1977. Additional funding, mostly from private sources, such as the Ford, Hewlett, and Hearst foundations, brought the support level to about $350,000 in 1978. Busterud projects an annual budget of about $500,000 in the next few years to support Resolve programs.

Balanced funding

While some critics of mediation are concerned that corporate financial support could make it difficult for Resolve to remain objective, Busterud believes that a proper balance can be struck between corporate, foundation, and government grants. And he is pleased that his principal donor, Atlantic Richfield Foundation, has maintained a completely neutral stance. He adds that he set out early to seek other sources of funding and has succeeded. Busterud notes also that Resolve's board of directors is broadly representative. Board chairman is Russell Train, president of the World Wildlife Fund and former administrator of the Environmental Protection Agency. Members include Robert Georgine, president of the Building and Construction Trades Department, AFL–CIO; Michael McCloskey, executive director of the Sierra Club; Elvis Stahr, president of the National Audubon Society; Louis Austin, chairman and chief executive of Texas Utilities Co.; and William Miller, vice president and provost of Stanford University.

In his contacts with responsible environmentalists, Busterud says he has found that "they are less concerned about the source of our funding, as long as the distribution is balanced, than they are about the credibility of the mediators." He points out that Resolve has been careful "to concentrate on development of new processes of conflict resolution and to refrain from taking positions on issues, such as whether nuclear power is good or bad."

In January, Resolve, the Sierra Club Foundation, and the Aspen Institute cosponsored a three-day conference in Reston, Virginia, to examine the field of environmental mediation and explored the prospects for establishing new techniques for settling complex and difficult environmental struggles. In the summary report of the conference published by Resolve, it is noted that the participants "were virtually unanimous in their view that this new approach to conflict resolution offers enough promise to justify

vigorous efforts to apply it to environmental disputes." Busterud commented that requests for help of one kind or another from some of the state governors and other public officials who received the report were numerous and made it difficult for Resolve's small staff to provide assistance. "We're going to have a busy year or two ahead of us," he says, "trying to raise enough funds to meet some of these needs and to advance the idea of new conflict resolution processes for environmental disputes."

Mediation defined

Gerald Cormick, director of the Office of Environmental Mediation at the University of Washington's Institute for Environmental Studies, one of a growing number of practitioners in the field today, has defined mediation as "a voluntary process in which those involved in a dispute jointly explore and reconcile their differences. The mediator has no authority to impose a settlement. His or her strength lies in the ability to assist the parties in resolving their differences. The mediated dispute is settled when the parties reach what they consider to be a workable solution."

Busterud observes that although the environmental mediation process resembles that used in labor-management disputes, there are important differences. Most labor negotiations involve only two parties (a union and a company, for instance), while environmental issues often affect several parties, each with different interests at stake, and all of whom may want to be involved in deciding the outcome of the conflict. Also, the periodic nature of labor negotiations makes compromise easier in any given bargaining round, since the parties can always try for a better deal the next time around. In environmental decisions, however, the result is often irrevocable with no chance for later revision. Further, the continuing contract relationship in labor-management conflicts usually assures performance of agreements, while there is no such assurance that environmental decisions will be carried out as agreed. The parties in labor disputes usually agree on the nature of the issues, while environmental opponents often

While a member of the Council on Environmental Quality, Busterud helped lead a group of inner-city youngsters on a Sierra Club outing in Shenandoah National Park.

In a series of meetings such as this over a seven-week period earlier this year in Colorado, individuals and groups reflecting a vast array of interests in the state worked at achieving a consensus of their views for consideration by the U.S. Forest Service in its designation of wilderness areas under the RARE II program. The process was proposed and facilitated by Resolve.

disagree—even over what issues need to be negotiated.

Busterud feels that many environmental conflicts could be avoided "if we can get environmentalists involved with industry people early in the planning stage of development projects. Projects that environmentalists have a hand in shaping are going to be more acceptable to them."

Delaying action

As for who benefits from the delay resulting from prolonged court action in environmental disputes, Busterud points out, "It depends on the nature of the controversy. If you're dealing with a pollution issue in which a chemical company, for instance, brings suit to prevent enforcement of standards or regulations, then the advantage in delay rests with the industrial firm. On the other hand, if the case involves opposition to building a refinery or power plant," he explains, "the delay could make the project uneconomical because of increased construction costs and thus benefit the environmentalists." Busterud adds, "Responsible environmentalists and business interests are coming to realize that they can't live off delay and protracted litigation because the public is becoming aware that one party or the other is simply using delay to get what it wants."

Resolve is drafting a list of criteria to gauge whether or not a given dispute lends itself to mediation. Busterud cites some questions that need to be considered in making such an evaluation: Is it so early in a dispute that the issues have not yet been clearly defined? Is there a basic difference in principles between the opposing parties? Is it a case where action can be taken to lessen damages? He foresees as good candidates for mediation the siting of power plants and the location of nuclear waste depositories.

Consensus experiment

Resolve's first major effort involved the process of consensus building and appears to have demonstrated that skillful facilitation can be effective. According to Busterud's chief assistant, Richard Livermore, who directed the project, Colorado was picked as the location because it "provided a microcosm of wilderness issues and a great diversity in geography." The plan was to bring together in a series of discussions representatives of the vast array of interest groups in the state that would be affected by the U.S. Forest Service's designation of wilderness areas under the Roadless Area Review and Evaluation Program (RARE II). There are 234 such roadless areas in Colorado that qualify as candidates for wilderness preservation. The Forest Service is expected to make recommendations to Congress this winter for additions to the national wilderness network. Resolve proposed the consensus process plan to the Forest Service in an effort to find out how workable and useful the process could be. The Forest Service provided some of the support for the project.

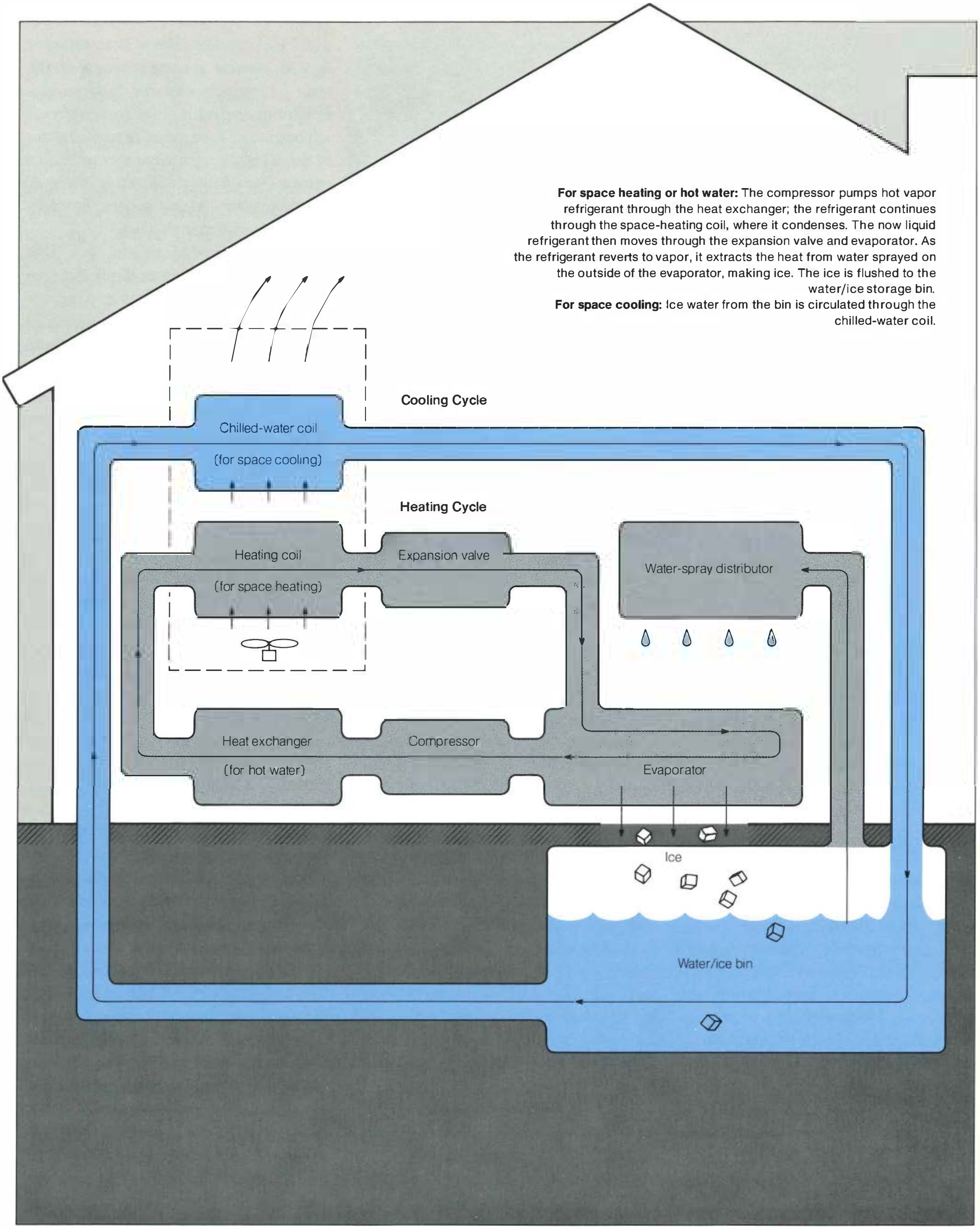
Over a seven-week period in August and September, nearly a dozen meetings were held, with some 100 individuals and group representatives actively participating. "Participants represented some 75 special interest groups throughout the state," Livermore reports, "a cross section from agriculturalists to wilderness advocates." There were representatives of the oil and gas producers, recreational vehicle users, hiking and skiing interests, water suppliers, ethnic groups, environmentalists, and many others.

Resolve offered a helpful but light hand, taking pains not to direct the process, but rather to facilitate it. The participants designed the format, decided which issues to discuss, what time would be allowed for discussion. And they decided that the meaning of consensus for them was 100% agreement. On some issues, Livermore notes, they actually achieved it.

Livermore characterizes the participants as "intelligent, energetic, and well briefed. People came to take part, not just listen. And they worked hard at building consensus." He adds, "I was amazed at how calm the groups were and how professional an atmosphere they maintained. Rarely was there a flareup." Resolve's report on the results of the consensus meetings was submitted in October and should "enable the Forest Service to identify the primary issues and get a sense of the degree of concern on these issues from each of the interest groups."

The Colorado experience has also provided an important measure of how participants react to the process of consensus building, Livermore notes, and can serve as the basis for a model. Says Busterud, "The important thing is that we got a good process set up that's effective and that we can use again." Both Busterud and Livermore would no doubt echo Charles Warren's conclusion in his keynote speech at Resolve's Reston conference. Warren, current chairman of the Council on Environmental Quality, quoted Franklin D. Roosevelt's advice to a staff aide: "Take a method and try it. If it fails, try another. But above all, try something." Warren added, "Mediation looks good. I say let's try it." ■

For space heating or hot water: The compressor pumps hot vapor refrigerant through the heat exchanger; the refrigerant continues through the space-heating coil, where it condenses. The now liquid refrigerant then moves through the expansion valve and evaporator. As the refrigerant reverts to vapor, it extracts the heat from water sprayed on the outside of the evaporator, making ice. The ice is flushed to the water/ice storage bin.
For space cooling: Ice water from the bin is circulated through the chilled-water coil.



House on Ice

DOE is pursuing an unusual concept for heating and cooling that has the potential for big energy savings. It involves freezing water and melting ice.

The basement of a Knoxville house was under eight feet of water late last summer, but no one called the plumber. The water is now freezing over, yet the owners remain unconcerned. In fact, they planned it that way. It's part of an unusual scheme to save heating and cooling energy.

The 2500-cubic-foot "basement" is actually an insulated water/ice bin. Add a heat pump and you have the basics of the annual cycle energy system (ACES) being developed by DOE at Oak Ridge National Laboratory (ORNL). (The laboratory is operated for DOE by Union Carbide Corp.) In wintertime, the pump removes heat from the water to warm the building and supply domestic hot water; the water in the bin is gradually frozen in the process. When summer arrives, the ice is used for air conditioning. If a building's heating and cooling requirements are balanced over the course of a year, the ice is completely melted when the heating season is about to begin.

Preliminary results indicate that when a good balance between annual heating and cooling requirements exists, ACES can save as much as 50–70% of the source energy used by conventional heating and cooling systems. An economic analysis of ACES is now being carried out under the auspices of DOE and ORNL; results are expected in January. And EPRI, aware of ACES' load management possibilities, has included an evaluation of this concept in a study of other cool storage systems.

One of several

The Knoxville demonstration house, result of a joint venture between DOE, the University of Tennessee, and the Tennessee Valley Authority, is only one of several similar installations going up across the United States. The ACES concept is being tried in both residential and commercial applications, either privately or publicly funded. A private house in Jackson, Mississippi; a 60-bed nursing home in Wilmington, Delaware; and a vocational school in Reedsburg, Wisconsin, are among the installations already in operation. Other installations in more preliminary stages include a visitors' center in Pennsylvania and two office buildings, one in North Dakota and another in Maryland.

The man behind the ice bin–heat pump combination is engineer and inventor Harry C. Fischer. In 1957 Fischer improved on the idea of extracting heat from freezing water by suggesting that the ice be saved for cooling. At the time, energy was cheap, and the relatively high capital cost of such a system could not be justified. Things changed by 1974, however, when Fischer approached ORNL with his scheme. The result: a feasibility study and DOE's subsequent initiation of an ACES development program, with Fischer as consultant.

Some system basics

The basic ACES system involves a little more technology than do most heating and cooling systems. When heat or hot water is required, an electric compressor pumps a hot, high-pressure vapor refrigerant through a heat exchanger. There, some of the vapor's heat is removed to heat domestic water. The hot refrigerant then circulates through a space-heating condenser coil, where it releases more energy, this time for indoor heating, and finally condenses. Next, the slightly warm, now-liquid refrigerant moves through an expansion valve, where its pressure is lowered, causing it to evaporate.

When the refrigeration compressor is running, water remaining in the ice bin is continuously sprayed across the outside surface of the evaporator, an ice-freezing plate. As the refrigerant evaporates, it extracts heat from the water, gradually changing it to ice. At 32°F (0°C), every pound of water transformed to ice yields 144 Btu. The refrigerant then leaves the evaporator and returns through the circuit to the compressor.

When a thin layer of ice has formed on the outside surface of the plate, the compressor stops, a harvesting valve opens, and warm refrigerant vapor is forced through the evaporator, momentarily warming the freezing plate and loosening the ice, which is then flushed to the bin for storage. The compressor starts again, boosting the heat content of the vapor, and the cycle is repeated.

When cooling is needed, ice water is circulated through a chilled-water coil. Air blowing over this coil provides air conditioning. During the cooling season, the compressor operates only when hot water is required.

Brine-carrying coils may be used instead of the ice-freezing plate. These coils are submerged in the water of the bin, where they freeze the water during the heating season and melt the ice during the cooling season.

Planning for flexibility

So the system works under ideal conditions, when heating needs equal cooling needs over a year's time. But climates vary, buildings are used for different purposes, and the people within them have different lifestyles. Radiant-convector panels and external fan coils provide the necessary flexibility to suit all purposes.

When the ice threatens to exceed bin capacity, the panels collect heat from the sun and the ambient air to melt some of the ice buildup, explains Robert E. Minturn, ACES program manager at ORNL. Conversely, if there isn't enough ice to meet cooling needs, the compressor is operated to make more ice; the heat extracted in the process is dissipated to the outside by an air-cooled fan coil. This can be done most economically by operating the compressor at night, when dissipation of waste heat is more efficient at lower nighttime temperatures. Nighttime operation also allows commercial installations to benefit from any off-peak electric power rates. Thus, the system can be used as an effective load management tool.

Because of its unique operation, ACES consumes considerably less energy than conventional systems. Peak loads, both daily and seasonal, are reduced as well. For example, the Knoxville house used only 5200 kWh of electricity last winter compared with 14,200 kWh required by a control house equipped with electric resistance heating. The peak load imposed by the ACES house last winter was 3.1 kW; by the control house, 14.1 kW. In an ACES, both the heating and cooling outputs of the heat pump are used; the compressor, operating betw :en fixed input and output temperatures, can be designed to operate at its highest efficiency.

Will it sell?

Few deny that ACES saves energy and decreases peak capacity requirements, but these advantages are in themselves no guarantee of commercial success. Roger Carlsmith, manager of ORNL's Energy Conservation section, concedes that the present system faces two obstacles to commercialization: cost and complexity. "The thing that needs to be settled is whether the energy savings are going to be sufficient to offset the system's greater initial cost and greater complexity." The forthcoming economic analysis of ACES should begin to answer that question.

The major reason for ACES' high front-end cost is the price of ice bin construction, according to Fischer. (As a rough rule of thumb, ACES requires a little more than one cubic foot of storage space for each square foot of floor space.) Because the bins are new and unfamiliar, contractors will charge more to build them. But prices will go down, Fischer says, as contractors gain more experience with the systems. Modular bins, prefab panels, and innovative building designs could cut costs still further.

As for system complexity, Fischer says, "ACES *is* complex. It has to do so many more things than a furnace or an air conditioner." But he is confident that a packaged control system, "a black box that will take care of itself," will be perfected. Ultimately, the owner's only worry should be setting a thermostat. To further clarify the unconventional system, DOE is developing two ACES design handbooks, one for residential applications and one for large commercial applications.

Likely markets

If economic feasibility can be established, ACES will probably break into the commercial sector first. The bigger the ACES, the greater the economies of scale, according to Minturn. The commercial owner is also more likely to have access to off-peak rates, which enhance system economics.

Furthermore, the commercial owner would not be dependent on the creation of a special ACES sales/service network. Because large commercial buildings are custom-engineered, it should be relatively simple to include ACES in a total building heating and ventilating plan. A large building is also likely to have a full-time engineer to supervise the system, and maintenance on a larger scale is, of course, less expensive.

The residential sector, particularly individual homes, lacks these incentives. The typical home system will be small, and off-peak electric rates may not be available. Then, too, "Someone in Grundy Center, Iowa, can't buy an ACES," says Minturn. "There's nobody there to sell, install, or service it." Except for a tiny percentage of innovators, most homeowners must wait for a less-expensive package deal and a servicing system.

Finally, the future of ACES is closely connected to the cost of energy. If energy prices continue to rise, the high initial cost of ACES might seem a small price to pay for the eventual energy savings the system has to offer. "As the price of energy goes up," concludes Fischer, "ACES looks better and better all the time." ■

UTILITIES AND COOL STORAGE

A number of summer-peaking utilities are currently investigating cool-storage systems—including ACES—that could smooth summer power demand profiles. EPRI recently identified over 30 utility cool-storage experiments; the majority involve daily load management systems that use off-peak power. Five ACES systems were also identified: Virginia Electric and Power Co., Georgia Power Co., and Northern States Power Co. are studying one system each, and Philadelphia Electric Co. is monitoring two. Although ACES is an annual energy management concept, it has some load management potential for utilities: summer air conditioning with stored ice does not require compressor operation, so little electricity is needed. The compressor can use off-peak electricity to make any additional ice required.

Cool-storage systems are not generally commercially available at this time. Their performance, utility impact, and economics are unclear. Accordingly, EPRI has funded supplemental instrumentation at 22 of these experimental installations, including one ACES system at a house in Richmond, Virginia. EPRI's contractor, the Research Division of Carrier Corp., will report on the performance and utility impact of the 22 installations, and develop handbooks on cool storage for utility use.

EPRI also hopes to get a first-hand look at ACES economics through the study. "The concept is simple and energy-efficient," comments Quentin Looney, program manager for Energy Utilization and Conservation Technology, "but the cost of saving the energy is not known."

Update: Edison Centennial Symposium

One hundred years after Edison's first light bulb, leaders in science, industry, and government will gather to probe future directions for science and technology.

Invitations have been mailed; key speakers have defined the focus of their topics; and national interest is building in the Edison Centennial Symposium, "Science, Technology, and the Human Prospect," April 1–4, 1979, at the San Francisco Hilton Hotel.

The symposium is an official event of the Centennial of Light celebration now under way to commemorate the 100th anniversary of Thomas Alva Edison's lighting the first practical incandescent electric lamp on October 21, 1879. EPRI is cosponsoring the meeting with the Thomas Alva Edison Foundation (TAEF), official coordinator of the centennial activities. TAEF was founded in 1946 to advance science and engineering education.

Symposium speakers. Top, from left: Basalla, Handler, Hoffer, Kantrowitz. Bottom: McIntyre, Ramo, Starr.

Chauncey Starr, EPRI vice chairman, is the chairman of the Edison Centennial Symposium. Starr sees the symposium as "a unique opportunity to reassess the role of science and technology in society's development." He explains that the intent is to examine not only past impact but also present attitudes and future directions as well.

"We have now reached the point where technology influences our lifestyle," Starr remarks. "The rate of new scientific discoveries is accelerating and we are swiftly incorporating these changes into our lives. Although many of us involved in science and technology believe these developments benefit humanity, we recognize that technological growth brings with it costly by-products. We believe that now is the time to reexamine what we are doing."

Starr explains that in examining the benefits and the undesirable by-products wrought by science and technology, the symposium will look at measurable values and costs, as well as intangible ones. "For example, we want to look at how the developments in science and technology have changed people's perceptions of where they fit in society and how they can best attain personal happiness," he explains.

"The issues we are addressing are of great public consequence and go right to the heart of our national planning in science and technology. One of the problems we face in planning a symposium like this is how to get this message out to a broader audience. This whole issue is very fundamental to the 'man in the street.' It affects his immediate activities, his future, and those of his children and grandchildren.

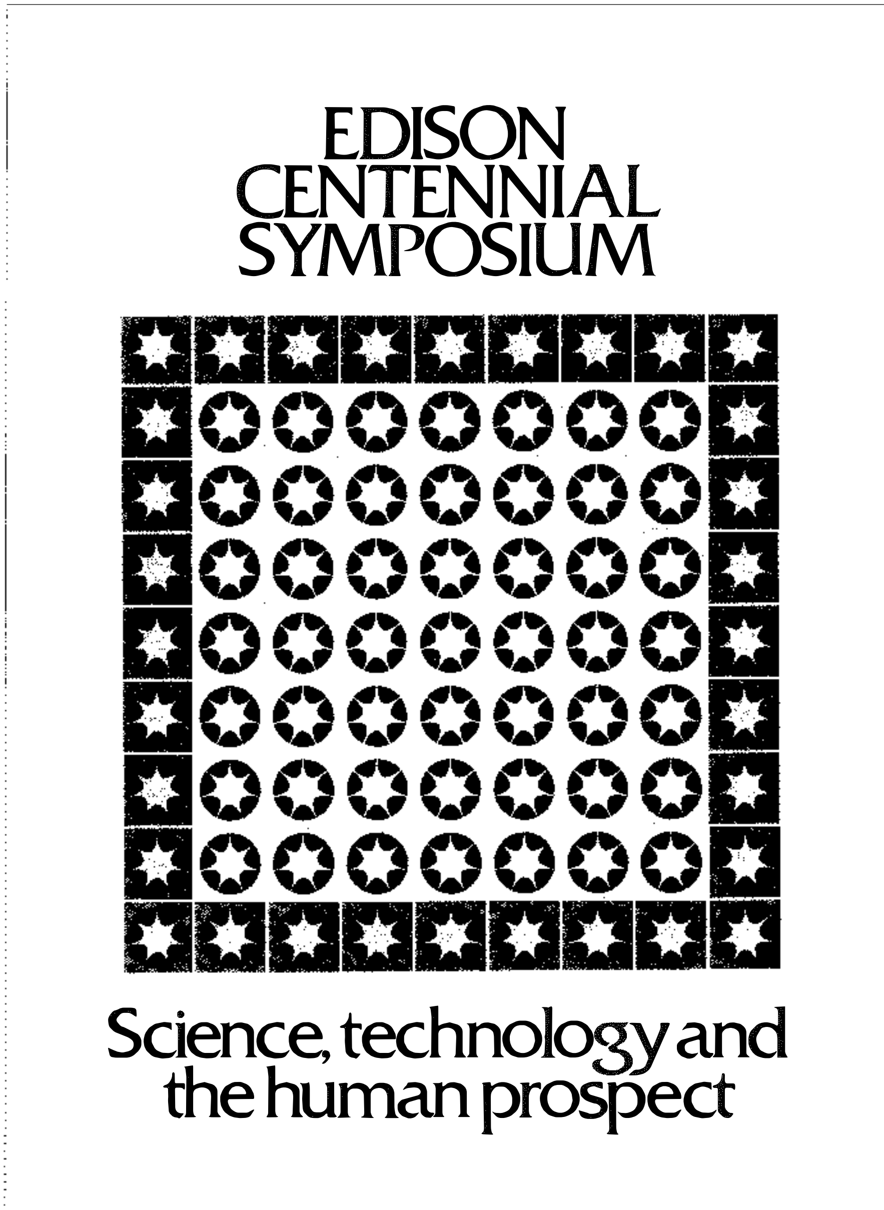
"We don't expect that the symposium will answer all the questions," Starr says. "What we do hope is that it will clarify the issues. And we hope to stimulate further discussion."

Growth of limits

Starr will address the symposium on the first day, challenging attendees with the theme, "Growth of Limits." Of his address Starr says, "Science and technology have constantly opened new frontiers for the human race, extending yesterday's limits into today's realities. For example, technology has permitted an enormous growth in world population by combating disease and improving nutrition. It has allowed humans to accommodate to previously harsh environments and has provided transportation to formerly remote areas. What it has done is to permit a 'growth of limits.' And so the real questions are, Do we want to accept the limits as they now exist, or do we want to keep moving them out? And what are the costs and benefits of doing that?"

Starr was EPRI's founding president, guiding the Institute during its first five years. Before that he was dean of the School of Engineering and Applied Science at the University of California at Los Angeles. His career has included 20 years in industry, holding such positions as vice president of Rockwell International Corp. and president of its Atomics International Division.

Following Starr's address, science historian George Basalla will focus on the impact of a specific technology, "Energy



Color posters commemorating the Edison Centennial Symposium are now available from: Communications Division, Electric Power Research Institute, Post Office Box 10412, Palo Alto, California 94303; or Electric Power Research Institute, 1750 New York Avenue, N.W., Suite 835, Washington, D.C. 20006. The posters measure 17 by 25 inches.

and Civilization." Basalla writes, "Because of the great influence the discovery of new energy sources had on the growth of western society, there emerged the belief that energy could be readily and easily transformed into civilization, that the society using the greatest amount of energy per capita was clearly the most civilized." Basalla plans to trace the origin and growth of this concept. Basalla is associate professor of the history of science and technology at the University of Delaware and has taught at the University of Texas at Austin and at Harvard University. Currently, Basalla is completing a book on science, technology, and popular culture.

"Science and the Concepts of Man" is the address planned by Philip Morrison, Massachusetts Institute of Technology. Morrison will examine the impact of scientific discovery and technical innovation on man's changing concepts of his physical and biological surroundings, his views on how society should be organized, and his concepts of his place in society.

Moral dimensions

Shifting the focus from social impacts to ethics, philosopher and political science specialist Alasdair MacIntyre's address at the symposium luncheon will be "Industry and Energy: Moral Dimensions of the Tasks." MacIntyre says, "Much of what is written on ethics of government, business, and industry is exclusively concerned with rules that constrain and forbid, that tell us what we ought not to do. Of course, such rules are important, but to be preoccupied with them may be to lose sight of what is centrally important to morality . . ."

He writes that the electric power industry has "an outstanding record of abstinence from wrong action . . . but abstinence from wrong action is not, or at least is no longer, enough." In his address, MacIntyre says, he will "try to formulate a list of the intellectual and moral virtues that are going to be required if the electric power industry is to discharge its present and future responsibilities to American society."

MacIntyre is university professor of philosophy and political science and chairman of the Department of Philosophy, at Boston University. His research specialties include the problems of medical ethics and the philosophy of medicine. He has served as consultant to the National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research and has held professorial and administrative positions at a number of universities in the United States and abroad, including Oxford, Essex, Princeton, and Leeds.

Urban development, health, energy

Following the luncheon, the symposium will break into smaller groups that will be continued the next afternoon. Seven workshops and two general sessions are planned for the two afternoons.

The chairperson of the session on urban development will be John P. Eberhard, director, Architectural Research Associates. Eberhard is a fellow and corporate member of the American Institute of Architects. His career has included positions as president of AIA Research Corporation in Washington, D.C.; dean, School of Architectural and Environmental Design, State University of New York at Buffalo; and director, Institute for Applied Technology, National Bureau of Standards.

Environmental health specialist Merril Eisenbud will lead the workshop on medicine and public health. Eisenbud was one of the first industrial hygienists in this country and in 1947 was chosen by the Atomic Energy Commission to establish its first health and safety laboratory. He also served as the first director of New York's Environmental Protection Agency. Today Eisenbud is director of the Laboratory for Environmental Studies at the New York University Medical Center.

Leading the workshop on energy will be Wolf Häfele, deputy director of the International Institute for Applied Systems Analysis in Austria. Häfele was formerly with the Karlsruhe Nuclear Research Center in Germany. He participated in the design of the first German-built nuclear reactor, FR 2, and later established the Fast Breeder Project.

Other workshops are planned on food and agriculture, communications, human population and ecology, and the humanistic aspects of science and technology. The workshops will actively involve all symposium participants in discussion of key issues.

History of electric power

A general session on the first afternoon will be built on the theme "Does the Past Have a Future? Trends and Issues in the History of Electric Power." Conducting the session will be electric power historian Thomas Hughes, professor of the history of technology and chairman of the Department of History and Sociology of Science at the University of Pennsylvania. Hughes is author of the prize-winning biography *Elmer Ambrose Sperry: Inventor and Engineer,* the founder of Sperry Rand Corporation. He is general editor of books on the history of technology for the Johns Hopkins University Press and is now writing a history of electric light and power systems and a biography of Thomas Edison.

On the second day of the symposium, the morning plenary session will provide an overview of the sequence of new technological concepts from conception to public use and acceptance. Gunnar Hambreaus will begin with discussing "Patterns of Creativity in Science." Hambreaus is managing director of the Royal Swedish Academy of Engineering and Sciences in Stockholm.

An address by Simon Ramo, "Technological Innovation," will be next. Ramo, an entrepreneur, is vice chairman of the board of TRW, Inc. He attained world recognition at an early age as a pioneer in microwaves at General Electric Co. and developed its electron microscope. Before age 30, he had accumulated 25 patents. He was a key organizer and developer of Hughes Aircraft Co.'s elec-

EDISON CENTENNIAL SYMPOSIUM
"SCIENCE, TECHNOLOGY, AND THE HUMAN PROSPECT"
San Francisco, California, April 1–4, 1979
(Preliminary Program)

Sunday, April 1	Reception at Exploratorium, Palace of Fine Arts	
Monday, April 2	Opening of Plenary Session	
	Remarks and introduction of speakers by the Honorary Chairman, Centennial of Light	Robert Smith, Chairman, Public Service Electric & Gas Company, New Jersey
	Remarks by Symposium Chairman	Chauncey Starr, Vice Chairman, EPRI
	Address: "Energy and Civilization"	George Basalla, Associate Professor, History of Science and Technology, University of Delaware
	Address: "Science and the Concepts of Man"	Philip Morrison, Massachusetts Institute of Technology
	Speakers' Press Conference	
	Luncheon	
	Address: "Industry and Energy: Moral Dimensions of the Tasks"	Alasdair MacIntyre, University Professor, Philosophy and Political Science, Boston University
	General Session: "Does the Past Have a Future?: Trends and Issues in the History of Electric Power"	Thomas Hughes, Chairman, Department of History and Sociology of Science, University of Pennsylvania
	Workshop Sessions	
	Communications	Chairperson: Michael Tyler, Communications Studies and Planning, Ltd., London
	Energy	Chairperson: Wolf Häfele, Deputy Director, International Institute for Applied Systems Analysis, Austria
	Food and Agriculture	Chairperson: René Dumont, Institut National Agronomique, Paris
	Humanistic Aspects of Science and Technology	Chairperson: Norman Birnbaum, Professor of Anthropology, Amherst College
	Human Population and Ecology	Chairperson: F. Kenneth Hare, Director, Institute for Environmental Studies, University of Toronto
	Medicine and Public Health	Chairperson: Merril Eisenbud, Director, Laboratory for Environmental Studies, New York University Medical Center
	Urban Development	Chairperson: John Eberhard, Director, Architectural Research Associates, Washington, D.C.
Tuesday, April 3	Plenary Session	Session Chairman: Arthur M. Bueche, Senior Vice President, Corporate Technology, General Electric Company
	Address: "Patterns of Creativity in Science"	Gunnar Hambreaus, Managing Director, Royal Swedish Academy of Engineering and Sciences, Stockholm
	Address: "Technological Innovations"	Simon Ramo, Vice Chairman of the Board, TRW, Inc.
	Address: "Public Reactions to Science and Technology"	Jean-Jacques Salomon, Head, Science Policy Division, Organization for Economic Cooperation and Development
	Speakers' Press Conference	
	General Session: "Resolution of Science and Technology Controversies"	Arthur Kantrowitz, Chairman of the Board (retired), Avco Everett Research Laboratory, Inc.
	Continuation of Workshop Sessions (statement of accomplishments, current and anticipated problems, and recommendations for action)	
	Reception	
	Banquet	
	Address: "Science, Technology, and the Human Factor"	Eric Hoffer, Philosopher and Author

Wednesday, April 4	Plenary Session	Session Chairman: Harvey Brooks, Professor, Harvard University
	Address: "Science, Technology, and Economic Growth"	Edwin Mansfield, Professor, Economics, University of Pennsylvania
	Address: "Technology and Global Economic Development"	Sumitro Djojohadikusumo, Professor, University of Indonesia
	Address: "Science, Technology, and Social Achievements"	Philip Handler, President, National Academy of Sciences
	Speakers' Press Conference	

tronics and missile operations and was cofounder of Ramo-Wooldridge Corp., which later merged with Thompson Products to become TRW, Inc.

The third morning speaker will be international science policy expert Jean-Jacques Salomon, who will discuss "Public Reactions to Science and Technology." Salomon writes that he will trace changing public attitudes "from the time of innovators such as Edison who were accorded a status and adulation that made them resemble mythical heroes" to today's era of "incorporated, capital-intensive research and world-scale diffusion of innovations [resulting in a] disenchantment with, if not suspicion of, technology."

Salomon is head of the Science Policy Division of the Organization for Economic Cooperation and Development in Paris. He is also professor of technology and society at the Conservatoire National des Arts et Métiers and has been a visiting professor at such universities as Harvard and MIT.

A general session is planned for the second afternoon on the topic "Resolution of Science and Technology Controversies." Chairing the session will be Arthur Kantrowitz, retired chairman of the board, Avco Everett Research Laboratory, Inc. Kantrowitz is well known for his research in physical gas dynamics, particularly for his pioneering application of the shock tube to high-temperature gas problems. He founded Avco in 1955, and under his leadership the organization contributed to solving the problem of ballistic missile reentry. Before his association with Avco, Kantrowitz was professor of aeronautical engineering and engineering physics at Cornell University.

Science, technology, and the human factor

Following the evening banquet for symposium attendees, philosopher and writer Eric Hoffer will deliver an address on "Science, Technology, and the Human Factor." Hoffer is a former migratory field laborer, gold miner, and longshoreman. He writes of his early life, "I had no schooling. I was practically blind up to the age of 15. When my eyesight came back I was seized with an enormous hunger for the printed word. I read indiscriminately everything within reach—English and German."

Hoffer is the author of *The True Believer, The Passionate State of Mind, The Temper of Our Time,* and *Reflections on the Human Condition.* A keen observer of human nature and a writer closely in touch with the people, Hoffer is well suited to discuss how science and technology relate to basic human needs.

On the third and final morning of the symposium, the program will focus on the relationship between science, technology, and economic growth and development. Speaking on this subject from the standpoint of the industrial countries will be economist Edwin Mansfield. His address will cover the role of technological change in economic growth; the role of basic research in increasing productivity; the shifting composition of industrial R&D in the United States; and recent rates of productivity change in the United States. Mansfield is professor of economics at the University of Pennsylvania. He has taught at Carnegie-Mellon, Yale, Harvard, and the California Institute of Technology, and has been consultant to the National Science Foundation, the Congressional Office of Technology Assessment, The Rand Corp., and other public agencies and industrial firms.

Sumitro Djojohadikusumo, professor of economics at the University of Indonesia, will speak from the perspective of the developing countries on "Technology and Global Economic Development." Sumitro recently served as Indonesia's minister of state for research and has also held positions as minister of trade and minister of finance.

The final speaker of the symposium will be Philip Handler, president of the National Academy of Sciences. Handler's topic, "Science, Technology, and Social Achievements," will bring together the various discussions of the symposium into a summary and conclusion. He is the former chairman of the Department of Biochemistry at the Duke University School of Medicine.

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For registration information about the Edison Centennial Symposium, use the business reply card in this issue or contact the conference managers:

Government Institutes, Inc.
4733 Bethesda Avenue, N.W.
Washington, D.C. 20014
(301) 656-1090 ■

SPECIAL SYMPOSIUM EVENTS

Student participation and exhibits highlighting the history of electricity are among the special events planned to enhance the symposium.

Students

Up to 100 students from colleges around the country will attend the symposium and participate in the discussions. EPRI and TAEF have chosen the Forum for the Advancement of Students in Science and Technology (FASST) to coordinate the student role and to design the selection process. FASST is a national student organization working for active student participation in the discussion of science and technology issues.

"We are looking forward to this opportunity to coordinate student involvement in one of the major science gatherings of 1979," FASST President Alan Ladwig stated. "We commend the foresight of EPRI and TAEF in devoting special attention to the student sector, and we look forward to beneficial interchanges between students and professionals during the symposium."

Ladwig explained that FASST will work with its established network of universities and colleges across the country to select student delegates. The organization will ask deans of academic institutions to identify appropriate students. If several applicants are tied, a committee at the FASST national office will make the final decision. Criteria for selection will include leadership ability, academic standing, communication skills, and involvement in extracurricular activities. Ladwig stressed that a broad cross section of geographic areas, age, and academic disciplines will be represented among the student delegates.

FASST is seeking sponsors from within the electric utility industry to assist the selected students with symposium expenses, such as travel, lodging, and meals. A utility would sponsor a student from within its service area. Edison Electric Institute (EEI) is encouraging its members to act as sponsors and is supporting FASST's overall coordinating efforts with a direct program grant.

In return for sponsorship by a utility, the student delegate will be required to make at least one presentation to report impressions and experiences at the conference, Ladwig explained. The report could be given at a special meeting with utility representatives or as a speech before a local civic organization.

Utilities interested in sponsoring a student and anyone wishing more information about the selection process may contact FASST, 2030 M Street, N.W., Suite 402, Washington, D.C. 20036, (202) 466-3860.

Exhibits

Construction began last month on the traveling Edison Exhibit that the Smithsonian Institution is developing for the Centennial of Light. The exhibit will tour the country during 1979, with planned stops in Houston, January 3–8, for the annual meeting of the American Association for the Advancement of Science and in San Francisco for the Edison Centennial Symposium.

Dr. Bernard Finn, curator of electricity and modern physics for the Smithsonian, explains that the exhibit will depict the growth of electric power systems, beginning with Edison's light bulb and the Pearl Street Station and moving forward to increasingly larger and more complex systems, such as Niagara Falls and the Tennessee Valley Authority. One unit of the exhibit will focus on customer demand. Artifacts, such as light bulbs used by Edison in his experiments and early consumer appliances, will also be on display.

Pacific Gas and Electric Co. (PG&E) will also exhibit memorabilia dating from the early days of electricity. PG&E will be observing 1979 as the centennial of the first central generating station for lighting (arc lighting) in the country. One of the San Francisco utility's predecessors, the California Electric Light Company, opened this station in 1879 to serve 10 customers. It was located on 4th Street near Market in San Francisco. PG&E's exhibit at the symposium will include equipment representative of this period.

At the Institute

Board Approves Gasification–Combined-Cycle Plant

The EPRI Board of Directors recently authorized EPRI's share of a $28 million effort to prepare a detailed design of the first large gasification–combined-cycle power plant.

EPRI, Southern California Edison Co. (SCE), and Texaco, Inc., are equally sharing the cost of designing the 100-MW demonstration plant, which will be located at SCE's Cool Water Station near Barstow, California.

In the plant, coal will be gasified and the resultant fuel gas burned to turn a gas turbine; the exhaust heat from the gas turbine will then be used to make steam to turn a steam turbine. According to EPRI, combined-cycle plants have the potential to provide electricity at competitive prices and to meet tight environmental standards more easily than other coal-fired power plants.

EPRI reports that the plant, which will consume about 1000 tons of coal a day, will be operational by 1983.

Another major funding authorization made November 3 by the EPRI Board at its quarterly meeting in Palo Alto, California, continues the development of large sodium-sulfur batteries for use by utilities in meeting peak power demands.

During the three-year, $10 million engineering development stage beginning in July 1979, researchers will fabricate and test seven 100-kW battery modules to determine their technical and manufacturing feasibility and their market potential.

A research and development program plan was approved for 1979 that totals $202 million, about $9 million more than the 1978 program plan. The directors also made eight appointments to the Research Advisory Committee, a group of utility executives that advises the EPRI Board, president, and staff on research and development policy and program planning.

The appointees are Shepard Bartnoff, president, Jersey Central Power & Light Co.; Robert A. Bell, assistant vice president, research and development, Consolidated Edison Co. of New York, Inc.; Joan T. Bok, vice president, New England Electric System; Nolan H. Daines, vice president, planning and research, Pacific Gas and Electric Co.; Samuel R. Hart, Jr., vice president, research and development, Southern Company Services, Inc.; John T. Kauffman, executive vice president, operations, Pennsylvania Power & Light Co.; J. James Roosen, general director, engineering research department, The Detroit Edison Co.; and L. S. Turner, Jr., executive vice president, Texas Utilities Co.

Social Impacts of Power Plant Construction

With the support of EPRI, a study has been started by the Denver Research Institute, University of Denver, to examine the impact of power plant construction on communities.

Researchers will investigate some of the events stemming from the arrival of large numbers of construction workers in communities that are planning power plant facilities. These events could include an increased demand for housing, hospitals, schools, and other social services.

Ronald Wyzga, EPRI project manager for the two-year study, says the initial research will primarily assess the value of current methods now used to predict community impact from power plant construction.

"Claims, both good and bad, are often made about the impact on a community from power plant construction with relatively little basis in fact," states Wyzga, a member of EPRI's Environmental Assessment Department.

Control for Galloping Lines

A small, pendulumlike device that hangs from transmission lines helps to reduce power outages during cold, rainy weather by preventing the violent up-and-down motion characteristic of iced transmission lines. On cold, stormy days, ice can collect on transmission lines and form airfoils that begin to oscillate in the wind. This oscillation can lead to what engineers call violent galloping, which may break lines or cause towers to fall.

The device, which was developed by Ontario Hydro, Canada, is about 8 inches long and 4 inches in diameter. It also offers the prospect of reduced transmission line costs through more compact tower design. According to EPRI Transmission Department Director Robert Perry, this means towers may no longer have to be as strong or as large as presently designed.

EPRI has been testing 2500 of the devices on 1250 spans of transmission lines throughout the United States. Data from field tests last winter indicate the devices are efficient and economical. They can be used on all sizes of transmission lines and only two devices are required between towers. They are expected to be commercially available by late 1979.

"Various so-called antigalloping devices have been available for many years," Perry says. "However, the utility industry has found them unacceptable, mainly because they have been too large, heavy, and expensive. The new devices, unlike the older ones, rely on design rather than weight to keep transmission lines under control."

Energy Technology Exchange

The nation's largest annual energy technology meeting will again be sponsored by EPRI in conjunction with the American Gas Association, the Gas Research Institute, the National Coal Association, and the Thomas Alva Edison Foundation.

The Sixth Energy Technology Conference and Exposition, also designated as an official event of the Edison Centennial of Light, is scheduled February 26–28, 1979, at the Sheraton Park Hotel in Washington, D.C., with an expected attendance of more than 6000 international energy leaders.

Richard L. Rudman, director of the EPRI Planning Staff and a member of the ET6 Program Advisory Committee, is coordinating EPRI's participation in the comprehensive 50-session program.

Keynote speaker will be Charles A. Anderson, president of SRI International, who will give the second annual "State of Energy" message. Anderson will review the progress and setbacks experienced since Sherwood Fawcett, president of Battelle Memorial Institute, presented the first "State of Energy" last year. At future conferences, each succeeding year's message will add to the previous years' messages, thus building a data base that measures progress in the world's efforts to provide a secure energy future.

John C. Sawhill, president of New York University, former federal energy administrator, and current energy authority for the Trilateral Commission, will present the luncheon address on Tuesday, February 27. Sawhill, who was the luncheon speaker for the first Energy Technology Conference in 1974, will examine the changes during the past five years in the international energy situation and in the annual conference itself. He is the principal author of "Energy—Managing the Transition," a recent Trilateral Commission study that disagrees with forecasts of an impending energy crisis brought on by oil shortages.

As part of the international celebration of the 100th anniversary of Thomas Edison's successful incandescent light bulb, James G. Cook, president of the Thomas Alva Edison Foundation, will present a special public session on Monday, February 26, focusing on Edison's many inventions and their effects on modern society. A commemorative Edison exhibit prepared by the Smithsonian Institution also will be on display.

Technical sessions during the three-day forum will discuss advances in cogeneration, conversion to and direct use of coal, nuclear technology, industrial energy use and conservation, photovoltaics, magnetohydrodynamics, environmental control technologies, conservation in large buildings, and many more topics of interest to the utility industry.

Concurrent with the conference will be 300 exhibits of the latest energy hardware and services covering a wide range of sources and technologies, among which will be an exhibit of EPRI's activities.

The complete conference program and registration information are available from the conference managers: Government Institutes, Inc., 4733 Bethesda Ave., N.W., Washington, D.C. 20014, (301) 656-1090.

Data From Solar Houses

A three-to-five-year EPRI research project involving the close monitoring of 10 experimental solar houses—five in Wading River, Long Island, and five in Albuquerque, New Mexico—officially entered its operational phase in late October.

As part of the $2 million research experiment, dozens of solar systems will be tested in combination with one another and with conventional backup equipment, such as heat pumps. Researchers will examine the differences in climate and architecture of the experimental homes to learn which combinations of solar heating and cooling equipment and electric backup systems work best together. A special effort will be made to determine what types of solar systems fit most efficiently into electric utility demand patterns.

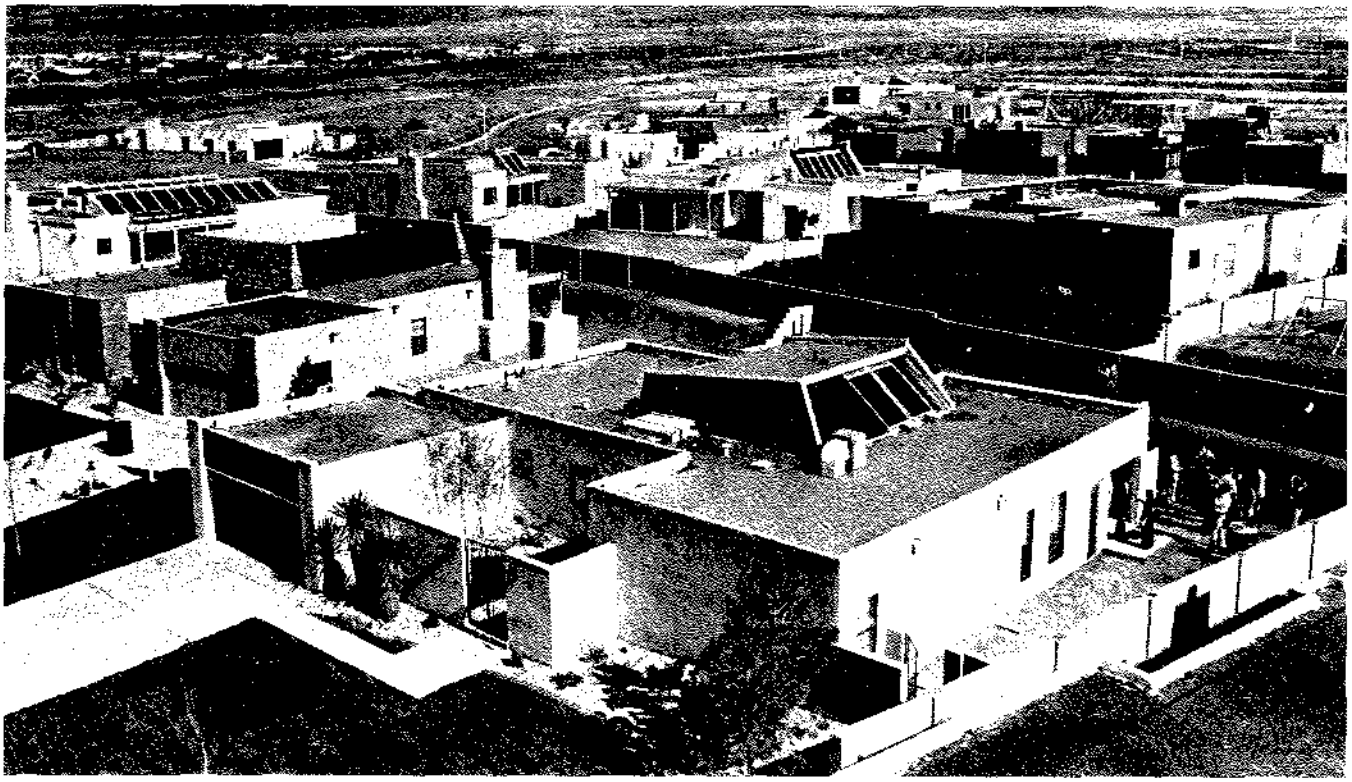
The houses vary in size and style, but their appearance is not very different from other new houses in the $75,000 to $95,000 price range. In both Albuquerque and Wading River, the architecture is typical of the area where the houses are located. Families, not researchers, will occupy the houses.

Each house is equipped with its own computerized monitoring and data-gathering system, which records fluid temperatures and flow rates throughout the heating and cooling systems, equipment performance, and energy use. The monitoring systems have been designed so that researchers can simulate the operation of many different solar systems and gather a wide variety of data, including daily sunshine levels at each site.

Although the number of solar houses in the United States is small today, it is clear that more and more new houses will be built with solar heating and cooling equipment.

Solar energy and storage systems could help stabilize utility costs and electric bills. If a solar house could store heat from the sun or from the lower-cost electricity generated during off-peak hours, such as late at night, it could use that

Solar houses in Albuquerque, New Mexico.



Solar house in Wading River, New York.

Computerized monitoring equipment in solar house.

energy on cloudy days. This would benefit the local utility because it would be able to run its existing generation equipment more hours and thus make better use of its power facilities. In addition, the storage of energy that is part of a solar system could help to level costly peaks in electricity demand patterns.

The chief contractor for the project is the Cambridge, Massachusetts, firm of Arthur D. Little, Inc. The Long Island Lighting Company and the Public Service Company of New Mexico are also providing support.

This project is one of several EPRI efforts to identify the best ways, in terms of cost and efficiency, to combine solar energy with today's electric systems.

Productivity Workshops Go on Tour

Workshops on availability engineering and power plant productivity improvement will be held in five cities around the country in early 1979. Sponsored and funded by EPRI and DOE and cosponsored by EEI and NERC, each workshop will be hosted by the utility or utilities in the region involved. Utility supervisory and middle management personnel in power generation and power plant design engineering are invited, particularly those involved in power plant improvement programs. There will be no registration fee. Each workshop will start on a Tuesday morning and end on Friday at noon.

The regional seminars sponsored by EPRI, DOE, EEI, and NERC in June 1978 accented the growing interest in the application of reliability technology to power plant productivity improvement. In response to this interest, the workshops will familiarize utility supervisory personnel and utility contractors with specific power plant applications of reliability technology; demonstrate important concepts and methodologies through their application to real-world productivity improvement problems; and provide information and guidelines on the organizational approaches and manpower requirements for implementing availability engineering and productivity improvement.

The workshop agenda will include presentations, problem-solving sessions, and discussion sessions. The general approach will be to illustrate reliability principles through specific applications. Wherever possible, the applications will be case histories of plant productivity improvement. While specific examples of plant problems will be used, each will emphasize a different aspect, highlighting such important reliability concepts as cost-benefit analysis, decision analysis, failure analysis, and system configuration studies.

The focus of the workshops will be to consider actual availability engineering and productivity improvement problems associated with the design and operation of power plants. Such problems will include trade-offs between replacement of existing equipment and its continued operation with high maintenance and loss of efficiency; the use of reliability methods to assist in making procurement decisions; reliability analysis of system designs; spare parts planning; capacity and configuration decisions on plant subsystems; outage planning and maintenance management; and reliability trade-offs.

In addition to the scheduled presentations, the workshop facilitators will be available throughout the problem-solving and discussion sessions to assist in the applications of the methods to specific problems typical of power plant design and operation phases.

Invitations are being issued by EPRI, and for practical considerations, attendance is being limited. For additional information, contact Joseph Prestele at EPRI, (415) 855-2020.

Location	Date	Host
Los Angeles	January 9–12	Southern California Edison Co. San Diego Gas & Electric Co.
Dallas	February 13–16	Texas Utilities Co. (Dallas Power & Light Co., Texas Electric Service Co., Texas Power & Light Co.) Arizona Public Service Co.
Atlanta	February 20–23	Georgia Power Co. Tennessee Valley Authority
Chicago	March 13–16	Commonwealth Edison Co. American Electric Power Co.
New York	March 27–30	Consolidated Edison Co. of New York, Inc. General Public Utilities Corp.

Successful Burn of Synthetic Liquids

Preliminary results of the nation's first large-scale combustion demonstration with a synthetic liquid made from coal indicate that performance and emissions characteristics are generally comparable to the low-sulfur oil normally burned in electric utility boilers.

In late October EPRI reported that some 4500 barrels of low-ash, low-sulfur fuel, called solvent-refined coal distillate (SRC-II), were burned at the Consolidated Edison's 74th Street generating station in Manhattan. The burn, conducted in September, was part of an engineering and emissions assessment of SRC-II sponsored by EPRI and Consolidated Edison in cooperation with DOE.

According to EPRI Project Manager William Rovesti, this program is helping to direct the research and development efforts of government and industry to reduce the nation's dependence on imported oil by identifying alternative fuels.

Early demonstration data indicate that the level of nitrogen oxide emissions measured during the combustion of SRC-II would readily meet the standard for coal-derived liquid fuels recently proposed by EPA. In addition, boiler efficiencies recorded in burning SRC-II were comparable to those obtained with regular fuel oil.

Further data assessment studies are being conducted by KVB, Inc., of Tustin, California, an independent engineering organization under contract to EPRI. KVB is preparing a report that will analyze results of the test program.

The SRC-II process is a direct coal liquefaction process in which a coal-derived solvent and hydrogen react with coal to transform it into a solids-containing liquid product, which is then distilled and condensed into a liquid fuel.

The process, developed by Gulf Mineral Resources Co. under sponsorship of DOE, is owned by the federal government. The fuel for the test program was supplied by DOE and was produced at Gulf's coal liquefaction pilot plant in Tacoma, Washington.

The U.S. government recently contracted with Gulf to design an SRC-II demonstration plant, which will be built in West Virginia. The facility is expected to produce 20,000 barrels a day of synthetic fuel from 6000 tons of coal.

Schurr Returns to EPRI

Sam Schurr, a former EPRI division director, will rejoin the Institute in early 1979 as deputy director of the newly formed Energy Study Center. Since leaving EPRI, Schurr has been affiliated with Resources for the Future (RFF), a research organization in Washington, D.C., as a senior fellow and codirector of the Center for Energy Policy Research.

Schurr was originally employed by EPRI in January 1974 as director of the technical division now known as the Energy Analysis and Environment Division. Before that, he had served for 20 years as the director of the Energy and Mineral Resources Program at RFF. He left EPRI in January 1976 to return to RFF.

Schurr has also held senior positions with the Rand Corp., the Department of the Interior, and the Department of Labor. An economist by training, he is the author of several books and technical papers on energy and economic issues. This year he was elected president of the International Association of Energy Economists.

The Energy Study Center will focus on technical and nontechnical national issues that are important in utility technology decisions, such as the relationship between economic growth and energy use. The center will be part of the President's Office and will be directed by Vice Chairman Chauncey Starr. Studies will be conducted in-house, by subcontract, and by consultants working with EPRI staff members.

French Nucleus Arrives

Professor Jean Teillac (left), who heads France's atomic energy commission, meets members of EPRI's staff while visiting the Institute to discuss fusion and nuclear reactor safety programs. Teillac was accompanied by Pierre Tanguy, director of the Institute for Nuclear Safety and Protection; Michel Trocheris, director of the French Thermonuclear Controlled Fusion Project; Jean Bussac, staff director for Professor Teillac; and Pierre Zaleski, atomic energy attache, French embassy, Washington, D.C.

Washington Report

What steps can the federal government take to stimulate innovation in private industry? President Carter wants to find out.

INDUSTRIAL INNOVATION: NEW LEASE ON LIFE?

As one of its strategies for fighting inflation and stabilizing the shaky U.S. dollar, the Carter administration is seeking ways to breathe new life into what some perceive as a faltering process—innovation in private industry.

The search vehicle is a domestic policy review—the highest level of federal studies—requested by President Carter last summer and due for completion in April 1979. Release of the final report will come appropriately at a time when industry itself will be focusing on the concepts of invention and innovation as part of the international Centennial of Light celebration (see article on page 29). Of further interest to those associated with EPRI, it appears that the study will recommend, among other actions, the establishment of several centers or institutions similar to EPRI for pursuing R&D on an industry-specific or technology-specific basis.

The study involves 30 federal agencies, nearly 100 government officials, and several advisory groups made up of industry, labor, academic, and public interest representatives. The Assistant Secretary of Commerce for Science and Technology, Jordan Baruch, is chief architect and day-to-day coordinator of the review.

Antidote to economic ills

Baruch explains that the study evolved not so much from a negative assessment of the status of innovation in industry as from a positive recognition of the role innovation could play in bolstering the troubled U.S. economy.

"There was a general feeling that our innovation rate was slowing," he admits, "but because of measurement difficulties, that general feeling was very hard to substantiate." Conversely, no one had trouble identifying economic problems that could benefit from innovation.

"We know that industrial innovation can affect inflation by making it cheaper to provide the goods and services society needs," Baruch continues. "We know that it can affect unemployment, since new industries generate, by and large, a greater growth rate of employment than old industries. And we know that it can affect our foreign competitiveness either by making our products more acceptable in foreign countries or by reducing their prices." It seemed reasonable to focus on innovation as an antidote to economic ills.

Actually, the push for the study came from President Carter, who, on examining the 1976 science indicators published by the National Science Foundation a year ago, grew concerned about a decline in R&D and a shift from long-term to short-term development.

"He asked for a study of what we could do to improve R&D," Baruch recalls. Yet Commerce Department officials emphasize that the issue extends beyond R&D, embracing all elements of the innovation process. The president "agreed wholeheartedly" and the study took on its present bent. Its end product will be a set of recommendations to the president on how federal policies can be used to encourage industrial innovation.

Social utility as the key

Within the context of the study, innovation is defined as an entire process—beginning with an idea; progressing through research, development, and demonstration; and ending with commercialization and diffusion of a new product or process throughout society. *Use* is a key concept. "Until society uses an innovation, there's no social benefit," Baruch notes. He draws the distinction between innovation and invention along these lines. "The Patent Office holds several patents on hat-tipping machines, for example. Now those may be very clever inventions, but they don't represent innovation."

The study is built on the premise that innovation occurs at the level of an individual firm and that actions and policies of the federal government have a significant effect on the firm's decision and ability to innovate. The government can influence these decisions through tax policies, regulations, patent policy, support of R&D, and so on. These influences are reflected in the five main policy areas under scrutiny in the study: economic and trade policy; environmental, health, and safety regulations; federal procurement and direct support for R&D; patent and information policy; and regulation of industry structure and competition. Interagency task forces are focusing on each of these policy areas and input is coming from the outside advisory groups.

The study is proceeding in two phases. Now in progress is the public information gathering phase, where the industry and other public advisory committees feed position papers on these options to the intergovernmental task forces. A set of seminars is planned for January to bring together the advisors and government task force officials to discuss the recommendations of the advisory groups. After January the operation closes its doors and the government task forces develop their final recommendations to the president.

What kind of recommendations are expected? First of all, rather than being broad macroeconomic policy suggestions, they will be specific and targeted toward various types of industries. "For example, we have talked about encouraging the formation of new innovative businesses," Baruch says, "so we will be looking at tax policies that relate specifically to small businesses rather than business in general. And we will be reviewing Securities and Exchange Commission regulations that affect small businesses. We will be trying to find ways to reduce the barriers to formation of small businesses, increase the payoff to them, and increase the flow of information and protection."

One specific area Baruch mentions that will involve innovation in large industries (such as the electric power industry) is resource conservation. "We are asking how the federal government can stimulate resource-conserving innovations," he says. "This may be in terms of the generation of electric power or resource recovery from metropolitan wastes."

Illustrative of the type of specific recommendations expected are the following examples, listed in the study's work plan:

- Selective reductions of the capital gains tax to promote the establishment and growth of new, high-technology enterprises
- Provision of regulatory risk insurance
- Introduction of a new patent reexamination system
- Policy guidelines on international flows of information, especially those that affect foreign trade

Centers of innovation

One recommendation Baruch expects concerns the increased collaboration between industry and government in a new type of institutional setting dedicated to innovation. He calls such institutions *centers,* and describes them as cooperative ventures between government and industry, where industry provides the support and identifies the research agenda and the federal government, when appropriate, provides support for individual projects.

Such a center sounds very similar to EPRI in concept. Baruch readily agrees: "EPRI is very much an example of such a center. That's not incidental, since we've watched EPRI grow." He qualifies the comparison, however, by noting that EPRI's mission is on a much larger scale than that envisioned for these cooperative centers. "And quite appropriately so," he adds, "because of the scale of the things you have to do."

As an example of such a center now in the offing, Baruch describes the organization his staff is helping to establish for the shoe industry. The center may be attached to a university, although this has not yet been determined. Among the services it will provide for the industry are the development of basic technology, consulting services to help individual firms adopt new technologies, programs to help management and labor deal with new technology, and—especially—liaison with government laboratories that may be doing work in areas that affect the industry.

Baruch says that his staff is currently considering the establishment of about a dozen such centers, some of which may cut across industry lines, embracing whole technologies. "For example, we visualize a joining center that looks at welding, cementing, and fastening—basically processes for putting two things together."

Baruch concedes that the recommendations represent considerable departure from conventional industry practice and may be met with skepticism and opposition at the outset. "When we started working with the shoe industry, the reaction was unbelievably hostile," he recalls. "After they learned more about us, the hostility changed to apathy and then the apathy changed to enthusiasm. Right now we've got an enthusiastic bunch of people out there who are pushing us."

He feels that other industries may respond with equal enthusiasm and come to believe, he says with a smile, that "within a certain area of constraint, it may be possible to trust—even to work with—the federal government." Both sides have to give, he feels, with the federal area constrained to building industry trust and with industry beginning to think more of itself as an agent of major social change. "We feel there is a real possibility for collaborative effort here," Baruch states.

Asked if this may be a major recommendation of the study, he indicates that it will be only one of many. "I hope there will be many, many more creative ideas than this," he says.

R&D Status Report
FOSSIL FUEL AND ADVANCED SYSTEMS DIVISION

Richard E. Balzhiser, Director

DRY COOLING IN POWER PLANTS

The availability of water for use in power plants is becoming one of the major social and political issues constraining plant siting in many parts of the country. The largest consumptive water use (hence the greatest potential for water conservation) is in condenser cooling, which is normally accomplished with evaporative cooling towers. EPRI is preparing to demonstrate an advanced dry-cooling system, based on evaporating and condensing ammonia in the condenser-tower transport loop, which is expected to reduce the cost of dry cooling to one-half that of present systems.

The need for dry cooling

Future increases in electric generation capacity and the associate reject heat load must be accommodated in a publicly acceptable manner, which means minimal depletion of water where it is scarce, conservation of fuel resources, and minimal adverse impact on jobs and lifestyle, on environment, and on power plant costs. While water scarcity is not a problem throughout the United States in the foreseeable future, local shortages do occur in many parts of the nation, such as in the West and Southwest where high generation growth rates are projected (Figure 1). Power plant cooling is the major consumptive requirement for water at both fossil and nuclear plants, and it is likely that societal pressure and legislative action will restrict utilities from using fresh water for evaporative cooling in water-short regions.

The use of dry cooling instead of evaporative cooling would save over 0.4 m^3/s (7000 gal/min; ~8000 acre-ft/yr) for a 1000-MW (e) plant and would be a major factor in increased siting flexibility. However, dry cooling will never be economically preferable to wet cooling if water is available. For example, although all cost and performance figures for cooling systems are site-specific, the general conclusion is that power from plants using evaporative towers and cooling ponds costs about 3–6% more than power from plants using once-through cooling. With presently available technology, power from plants that use only dry-cooling systems would cost 10–15% more than power from plants with wet-cooling towers and 15–20% more than power from plants with once-through cooling units.

Basis for research on dry cooling

Earlier reports (*EPRI Journal*, December 1977, p. 41) presented the results of EPRI and ERDA research, which identified the use of ammonia and of augmented heat transfer surfaces as the best possibility for significant cost reductions in dry- and dry–wet-cooling systems. These savings result from the reduction in power used for pumping in the transport loop, elimination of the temperature range in the condenser cooling water, reduction of the terminal temperature difference in the condenser, the use of low-cost techniques in fabricating the cooling tower, and the elimination of devices needed for freeze protection.

Figure 1 Projections of water availability and use indicate potentially serious water shortages in the shaded regions by the year 1990. Coupled with projected requirements for electric power generation in these regions, these estimates indicate the probable need for dry or dry-wet cooling on 14–26 GW (e) of new capacity by the year 2000.

Research activities have demonstrated that ammonia dry and dry-wet systems are feasible concepts. Pilot studies at Union Carbide Corp., Linde Division, show that the performance of the enhanced heat transfer surfaces in the steam condenser–ammonia reboiler, as well as overall system behavior, is essentially as expected. Although new to the utility industry, much of the technology of handling ammonia is understood and widely used in the chemical process industry.

The performance of a plate-fin heat exchanger operated in the deluge mode (flooding the heat exchanger surface with water) has been studied extensively at Battelle, Pacific Northwest Laboratories. A determination of the range of acceptable water quality for this mode of operation is also under way at Battelle-Northwest. Results to date support the feasibility of this mode of coupling an ammonia dry-cooling system to evaporative cooling for augmented performance.

Economic studies have shown that use of ammonia as an intermediate heat transfer medium may markedly reduce the cost of dry cooling in power plants. Other cost evaluations have indicated that wet augmentation of a dry system is the most likely initial application of dry cooling.

A conservative estimate shows total cost savings of \$100/kW (e) from using available dry-cooling technology. This represents a total potential savings to the industry of from \$2 billion to \$5 billion by the year 2000. On the basis of these studies, the decision has been made to proceed with a demonstration of the technology at the 6-MW (e) level at a utility plant (RP422).

Project at Kern plant

An ammonia, phase-change cooling system at Pacific Gas and Electric Co.'s Kern plant will demonstrate the best available technologies for both dry and dry-wet operation on a 6-MW (e) house turbine used for on-site power generation. The system (Figure 2) will condense up to 7.5 kg/s (60,000 lb/h) of steam from this turbine, which is an integral part of the power plant.

The demonstration will provide validation of performance predictions from pilot-scale tests, assurance of safe, reliable operation over a period of a few years, and evidence of operability and maintainability by utility operators.

The process flow is outlined in Figure 3. Exhaust steam from the last stage of the turbine is condensed in the condenser-reboiler. Liquid ammonia is boiled as it is pumped through the tubes. The flow rate is set so that most of the liquid is vaporized. This two-phase mixture is passed through a vapor-liquid separator, from which the vapor is sent to the air-cooled heat exchanger where it is condensed, and the liquid is combined with the ammonia condensate from the dry tower and recycled through the condenser-reboiler.

The project will be a joint effort by EPRI and DOE. EPRI will take major cost and management responsibility for the design, procurement, and construction phases, while DOE will assume similar responsibility for the testing and operations phase.

The objectives of this advanced dry-cooling tower project are to demonstrate the design, fabrication, construction, and maintenance of an advanced dry-cooling system that incorporates evaporating and condensing ammonia in the condenser-tower transport loop; high-performance heat transfer surfaces in the steam condenser–ammonia reboiler; and low-cost cooling-tower heat transfer surfaces and fabrication methods suitable for both all-dry and dry-wet operation.

The major technological issues that will be emphasized in the large-scale test are:

- Effect of environment on components.

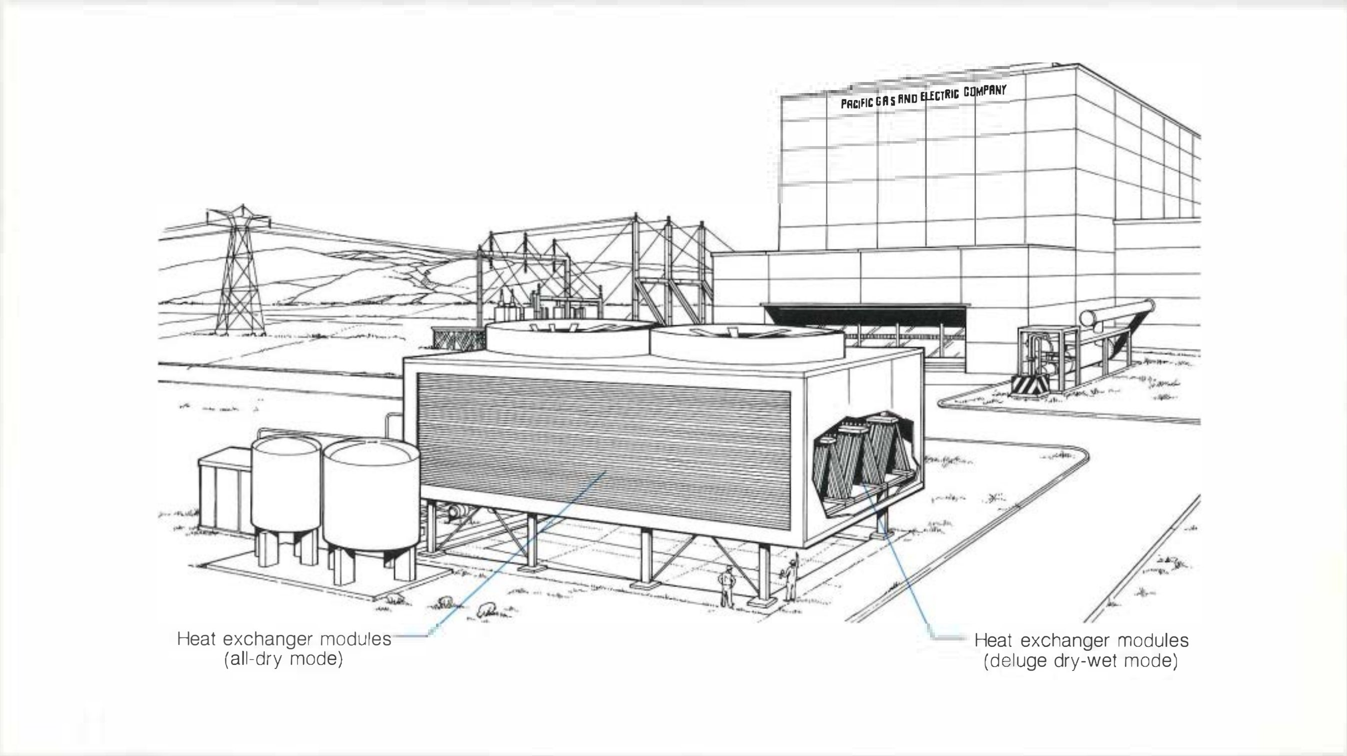
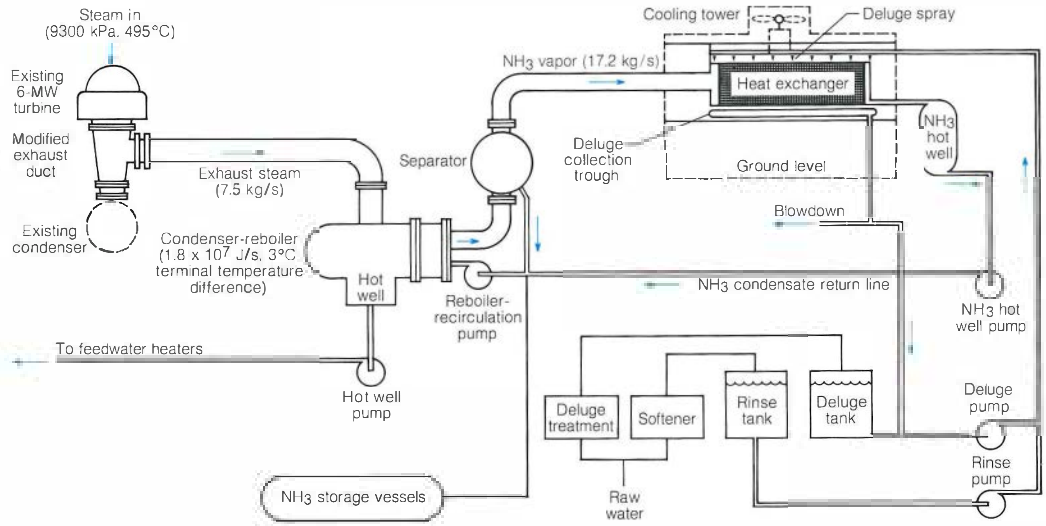


Figure 2 At the proposed demonstration facility to be installed on an existing 6-MW (e) turbine at PG&E's Kern plant, heat exchanger modules on the side of the cooling tower operate in the all-dry mode. Those visible in the cutaway at the end of the tower will demonstrate the deluge dry-wet option.

Figure 3 Process flow for the proposed dry-cooling demonstration system.



The economics of the system are closely tied to the performance of the condenser-reboiler and the dry tower. Extensive fouling of surfaces in either component would be detrimental. Operating experience is the only means of determining the extent of fouling, which must be allowed for in the design. With respect to deluge cooling, the extrapolation from accelerated laboratory studies of water chemistry to long-term performance under actual on-site conditions is uncertain.

▫ Component reliability. Aluminum tubing in the condenser-reboiler is believed to be the material of choice so long as no leaks occur. Since aluminum cannot withstand ammonia in the presence of water, the integrity of tube-to-header joints will be critical. Similarly, the dry-tower surface must be fabricated with a higher degree of reliability than is the case in a conventional water cooler.

▫ Process integration. The dynamic response of the system has not been studied in great detail. While it is not expected to differ significantly from a conventional dry-cooling system, this must be substantiated by tests on an actual turbine system.

▫ Environmental effects. The health and safety of workers and the public and other environmental aspects will be addressed in detail, which will help simplify licensing of commercial installations.

Extensive design studies and pilot facility work have paved the way for successfully addressing these problems on a pilot scale, and hence they are technically in control. It remains to be shown that a system based on full-size component modules and run under standard utility operating and maintenance procedures will be acceptable for scale-up to a commercial-size unit. Design alternatives are available if process changes are deemed necessary. *Program Manager: John Maulbetsch; Project Manager: John Bartz*

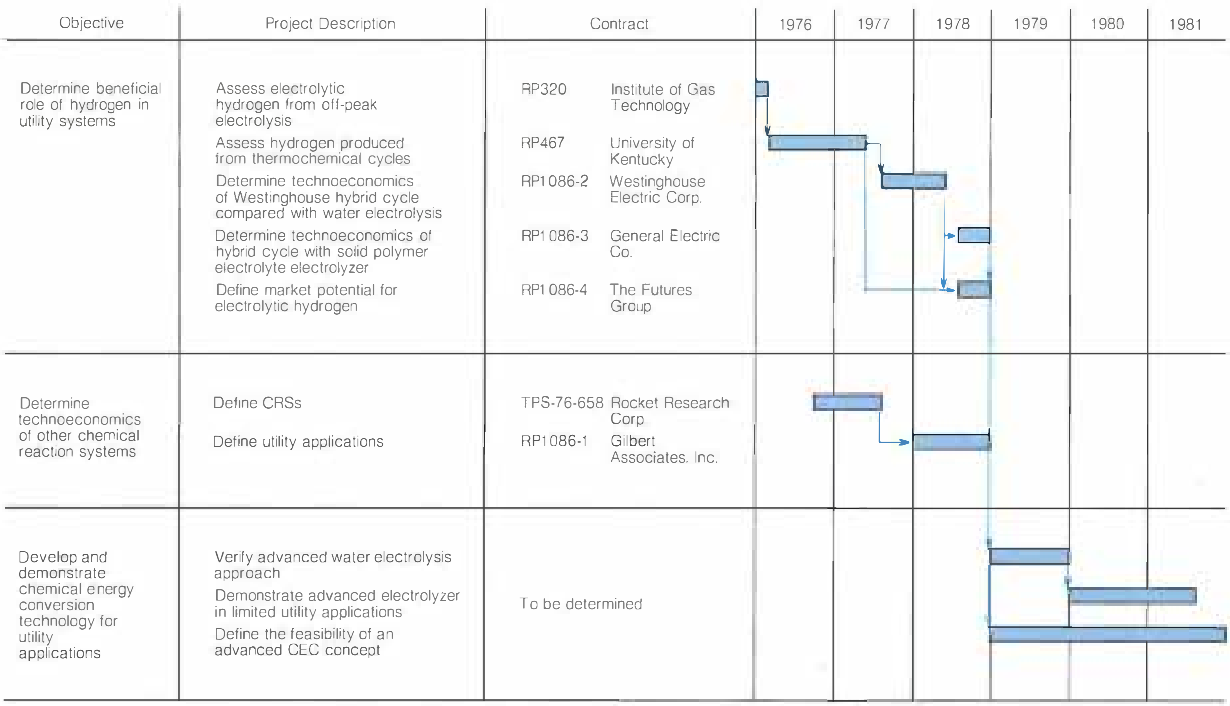
CHEMICAL ENERGY CONVERSION

As used in this report, the term chemical energy conversion (CEC) systems *denotes chemical systems that can be converted from a low-energy chemical state into a high-energy state by the application of heat or another energy form (e.g., electricity) and returned to the original state with release of energy. Because the energy-rich state in systems of practical interest is sufficiently stable to permit long-term storage and long-distance transport of energy, CEC systems have the basic potential to improve the efficiency, flexibility, and economics of energy supply and use in electric utilities.*

The objectives of EPRI's CEC subprogram are to determine whether any of the practical CEC systems that are under development or have been proposed can, in fact, play beneficial roles in future electric utility systems.

The most prominent example of a CEC system is the production of hydrogen from water. The hydrogen can be used as an energy carrier; it can be transported and/or stored and then reconverted to water with a simultaneous release of electric or thermal energy. Other candidates involve reversible chemical reaction systems (CRSs), such as the methane-steam reaction, the thermal decomposition of sulfur trioxide to sulfur dioxide, and the dehydrogenation of cyclohexane to benzene. These systems have the capability to "freeze" a variety of energy forms into a metastable chemical state. Chemical energy in such a state can be readily transported and stored at ambient temperatures. It can later be reconverted efficiently and cleanly into the end-use energy form. This unique capability makes

Figure 4 The objectives of EPRI's CEC subprogram.



CEC different from the more conventional concepts for storage and transportation of thermal energy, which are based on sensible heat or phase change and which suffer consequent energy losses.

A cautious approach

Because CEC concepts are relatively long-term and speculative, funding of EPRI's CEC subprogram is modest—less than $1 million over the five-year period 1977–1981. This level represents a minimum effort by EPRI to perform key assessments (Figure 4) and maintain utility involvement in the much larger, government-sponsored programs in CEC. The viability of CEC concepts will be largely determined by improving efficiency and reducing costs. Since hydrogen will likely emerge as an energy carrier and storage medium in the long term, in addition to being an important chemical ingredient of future energy sources, the CEC subprogram will focus on the intermediate-term hydrogen scenarios that will benefit the utility industry.

Hydrogen systems

In a project on assessment of energy storage systems with Public Service Electric and Gas Co., it was found that hydrogen can play an important role in load management when electrolytic hydrogen is produced with off-peak power (RP225). The combination electric-gas utilities could store off-peak hydrogen in dispersed locations close to the load centers and use it to supplement gas or to generate electricity at peak gas or electric demands, assuming that these peaks do not coincide. Such hydrogen could also be used in limited quantities for generator cooling within the utilities' own plants and for sale in hydrogen specialty markets.

The imaginative concept of hydrogen as a universal fuel and energy carrier has not come of age because of its cost. Hydrogen's emergence as a major fuel will depend essentially on the availability and cost of existing fossil fuels. Earlier introduction of hydrogen into utility operations will require a major technological breakthrough that makes it competitive with other fuels. Such nontechnical forces as the environmental "CO_2 greenhouse" issue, societal pressure, and government intervention are not likely to bring this about before the year 2000.

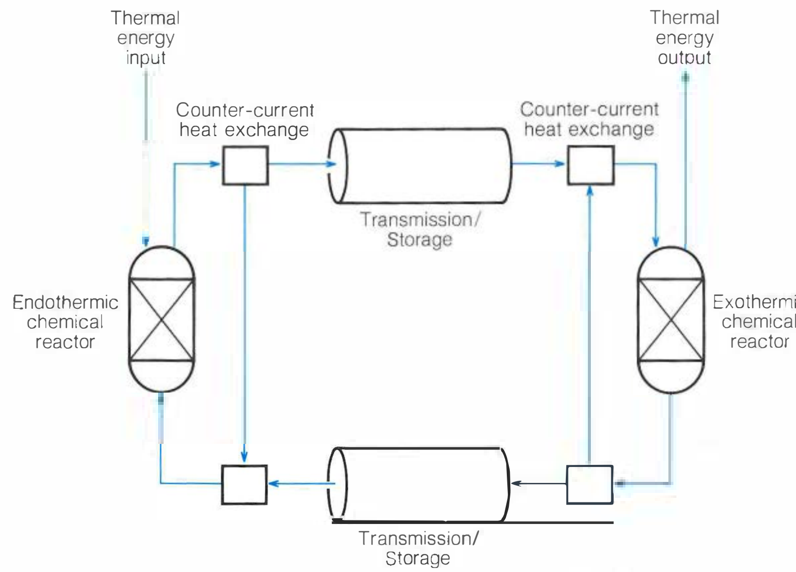
Three possible future sources of hydrogen now exist. Hydrogen from coal will be the near-term source of industrial hydrogen as petroleum liquids and natural gas become too expensive or unavailable for hydrogen production. A fuels assessment by Arthur D. Little, Inc., estimated that coal-derived hydrogen costs (1975 dollars) would be $\$5.50/10^6$ Btu for current gasification technology and $\$4.25/10^6$ Btu for advanced technologies, using $\$1/10^6$ Btu coal in both cases (RP318 and RP1042).

The next source of hydrogen would be electrolytic hydrogen at $\$7$–$\$12/10^6$ Btu (1975 dollars), using 15 mills/kWh power. Electrolytic hydrogen could emerge as an attractive alternative for specialty markets that are widely dispersed and adversely affected by gas curtailments and the rising cost of distributing merchant hydrogen. In a study on the utilization of off-peak power to produce industrial hydrogen, the Institute of Gas Technology suggested that such hydrogen would be expensive because the hydrogen plant could not be used at those times when off-peak power was unavailable (RP320-1). However, such hydrogen could, in certain scenarios, compete with the merchant hydrogen that currently sells at prices of \$20–\$100/10^6 Btu. The Futures Group is conducting a study to define the electrolytic hydrogen market potential and its growth through the year 2000 (RP1086-4).

The third group of processes for generating hydrogen depends on thermochemical decomposition of water and requires a source of high-temperature thermal energy. Hydrogen from pure thermochemical processes is likely to cost \$12–\$15/10^6 Btu (1975 dollars), using 50¢/10^6 Btu nuclear fuel. The technoeconomic analysis of the three thermochemical cycles (RP467) indicated that the cost of hydrogen produced in such plants could be improved by a hybrid electrochemical-thermochemical process. Westinghouse Electric Corp. has developed such a process—the hybrid sulfur cycle. Westinghouse compared the technoeconomics of hydrogen produced by the hybrid sulfur cycle with hydrogen produced by water electrolysis (RP1086-2). The results indicated there would be little incentive to develop the more esoteric hybrid cycle.

The key contribution to efficiency and cost improvement due to the integration of the electrochemical generation of hydrogen in the sulfur cycle can be enhanced by using advanced electrolyzers. General Electric Co. is conducting a project to determine if the incorporation of the advanced solid polymer electrolyte electrolyzer could change the comparative economics (RP1086-3).

Figure 5 This diagram describes the CRS applications, in which thermal energy is transported over long distances and stored for long periods at ambient temperatures without energy loss. The reversible chemical reactions are energized in the endothermic reactor at the source and release energy exothermally at the user site (for application to power generation; heating, ventilating, and air conditioning; or dual energy utilization systems).



$CH_4 + H_2O \rightarrow CO + 3H_2$ (1)

$SO_3 \rightarrow SO_2 + \frac{1}{2} O_2$ (2)

$C_6H_{12} \rightarrow C_6H_6 + 3H_2$ (3)

$CO + 3H_2 \rightarrow CH_4 + H_2O$ (4)

$SO_2 + \frac{1}{2} O_2 \rightarrow SO_3$ (5)

$C_6H_6 + 3H_2 \rightarrow C_6H_{12}$ (6)

Chemical reaction systems

There are many interesting reversible CRSs that might be beneficial to the utility industry. These systems characteristically involve:

- Charging the CRS to a metastable chemical state by using thermal energy
- Transporting and storing the charged CRS at ambient temperatures without energy loss
- Reversing the reaction to release frozen energy

The chemicals, after delivering thermal energy through an exothermal reaction, are returned to the charging site. Some CRSs being evaluated (RP1086-1) are shown schematically in Figure 5. For example, the endothermic Reaction 1 of methane with steam will freeze primary or reject thermal energy in the endothermic reactor and form carbon monoxide and hydrogen, which could be piped over long distances at ambient temperatures without energy loss. These gases could then be catalytically reacted in the exothermic reactor at the site of the thermal-energy user to produce heat, methane, and water, as in Reaction 4. The methane and water could be recycled back to the endothermic end for a closed-cycle operation.

The potential applications of CRSs for coupling thermal (primary or reject) sources with users in the utility sector and the industrial sector are numerous and technically feasible. However, RP1086-1 has shown that CRSs are capital-intensive and will likely have beneficial applications only where long-term energy storage or long-distance energy transmission is required. *Project Manager: B. R. Mehta*

R&D Status Report
NUCLEAR POWER DIVISION

Milton Levenson, Director

INCENTIVES FOR EXTENDING FUEL BURNUP

Because U.S. government policy calls for indefinite deferral of reprocessing and recycling of nuclear fuel, fuel management practices have been reevaluated to determine what savings could be realized from reoptimizing the LWR fuel cycle. As extended burnup of fuel is the most practical near-term option, EPRI's fuels programs are being focused on obtaining the fuel performance data necessary to license extended-burnup reload demonstration.

U.S. government deferral of reprocessing and recycling of nuclear fuel stems from the primary concern that if other countries followed a U.S. pattern of reprocessing and recycling, they might come closer to having the capability for producing materials from which nuclear weapons could be made. The economic and resource utilization advantages of closing the fuel cycle are deemed to be of secondary importance. This deferral policy has several ramifications. First, storage requirements for spent fuel must be reassessed, and plans for expansion of storage pools must be made; such studies have been made by industry groups, DOE, and individual utilities. Second, increased requirements for uranium and enrichment must be met, since about 20–30% more of each is needed per kWh than with recycle. Finally, the policy change provides an incentive to reoptimize the once-through fuel cycle to minimize uranium and enrichment requirements.

In reevaluation of fuel management practices, nearly a dozen changes in design and operation of LWR fuel and reactors have been identified that could reduce uranium consumption by small percentages. Each change involves complex trade-offs between the costs of materials, fabrication, operation, and capacity factor. In general, the small improvements are not simply additive. The potential for larger savings in uranium utilization by implementing design changes that are more basic has been studied in several EPRI programs over recent years. A large number of paper studies on the subject have also been produced by national laboratories, universities, and contractors for DOE, the U.S. State Department, and the Arms Control and Disarmament Agency under the Nonproliferation Alternatives Systems Assessment Program and by 53 countries under the International Fuel Cycle Evaluation Program.

Larger reductions in uranium requirements generally involve major changes in reactor design and licensing, extensive development efforts, and substantial front-end costs, and are marginal or noncompetitive under present conditions. Nevertheless, the subject is under continuing study for possible application of reductions in the late 1980s and beyond.

Of the various options, extended burnup of fuel has the greatest near-term prospect of practicality. If the mechanical lifetime of the fuel can be extended reliably, it appears that both worthwhile net savings in uranium and fuel storage requirements and small savings in enrichment are attainable. The increased burnup, if attained, can be exploited to provide longer runs between refuelings (e.g., 18-month cycles) and consequently increased average availability and capacity in a plant. Alternatively, more fuel rod batches can be installed at annual refuelings, giving savings in uranium and enrichment, though essentially no gain in availability. The greatest saving in uranium could come from shortened refueling intervals (with an increased number of batches), but the penalty of greater loss of availability makes this economically unattractive unless turn-around is always rapid.

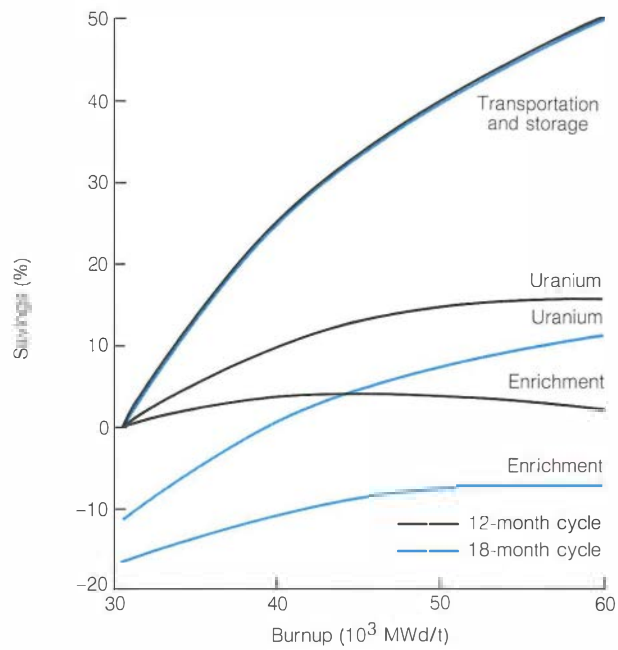
Preliminary analysis for PWRs (based on a five-batch, 12-month cycle and a 5-year residence resulting in 50,000 MWd/t) indicates a savings of 14–18% for uranium, 2–4% for enrichment, and 40% for storage and transportation (Figure 1). On a plant basis this could amount to a savings of $3 million to $5 million a year (i.e., 0.5–0.8 mill/kWh) if mechanical reliability of the fuel is attained. Burnups achievable in BWRs may be lower because of control limitations, but significant savings are still possible.

Several utilities are seeking to combine extended fuel burnup with an 18-month cycle. Thus, two 18-month cycles would replace the three 12-month cycles, or four 18-month cycles would replace six 12-month cycles. The indicated savings for uranium and enrichment are not as high in the case of 18-month cycles (5–8% less uranium; 6–8% more enrichment), but they are still an improvement over lower-burnup (30,000-MWd/t) 18-month cycles. For utilities with more than one plant to refuel, the increased flexibility in scheduling manpower and equipment and the possibility of reduced total outage time over a three-year period become important added factors. One estimate of savings that might result from switching to 18-month cycles for a two-PWR plant site is as high as $6 million a year.

To summarize, the benefits of extending batch-average burnup at discharge can include lower fuel-cycle costs, facilitation of longer cycle length, reduction in spent fuel, and conservation of resources. Consequently, with plutonium recycle unavailable in the United States, this appears to be the single largest near-term method of improving uranium utilization. EPRI's existing power reactor fuel test and surveillance projects (*1–3*) are being focused on extended burnup to obtain the lead assembly data and fuel rod data needed for licensing extended-burnup reload demonstrations. DOE supports this view and is also planning a program to demonstrate high-burnup fuel. Utilities and fuel vendors are participating with DOE or EPRI, or are entering into demonstration programs of their own.

The extension of batch-average burnup beyond 40,000 MWd/t brings with it several

Figure 1 Percentage savings are predicted for the three major components of the fuel cycle (uranium, enrichment, and transportation and storage) for 12- and 18-month irradiation cycles. Savings in uranium and enrichment level off above 50,000-MWd/t burnup and are higher for a 12-month cycle. Savings in transportation and storage become appreciable as burnup is extended.



uncertainties of a technical nature that must be answered before such fuel cycles can be widely applied. These uncertainties fall into three main categories:

▫ Fuel performance. With extended burnups, peak burnups in the fuel pellet will exceed 60,000 MWd/t (up from 40,000 MWd/t). At these burnup levels, few statistics exist on the behavior of Zircaloy-clad fuel rods, particularly with respect to dimensional stability, susceptibility to pellet-cladding interaction (PCI) distortions or defects, waterside corrosion resistance, and effects of increased fuel rod pressure due to released fission gas. Data on integral fuel assembly performance are even more limited. Since regulatory agencies are setting stricter limits on coolant radioactivity and occupational exposure, fuel reliability is clearly the main factor that restricts realization of savings from increased burnup.

▫ Core performance. Achievement of extended burnups will necessitate higher ^{235}U enrichments. Hence, higher initial loadings of burnable poison rods and their behavior over the long term need to be evaluated. Also, fuel management schemes must be carefully studied to ensure that operational flexibility is not adversely affected and that fuel rod integrity is maintained.

▫ System interactions. The switch to 18-month cycles will have significant effects on inspection schedules for both core and balance-of-plant components. Increased burnup and/or increased residence times generally result in increased probability of fuel rod defects in the core. The increased radiation levels that might result from this will influence both the cost and time of such inspections. The savings from extended burnup can be offset by unscheduled outages to remove failed fuel assemblies. The cost of one day of unscheduled outage ranges from $200,000 to $400,000 a day in replacement fuel costs. Ten days of unscheduled outage time can eliminate all the economic benefit and some of the uranium and storage space benefits.

The EPRI LWR fuel performance subprogram, which has been in operation over four years, addresses the first category and will provide the major source of engineering data and performance statistics to justify extended-burnup reload demonstrations. The performance areas that will be assessed include fission gas release, cladding corrosion, and PCI-related distortions in the fuel rods, and Zircaloy-component integrity and grid relaxation in the fuel assemblies. Ongoing fuel surveillance projects will be extended through the fourth and fifth cycles to achieve assembly-average burnups of 40,000–50,000 MWd/t in the 1980–1983 period (Figure 2). Projects in three PWRs and two BWRs will cover performance of 14 × 14, 15 × 15, and 17 × 17 array PWR assemblies and 8 × 8 array BWR fuel. The statistics on individual rod performance and dimensional changes in the fuel assembly will be supplemented by more-detailed studies of potential performance-limiting phenomena in test reactor experiments that are planned or under way.

In summary, it appears that data from present and planned EPRI projects will provide utilities with the confidence to pursue demonstrations of 12-month and 18-month reloads to 50,000-MWd/t burnup. Technical assessment of the impact of extended burnups on the total fuel cycle, including fuel management and plant operations, will become a continuing activity within EPRI's Nuclear Power Division. *Project Managers: Adrian Roberts, Robert Williams, and Edwin Zebroski*

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2. "PWR Fuel Performance Surveillance Studies." Nuclear Power Division Report, *EPRI Journal,* September 1977, pp. 44–46.

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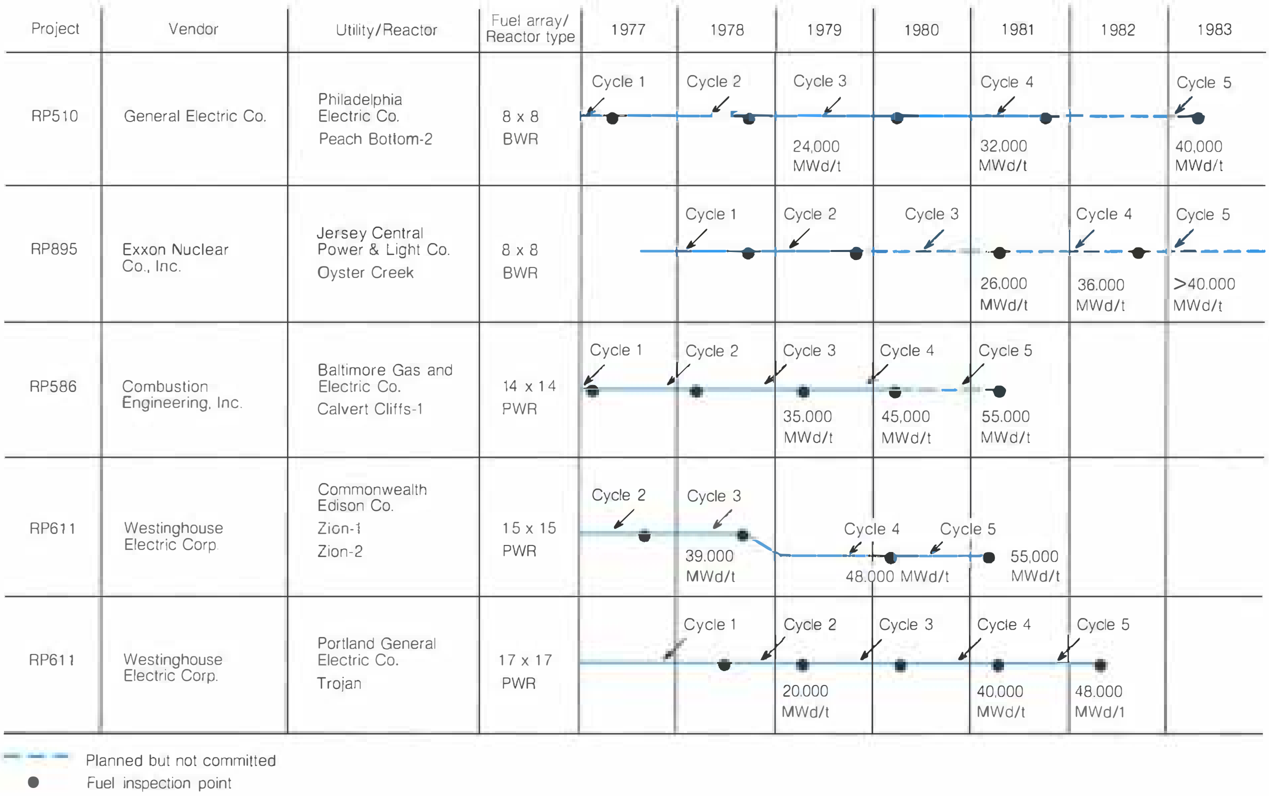
TWO-PHASE FLOW INSTRUMENTATION

Improvement in two-phase flow instrumentation has become a critical path item in nuclear safety research. Three EPRI projects are representative of the continuing efforts being made in this area by the industry. The Auburn void fraction meter is now a proved instrument that can be used in thermal-hydraulic testing. The Micromotion mass flowmeter and the gamma scanning densitometer are promising instrumentation concepts under active development to meet near-term needs.

Conducting measurements in multiphase media has been a technical problem in a variety of engineering disciplines. Pipeline slurry, engine carburetion, and aircraft

Figure 2 EPRI extended-burnup program in power reactors. The cycle number indicates the irradiation cycle of fuel assemblies, and the burnup number represents the expected assembly average at the end of the cycle.



design are particular areas where multiphase measurements play an important role. A special province of multiphase instrumentation is two-phase flow measurement. This has developed in recent years in the field of applied nuclear safety research.

The hypothetical loss-of-coolant accident gives rise to chaotic two-phase (steam-liquid) conditions throughout the reactor system following rupture of the pressure boundary. The safety system designed to cope with such an accident must rely on analytic tools that predict the course of events. These tools rely in turn on experimental two-phase fluid studies for which instrumentation capable of making accurate measurements is a prerequisite.

Two-phase flow instrumentation has been a weak link in nuclear safety research, and the gap between the need and the state of the art has grown with time. Two-phase flow analysis and instrumentation have both evolved by extrapolation from the single-phase flow condition. That is, the fluid mixture was originally assumed to be homogeneous. Researchers have attempted two-phase measurements using orifices, drag disks, and turbine flowmeters.

The assumption that the mixture was homogeneous did not work out well. Although theoretical models are being extended to account for nonhomogeneous effects, instrument development has not kept pace. As a general rule, it is best to be able to make experimental measurements that are more precise than theoretical predictions. In two-phase thermal hydraulics, this condition is rarely met.

This limitation has led to fundamental changes in the way two-phase flow instrumentation is developed. Increasingly, instrumentation is receiving stand-alone project support. NRC supports much of this work, and EPRI also sponsors an active instrument development program as part of its water reactor safety research. Foreign R&D, especially in the United Kingdom, France, and Germany, figures prominently in this area as well.

What kinds of measurements are important in two-phase flow? The parameters of interest fall into three general categories. There are the macroscopic parameters, which include pressure, bulk temperature, mass flow rate, density, and void fraction (the fractional volume of gas as a constituent of the total mixture). There are phase-specific quantities, such as liquid or gas velocity, phase temperature, and interphase friction. Finally, there are local parameters—local velocity, temperature, density, and so on—which account for spatial variation within a mixture.

The complexity imposed by the gamut of two-phase parameters is matched by the range of conditions under which measurements must be made. In nuclear safety applications, it is not uncommon to demand responses to flow rates-of-change up to ±100 m/sec² at temperatures and pressures of 100–400°C and 0–16.5 MPa, respectively (NP-195). The environmental stresses imposed by these conditions, not to mention the dynamic range required as part of the measurement, present a severe challenge to instrument designers.

The efforts to provide suitable two-phase flow instrumentation for reactor safety research have fostered a rethinking of the traditional approach. This has led to a radical departure from standard instrumentation concepts in several major instances.

One of the successful innovations in two-phase instrumentation is the Auburn void fraction meter (RP1019). The Auburn meter works on the conductance principle. The conductance is related to the relative proportion of liquid (conducting) and vapor (nonconducting) phases that are present in the mixture.

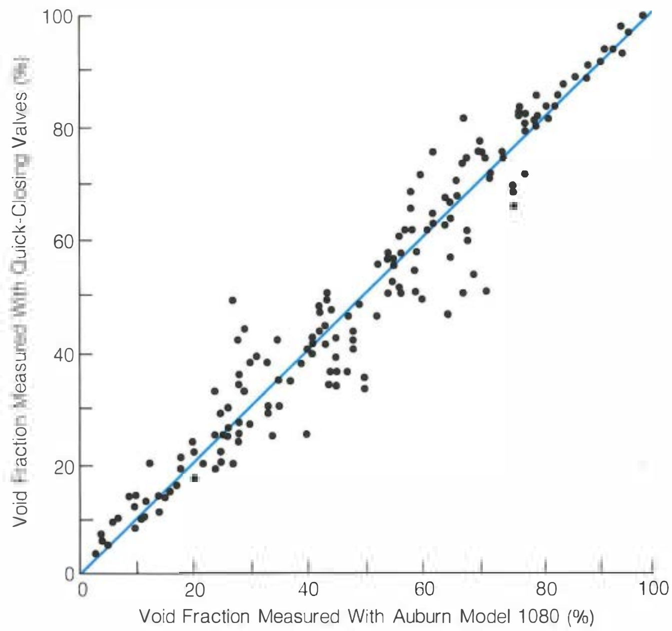
The meter's operating configuration is quite simple. Conductors are arranged around the test section like barrel staves. A 5-kHz rotating electric field is set up in the flow path using a three-phase signal. The rotating field sweeps through the mixture, producing currents that are combined and referenced to the single-phase (100% liquid) value.

The meter geometry is such that minimal disturbance to the flow occurs; moreover, there are no moving parts. The intrinsic value of the meter depends, of course, on whether it can provide an accurate range of void fraction readings (0–100%) independent of the fluid flow regime (i.e., independent of variations in time and space). This characteristic is apparent from a comparison of readings taken with the Auburn meter and values measured with quick-closing valves that trap the fluid (Figure 3).

The Auburn meter has reached a level of development where it can be used in thermal-hydraulic tests. Thus it provides a viable alternative to density measurement techniques that employ radioactive sources. Work is under way to further upgrade the meter to provide capability for flow regime identification.

A second instrument concept receiving EPRI support is based on a rather unusual measurement scheme. The idea is that by shaking a pipe, it is possible to make accurate measurements of both mass flow and density of the fluid passing through it. This measurement technique has been developed by Micromotion, Inc., and is being evaluated by Utah State University for two-

Figure 3 Comparison of void fraction measurements made with the Auburn meter and with quick-closing valves over a range of flow conditions. Statistical scatter is largely due to variations in the amount of fluid trapped between the valves at a given flow condition.



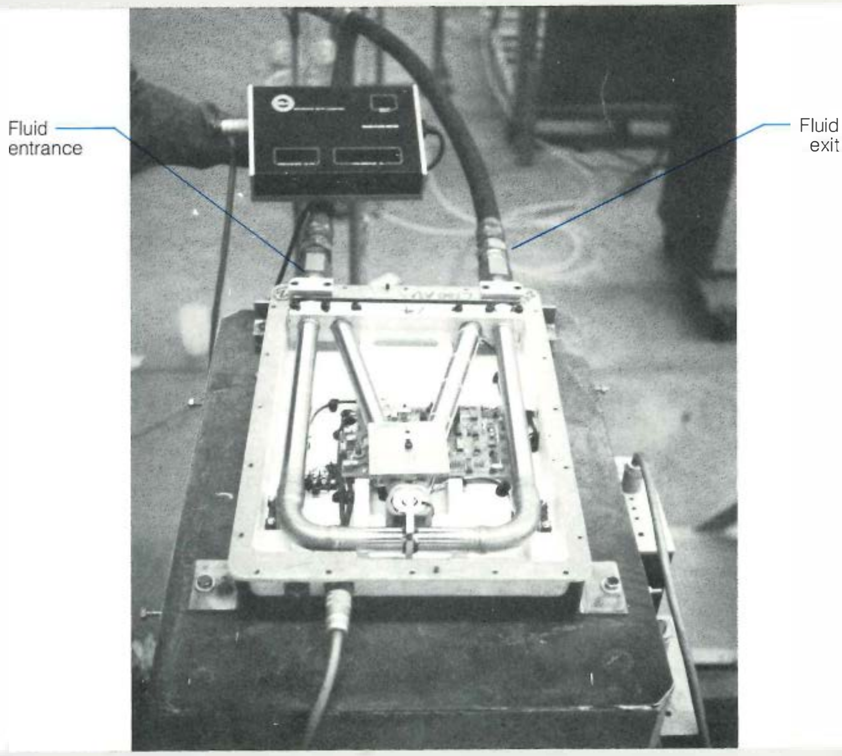


Figure 4 Internal structure of 1-in-diam mass flowmeter supplied by Micromotion, Inc. Fluid mixture circulates through the U-tube.

phase flow applications on behalf of EPRI (RP1159-2).

The instrument directs the fluid around a U-bend pipe, which vibrates like a large tuning fork (Figure 4). Fluid moving in the semicircular bend and the mechanical vibration of the pipe set up Coriolis (gyroscopic) forces, which distort the pipe structure. These distortions are picked up by sensitive optical probes mounted on both sides of the sensor. The distortion is directly proportional to the mass flow; the natural frequency of vibration is related to the fluid density.

The meter has exhibited accuracies for mass flow rate of better than 0.5% for liquids and 5% for gases. Qualitative two-phase tests suggest that accuracies for mass flow rate of better than 10% are achievable. Preparations are under way for two-phase (air-water) tests at Utah State to provide a comprehensive evaluation of the concept.

An instinctive desire of experimental investigators is to be able to look inside a test apparatus and see what is going on. This is especially true in two-phase fluid thermal hydraulics. However, at high temperatures and pressures this capability is very difficult to achieve. Even if it were possible, two-phase mixtures distort visual observation, and the chaotic conditions allow only qualitative impressions to be made.

A prospective means of overcoming these limitations is through the use of gamma tomography. The idea is to combine the most favorable aspects of medical X-ray tomography with advanced two-phase gamma densitometer designs. Medical tomography is a highly refined technology in which X-ray scans are converted into reconstructed images of body cross sections. By replacing the rotating X-ray apparatus with a high-speed rotating gamma source, it should be possible to generate density profiles for transient two-phase mixtures within a test section.

Ohio State University is studying the feasibility of a gamma scanning densitometer for this application (TPS77-7713). The basic configuration for a hypothetical scanning system is shown in Figure 5. Scoping calculations suggest that scanning systems can be built at reasonable cost that could accommodate a 6-in-diam (15-cm) section and provide 0.1-s scans with 0.15-g/cm³ density and 1-cm² spatial resolutions.

It is anticipated that continued progress

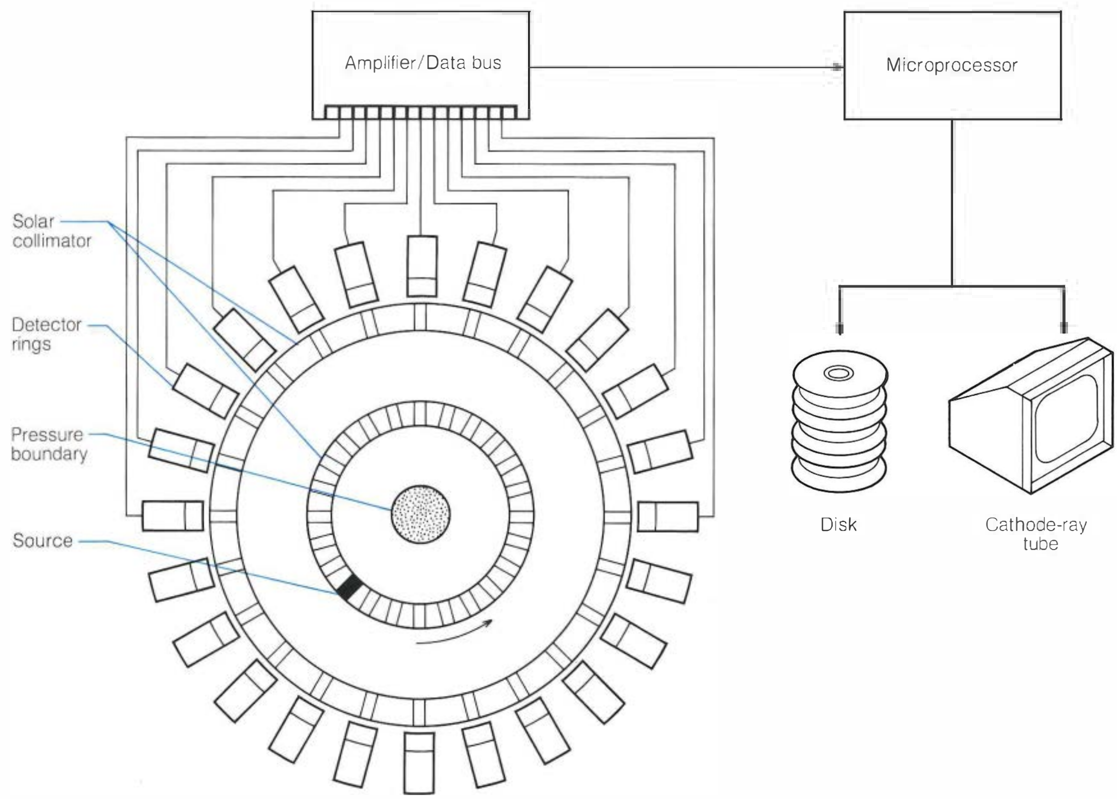


Figure 5 Conceptual layout of a gamma scanning densitometer system. A rotating radioactive source transmits gamma rays through the container and fluid to a circular array of detectors. The microprocessor is used for high-speed data storage and density profile reconstruction.

in EPRI-supported projects and those sponsored by other research organizations will gradually resolve the two-phase flow instrumentation problems confronting the industry. These developments may also prove to be useful in overcoming flow measurement problems in other fields. *Project Manager: David Cain*

EARLY DETECTION OF ELECTRIC GENERATOR ARCING

A recent survey of forced generator outages estimated that 824 GWd could have been saved between 1969 and 1977 had the generators been equipped with an effective device for detecting incipient arcing (RP970-1).

Many failures in electric generator stator windings are believed to be preceded by localized arcing across conductors that have broken as a result of copper fatigue or have suffered localized overheating and melting. Arcing may also occur across insulation between individual copper strands within a stator coil. If allowed to continue, arcing can result in flashover between stator windings and ground, destroying the stator windings before protective relays can act. Figure 6 shows the consequences of such a flashover. Repair of this generator will require approximately three months.

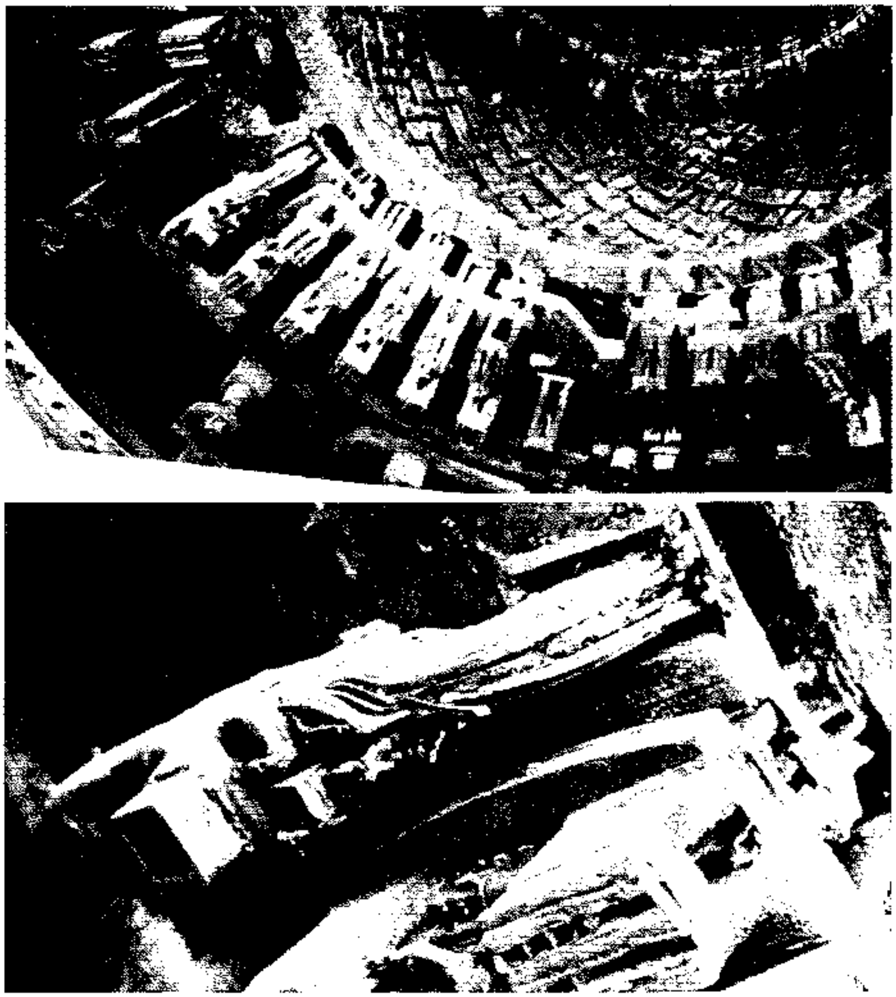
In contrast, early detection of arcing can reduce repair time from months to days. An example of the minimal damage done to a copper cover plate by incipient arcing is shown in Figure 7. The arcing was detected during field tests of the radio frequency (RF) signal monitoring technique, described below. The affected cover plate was replaced, and the generator was made ready for service during a regularly scheduled weekend outage.

RF signal sources

There are several sources of RF signals associated with generators. Some come from outside the generator but might be detected in the generator windings. These sources include corona in the high-voltage distribution system, lightning, and switching surges. Sources within the generator include field excitation systems, ionization both within and at the surface of the high-voltage stator-winding insulation, slot discharges between stator coil surfaces and stator iron, and arcing across a broken stator-winding strand or between strands.

Of the above conditions, arcing from broken strands or between strands has the greatest consequence, namely flashover. These arcs are not continuous but are

Figure 6 Electric generator arcing, if not corrected at an early stage, can result in flashover between stator windings and ground, destroying the stator windings before protective relays can act. Shown here are **(a)** a generator in which flashover occurred and **(b)** a close-up of one of its destroyed series connections.



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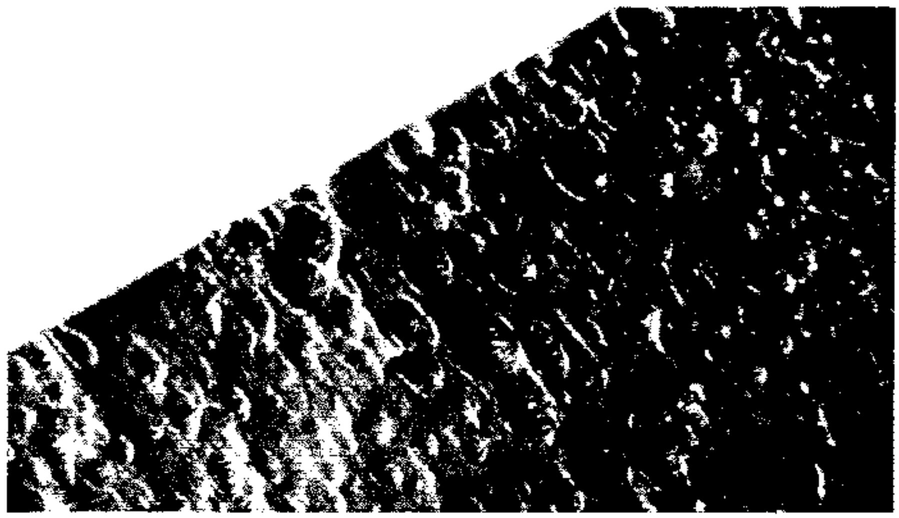
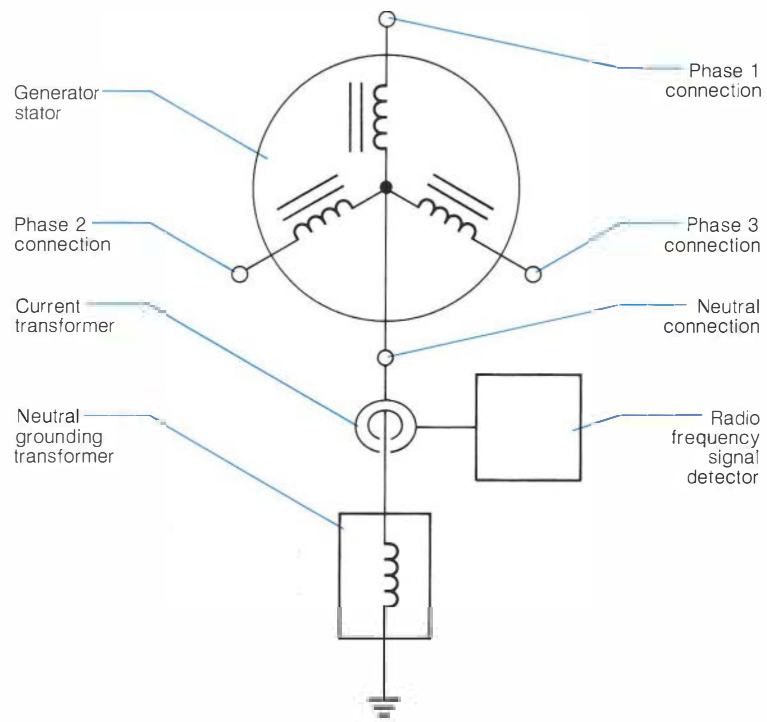


Figure 7 During field tests, incipient arcing was suspected in a generator. Relatively minor damage was found on this copper cover plate (magnified 7×). The plate was replaced and the unit made ready for service during a regularly scheduled weekend outage.

regularly interrupted and reignited because of both the movement of the surfaces between which the arcing occurs and the zero crossing of the alternating current. In some situations the arc is reignited each time the voltage exceeds the breakdown strength of the gap between the arcing surfaces. The interruption and reignition of the arc causes short-duration current pulses (containing RF signal components) to flow in the conductors leading to the arcing region. The RF currents propagate through the stator windings as if the windings were a set of transmission lines. Preliminary work done by Westinghouse Electric Corp. indicated that because of this phenomenon, RF signals produced by arcing could be distinguished from those from other sources (*1*).

Figure 8 Instrumentation used for the detection of arcing consists of a current transformer, which is placed around the generator neutral connection, and a radio frequency signal detector. No direct connection to the generator is required.



RF signal monitoring tests

To determine the feasibility of using RF signal monitoring to detect arcing, Westinghouse conducted a series of experiments to simulate strand arcing. The instrumentation used in the tests is shown in Figure 8. A current transformer was placed around the neutral lead and connected to a tunable RF signal meter. The neutral lead was chosen because it normally is at a very low potential with respect to ground and also because signals generated in any of the three-phase windings might also flow in the neutral lead.

Simulated arcing was introduced in the stator windings by a relay, which interrupted the currents in some strands. Measurements were taken for the following conditions: background with no current flowing in the stator, current flowing in the stator but with no arcing introduced, and current flowing in the stator with simulated arcing. Tests were repeated with arcing introduced at various distances from the neutral connection. Results indicate that RF signal monitoring at the generator neutral could detect arcing anywhere in the stator windings.

In addition to these shop tests, Westinghouse conducted field tests on several generators operating at various power levels. Results showed that for most generators, the measurements at the generator neutral did not vary significantly with power level and were not significantly affected by noise from the external transmission line. Signals were, however, typically higher for generators with brush-type exciters than for those with brushless exciters.

Incipient arcing detected

Three generators did have RF signals that varied with power level and also were much higher than average. Arcing was confirmed in two of these generators by subsequent disassembly and visual inspection, performed at the request of the station managers. In one case, arcing was discovered on a loose copper cover plate (Figure 7). The cover plate was replaced and the unit was returned to service. The RF signal spectra from before and after the repair are shown in Figure 9. The signal levels after the repair were typical of those encountered with nonarcing generators.

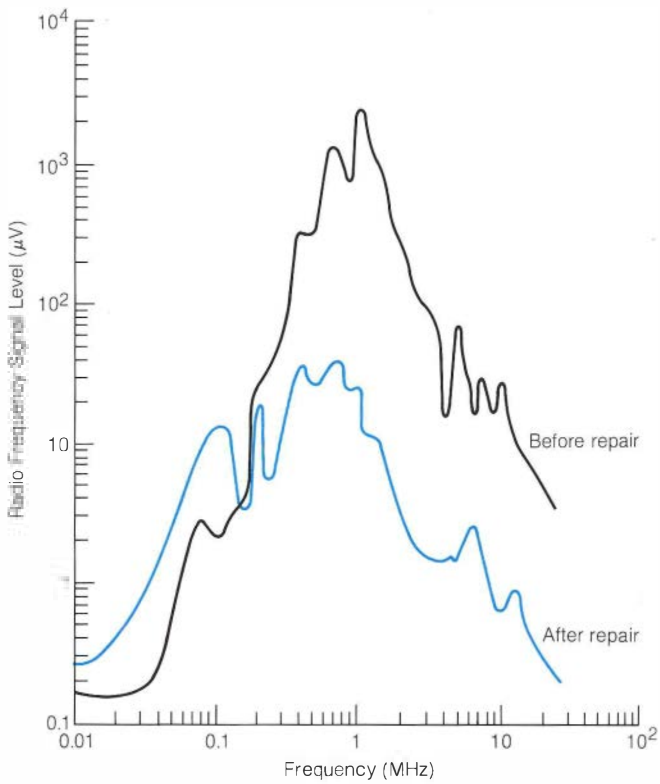
In the second case, a fixed-frequency RF signal detector was connected to corroborate the existence of a problem indicated by a particulate sensor, a device for detecting overheating within the generator. During the subsequent visual inspection, several sheared strands in one winding were found, along with evidence of arcing and overheating. The winding was repaired, and the generator was returned to service in one week. However, RF signal levels after repair were intermittently higher than normal when the generator operated at high power levels. The unit was monitored continuously for about one month. Then during a regularly scheduled maintenance outage, one additional arcing strand, located at the opposite end (electrically) of the generator stator from the RF signal detector, was discovered and repaired.

The third generator tripped off the line about a month after the RF signal measurements were made. A visual inspection showed that foreign material in the generator had eroded some insulation in one spot. A repair was completed, and RF signal measurements taken several weeks later—shortly before a scheduled outage—were found to be typical of nonarcing generators. During the outage, a visual inspection revealed no evidence of arcing.

Further test results

With the feasibility of RF signal monitoring for incipient arcing detection established by shop and field tests, Westinghouse proceeded to perform a series of tests to deter-

Figure 9 Radio frequency signal levels before and after repair and replacement of the copper cover plate shown in Figure 7.



mine the optimal location and method for detecting RF signals and to determine how to select a particular frequency or set of frequencies for an on-line monitoring system. RF spectra for arcing generators had exhibited several peaks, such as those shown in Figure 9, which indicated that perhaps there were RF resonances in the windings that could be exploited to provide greater sensitivity for arcing detection. The tests confirmed the resonances by injecting RF signals over a frequency range of 10 kHz–30 MHz into various locations within generator stator windings. Measurements were made at several locations to characterize the winding impedance and to develop an approximate equivalent RF circuit for the winding.

Preliminary results indicate that arcing signals excite a particular resonance determined by the inductance and capacitance of a one-half coil. Additional details are given in the final report (NP-902). Further work is under way to develop a prototype single-frequency arcing-detection system and to evaluate it on several operating generators over the next year (RP970-2). *Project Manager: Gordon Shugars*

References

1. R. T. Harrold, F. T. Emery, F. J. Murphy, and S. A. Drinkut. "Radio Frequency Sensing of Incipient Arcing Faults Within Large Turbine Generators." IEEE Conference Paper F78684-3-PES. Presented at the 1978 Summer Meeting of the IEEE Power Engineering Society, Los Angeles, California, July 1978.

RADIATION CONTROL IN NUCLEAR POWER PLANTS

Techniques for reducing radiation field buildup include control of cobalt release and transport, filtration of corrosion products, and decontamination of system components. Projects in these areas range from laboratory studies on corrosion-product solubility and colloids to the sampling of deposits from fuel, pipes, and steam generators in operating nuclear power plants.

The amount of radiation exposure experienced by nuclear power plant workers continues to increase. The results of NRC compilations through 1977 show this in Figure 10. In recent years, annual exposure rates have increased by about 75 man-rems for each BWR reactor, whereas exposure in PWR plants has been relatively constant.

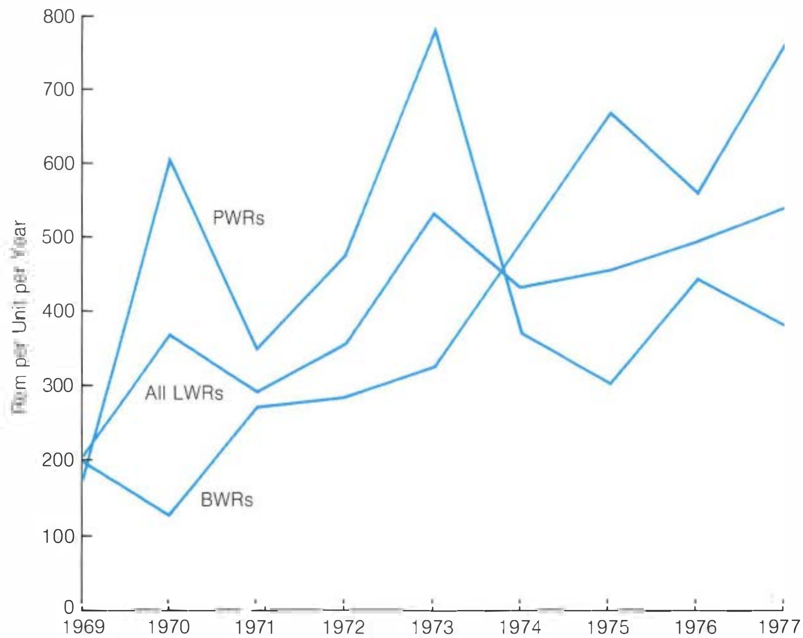
It is important to note that this average exposure rate in any given year is a combination of a range of plant situations: new large plants in their first year of operation as well as older, smaller plants; and plants requiring substantial maintenance in addition to those with a relatively smooth year of operation. As a particular instance of such situations, the major perturbations in the PWR curves in 1970 and 1973 were each caused by a major repair project in a single first-generation plant. Consequently, these exposure histories are substantially influenced by the various programs and projects implemented by the utilities to keep radiation exposure "as low as reasonably achievable"; by the new plants coming on line each year; and by the recent major increases in inspection requirements, especially for PWR steam generators and BWR piping.

EPRI projects on radiation control emphasize the reduction of in-plant radiation exposure through the development of techniques to improve control over the source of these exposures—the radioisotopes that produce the radiation fields in the plant.

The development of techniques to improve control over radiation fields in reactor coolant systems is the primary goal of a number of related EPRI projects. The radioisotope Co-60, derived from natural cobalt, is the main source of radiation fields in most nuclear power plants (RP404-2). (In the early operating years of PWR plants, Co-58, derived from nickel, predominates over Co-60.) Hence, a common theme in these projects is the search for cobalt control. Presently, this search involves identifying the components and materials responsible for cobalt release to the coolant, reducing the deposition of these materials through the development of coolant purification and chemistry control techniques, and developing techniques for decontaminating system surfaces.

The key efforts in radiation control for BWR plants are part of a project conducted by General Electric Co. (RP819). A loop has been installed at the Hatch-2 reactor of Georgia Power Co. to determine the characteristics of corrosion product deposition from the reactor coolant; the effect of high-temperature filtration on such deposition

Figure 10 NRC compilation of average annual in-plant exposure to radiation at operating U.S. nuclear power plants.



and the resultant radiation fields; and the influence of chemical additives on the deposition and removal of these corrosion products. Other efforts, including a major project that is monitoring coolant contaminants throughout the feedwater train in the Brunswick-2 reactor of Carolina Power & Light Co., have identified high-cobalt alloy pins and rollers on BWR control blades as primary contributors of Co-60. Another project by General Electric was begun in August 1978 to identify alternative materials for BWR control blade pins and rollers that contain significantly less cobalt (RP1331).

The transport of corrosion products by the reactor coolant concerns their release from corroding metallic surfaces, their deposition or precipitation, and their subsequent release from these deposits. The process involves ionic, colloidal, and particulate states. Solubility studies for cobalt-containing metal oxides under typical reactor coolant conditions are under way at Westinghouse (RP825-2). Techniques for forming aqueous colloidal systems of uniform size and shape of the metal oxides found in reactor coolant have been developed at Clarkson College of Technology (RP966). These uniform systems are used to study the effect of coolant pH and material surfaces on colloid deposition and release and the effect of decontamination reagent interaction with these colloids. The removal of contaminants from the reactor coolant is limited by the flow capacity of the ion-exchange system used to process the reactor coolant. Since the reactor coolant must be cooled significantly before treatment (to prevent decomposition of the ion-exchange resin), a penalty on the thermal efficiency of the plant accompanies any increase of the flow rate in these systems. An alternative is offered by high-temperature filtration (HTF) using electromagnetic filters, etched disk filters, or graphite or magnetite beds. Proposals for a demonstration of HTF for reactor coolant treatment are under review. This demonstration would emphasize considerations of HTF operations, effects on radwaste, and the ability of HTF units to remove corrosion products and reduce radiation-field buildup.

Coolant chemistry control is the focus of radiation control efforts applied to PWR plants. The use of additives to PWR reactor coolant during normal operation permits some control over pH and oxidation potential during operation and shutdown. Westinghouse is studying the use of pH control in reactor coolant and the solubility characteristics of PWR corrosion products to attempt to reduce deposition and precipitation on fuel surfaces (RP825-2). The Trojan plant of Portland General Electric Co. and the Beaver Valley-1 reactor of Duquesne Light Co. are both participating in this project by maintaining their reactor coolant pH near the lower and upper limits of the operating range, respectively. The effects of these operations with coolant pH control are being evaluated by coolant sample analyses, radiation-field monitoring, and characterization of fuel and steam generator deposits.

Coolant chemistry control during the cool-down stages of a refueling shutdown has been used in PWR plants to control the transport of corrosion products. The addition of hydrogen peroxide has been shown to provide an earlier release of Co-58 during the cool-down. The suspended Co-58 can be removed by the reactor coolant purification system during the early stages of cool-down. This earlier release has been determined to have little if any effect on steam generator radiation fields (RP821). Delay of the removal of dissolved hydrogen from the reactor coolant during cool-down was proposed as a technique for radiation-field reduction but has been shown to have insignificant effects. The test that produced these conclusions was monitored by Westinghouse during a shutdown at the Point Beach plant of Wisconsin Electric Power Co.

Babcock & Wilcox Co. is developing a basis for pH and oxidation control techniques during cool-down for radiation-field control (RP825-1). Experimental work is planned at the Oconee plants of Duke Power Co. and at the Rancho Seco plant of Sacramento Municipal Utility District.

The projects to develop a decontamination process are focused on selecting a mild chemical additive that would reduce the fields by a factor of 2–3 or better and that would permit processing of the decontaminating solution by available in-plant chemical systems. Battelle, Pacific Northwest Laboratories has shown that ethylenediaminetetraacetic acid (EDTA) can be used to remove about 85% of the Co-60 on BWR piping in a few hours (RP828). Similar work is under way on PWR samples. The Central Electricity Generating Board of England is screening candidate reagents for use in decontamination (RP1329). This screening is based on the rate of dissolution of typical corrosion products under the influence of various reagents.

Projects in associated areas, such as exposure control and radwaste processing, are in various stages of planning and initiation. *Project Manager: Robert Shaw*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Director

DISTRIBUTION

Concentric neutral cable corrosion

Corrosion of the neutral wires surrounding buried distribution cables continues to be a matter of serious concern to utilities. As reports of corrosion in copper concentric neutral wires increase, utilities are understandably becoming more concerned about system reliability, equipment operation, construction economics, and operating practices. It is therefore necessary to find ways to mitigate the corrosion of the concentric neutrals presently installed and of installations planned for the future.

A research project to provide a method for mitigating corrosion on future installations is already complete (RP671). It has developed data on the viability of extruding semiconducting or insulating jackets over the neutral wires during manufacture. Although this may prove effective, it adds the costs of the jacketing material and manufacturing; another factor is that the industry has already expressed a preference to continue the use of bare neutral cables. Therefore, the causes and mechanisms of copper concentric neutral corrosion need to be determined in order to provide some direction for industry.

EPRI, in conjunction with Florida Power & Light Co., will conduct a controlled field and laboratory investigation to determine the contribution of the following to the concentric neutral corrosion process:

- Tin and alloy coatings over the copper wires
- Flow of ac currents in the neutral wires
- Long-line cell corrosion phenomenon
- Possible rectification of ac currents
- Local galvanic cell phenomenon
- Stray dc currents
- Galvanic coupling between the carbon-filled insulation shield of the cable and the bare metallic neutral wires
- Thermal-cycling effects

Data obtained from this project and from RP1049 (cathodic protection of in situ underground residential distribution [URD] cables) will make up an appropriate corrosion data base. RP1049 addresses the problem of corroded in-service cables by developing guidelines for the application of cathodic protection (*EPRI Journal,* May 1977, p. 32). The first phase of RP1049 includes an in-depth study of soil chemistry in areas where corrosion was known to occur and also in areas where no corrosion was found. A statistical analysis is being used to identify soil types in which cable may or may not require protection. The contractor, Pacific Gas and Electric Co. (PG&E), has almost completed this phase of the project.

In the second phase, PG&E will design and install cathodic protection systems on URD cables in areas where conditions call for some form of protection from corrosion. The results of this work will be used to establish guidelines on cathodic protection. The guidelines will include a summary of potential corrosion mechanisms and causes and a description of conditions under which cathodic protection would be effective. Comprehensive instructions will follow on how to perform a field survey, with guidance on the interpretation of field survey data and instructions on how to apply a cathodic protection system. For example, the guide will suggest methods of design, installation, system testing and evaluation, monitoring, and maintenance. Economic data on types of cathodic protection systems will be provided, as well as information on their effectiveness and limitations. *Project Manager: Thomas Kendrew*

Emergency operating temperatures for extruded cables

The maximum emergency operating temperatures for extruded dielectric cables (Table 1) were established many years ago and are currently undergoing reevaluation in view of advances in materials and cable technology. A research program at the Institut de Recherche de l'Hydro-Quebec (IREQ) was undertaken in early 1977 to determine satisfactory limits of operation for extruded materials at elevated temperatures (RP933).

The work focused on the response to thermal stress of several polymeric insulation materials used in conventional extruded cables. This comprehensive study evaluated the electrical, mechanical, physicochemical, and thermal properties of various extruded dielectric materials as a function of temperature. This information is vital, since when normal conductor temperature increases under emergency operating conditions, the surrounding insulation undergoes a temperature rise and the above-mentioned properties diminish. It is generally known that under these conditions, cross-linked polyethylene (XLPE) loses a portion of its mechanical strength more markedly than does mineral-filled ethylene-propylene rubber (EPR) or mineral-filled XLPE. However, reliable information on the quantitative effects and the influence of these changes on overall properties has not been available for cable-grade material.

Materials studied include XLPE, mineral-filled XLPE, EPR compounds, and semiconducting XLPE. Data were obtained on specimens removed from full-size extruded cables and on laboratory-molded specimens. Dielectric, mechanical, and chemical properties were measured over a temperature range of 25–170°C.

A major point established by IREQ at the

Table 1
MAXIMUM TEMPERATURES FOR EXTRUDED DIELECTRIC CABLES
(°C)

Cable Material	Normal Operation	Emergency Operation	Short-Circuit Condition
High-molecular-weight polyethylene	75	90	150
Cross-linked polyethylene	90	130	250
Ethylene-propylene rubber	90	130	250

beginning of this work was the fact that property measurements made on specimens cut from cables and on specimens molded in the laboratory directly from pellets agree with each other. This enabled cables to be validly compared with molded sheets of dielectric material.

IREQ observed that increased temperature reduces an insulation material's mechanical strength more markedly than its dielectric strength. Above about 110°C, property changes caused by increasing temperature are negligible.

The rate at which the mechanical properties of XLPE materials change with time and temperature is greater than the rate of change for EPR materials. At higher temperatures, the latter show a higher mechanical strength than either mineral-filled or mineral-free XLPE.

The incorporation of mineral fillers (i.e., for XLPE and for EPR compounds) has beneficial effects in reducing both the temperature dependence of several mechanical properties and the thermal expansion coefficient. However, this incorporation adversely influences the dielectric breakdown strength at low temperatures (90°C), the dielectric loss, and the dielectric constant.

Since the XLPE insulation must be cross-linked to render the insulation form-stable at elevated temperatures, the degree of cross-linking (referred to as the gel fraction) is a well-known and important insulation parameter. It was found that a sol fraction (portion not cross-linked) of 28% does not have a significantly greater effect on the overall performance of a material than a sol fraction of 17%, although the partially (28%) cured XLPE consistently showed somewhat poorer mechanical properties. Achievement of a lower sol fraction remains a highly desirable goal (current industry specifications allow a maximum of 30%).

IREQ also developed a method to correlate the degree of curing of XLPE with the insulation behavior, using differential scanning calorimetry,

A high-pressure-liquid chromatographic technique was developed to simultaneously determine the level of antioxidant, peroxide, and peroxide decomposition products present in XLPE cables. There is evidence that an antioxidant may not be present in the XLPE cable samples examined, even under partial curing conditions. However, the sensitivity of the measuring technique must still be determined.

As part of the dielectric-testing phase of this work, IREQ developed a modified sample test cell to obtain more reliable dielectric breakdown data at elevated temperatures. The special electrode assembly, which is cast in epoxy resin, is shown in Figure 1. This unit was developed to hold the specimens flat between the electrodes up to the maximum test temperature of 170°C and to avoid surface discharges prior to dielectric breakdown.

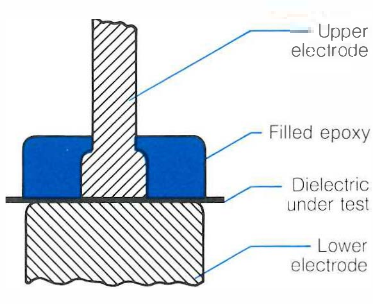


Figure 1 Dielectric test cell employed by Institut de Recherche de l'Hydro-Quebec to measure insulation breakdown strength as a function of temperature.

Figure 2 shows typical 60-Hz ac breakdown data for XLPE insulation and for various EPR compounds. The dielectric breakdown characteristics of the two insulations are shown to be different with respect to temperature dependence. At temperatures above 90°C, EPR materials have slightly higher and more linear breakdown characteristics than XLPE, although at near-normal operating temperatures, the observed differences are only marginal; below 90°C, the breakdown strength of XLPE is much higher. Figure 3 shows similar test results for impulse testing, and the pattern is similar to that of the ac breakdown behavior. Results indicate that cables could be somewhat more vulnerable to failure during prolonged thermal overload conditions.

In addition it was concluded that both XLPE and EPR are susceptible to corona discharge degradation at temperatures exceeding 25°C, and the intensity of surface erosion (or pitting) increases with increasing temperature. The dielectric loss, dielectric constant, and electrical conductivity of EPR materials are somewhat higher than those of unfilled XLPE at any temperature.

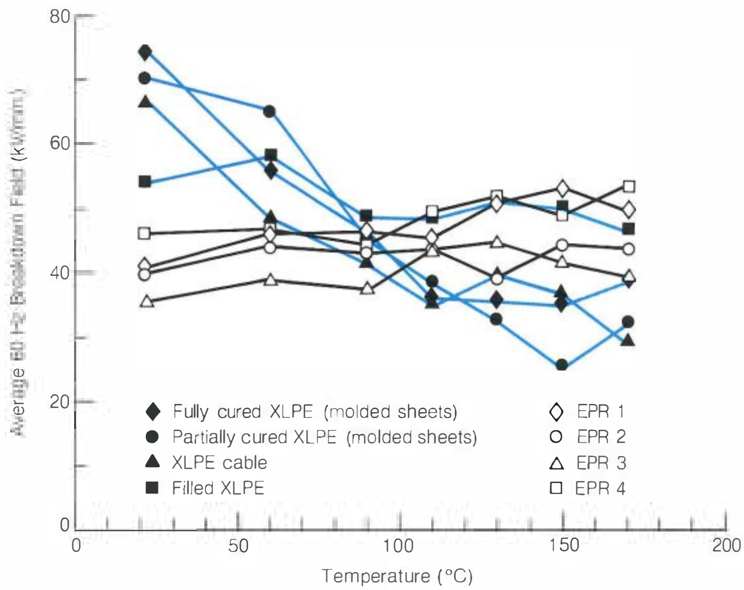
The overall results from this project indicate the capabilities and limitations of each type of insulation material. Testing on full-size cables will verify this information for cables operating under real-world stresses and should determine satisfactory limits of operation for extruded cables under emergency overload conditions. *Project Manager: Bruce Bernstein*

Detection of voids in solid dielectric insulation

Voids and contaminants in unfilled cable often impair the dielectric strength of the cable and result in premature and costly failure. Inspection of cable for these imperfections is performed by inference (i.e., by corona measurements on a complete reel) and by visual microscopic inspection of a very small length of cable, obtained from the ends.

United Technologies Corp. has developed a technique for detecting discrete voids and contaminants throughout the entire length of cable insulation by means of a far-infrared (FIR) laser, whose wavelength of 119 μm has been chosen to penetrate the insulation in a single columnated beam without attenuation or scattering. Scattering does occur, however, at refraction points (where voids or contaminants are present) and is identified by specially designed detectors sensitive to

Figure 2 Average 60-Hz breakdown strength as a function of temperature for filled and unfilled XLPE insulations and four EPR insulations.



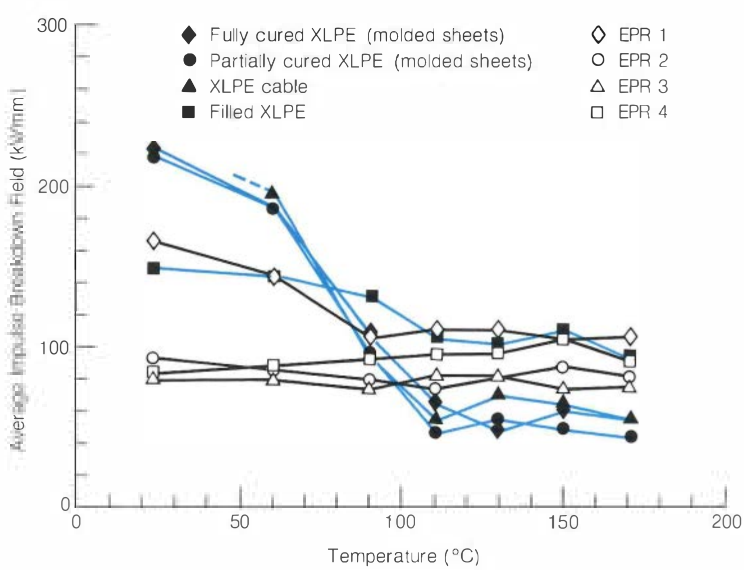


Figure 3 Average impulse breakdown strength as a function of temperature for filled and unfilled XLPE insulations and four EPR insulations.

the FIR laser frequency (Figure 4).

Phase 1 of the project demonstrated the reliable detection of voids and contaminants as small as 100 μm. Stationary samples were used for this demonstration.

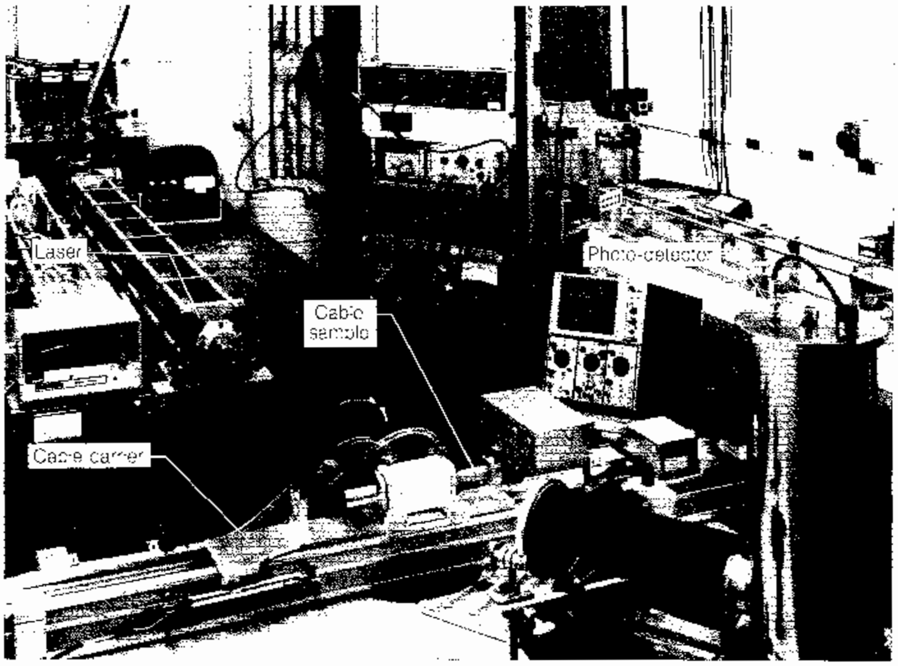
Because of the success of the Phase 1 feasibility study, the development of a breadboard laboratory prototype (Phase 2) was begun in January 1978. This prototype uses a laser that scans the entire insulating sheath of a moving cable and signals the presence and location of voids and contaminants in real time. In this phase, the FIR laser and detectors will be optimized and stabilized. The laser light will be swept rapidly along the axis of the insulating material as the cable moves through the inspection system. An array of detectors will be arranged to intercept and respond to FIR laser signals scattered by voids or contaminants. Computer control and signal identification techniques are being developed to characterize and locate defects. A laboratory demonstration of real-time inspection of defects in power cable insulation is planned, and the project is scheduled for completion in mid-1979. *Project Manager: Joseph Porter*

Study of arc by-products in gas-insulated equipment

Sulfur hexafluoride (SF_6) has been used in circuit breakers for many years and is now being used increasingly for other substation components and gas-insulated transmission lines. However, corrosive and potentially toxic by-products can be produced by arc discharges within SF_6-filled electrical equipment. For example, circuit breakers routinely experience arcs during closing and opening operations and arc discharges in the gas during dielectric failure. The majority of the constituents generated recombine rapidly after the arc ceases. However, certain solid by-products formed through chemical reaction with the metal components in the equipment remain outside the recombination and generally form a deposit at the bottom of the equipment. When the equipment is opened for maintenance or repair, these solid by-products are exposed to the moist ambient air, and it is suspected that they produce gases such as HF, SOF_2, SO_2F_2, SF_4, and H_2S. Throughout the industry, efforts have been made to understand the chemical composition of these materials because of concern for the safety of maintenance workers.

A project has been initiated with Gould Inc. to develop a data base on the chemical by-products generated by arcing in gas-insulated equipment (RP1204). The data

Figure 4 Initial laboratory setup for demonstrating proof of concept for laser detection of voids and contaminants in polyethylene-insulated power cables.



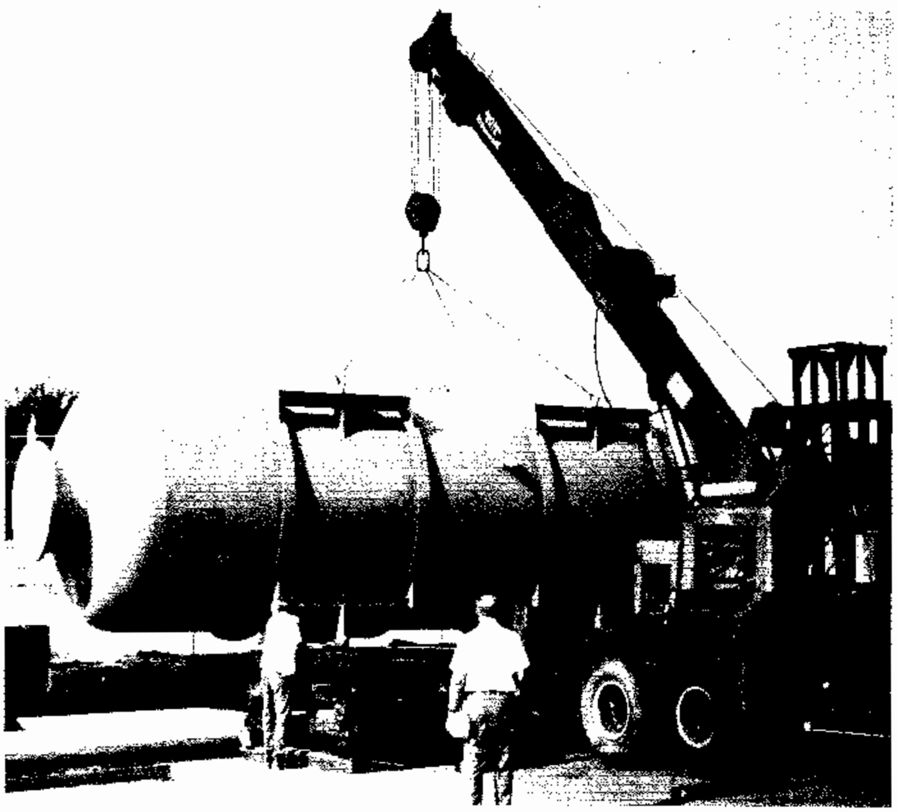


Figure 5 Prototype compact capacitor tank being off-loaded at Gould's Greensburg, Pennsylvania, facility for testing. This tank houses a 345-kV, 24-MVAR capacitor bank intended for installation on Consolidated Edison's system in New York.

base is planned to cover both solid and gaseous products. In addition to the final by-products, the intermediate sequence of chemical reactions will be identified for better understanding of the process. Once the data base is established, simple decontamination and disposal methods will be developed to properly handle the by-products. *Project Manager: Vasu Tahiliani*

Compact capacitors for ac and dc transmission substations

Capacitor banks are an important part of bulk power ac substations and dc converter stations. But they present two problems: they occupy a large area (particularly in HVDC and large EHV substations) and they attract rodents, snakes, and birds because of their warmth and open-lattice structure.

A 400-MVAR shunt capacitor installation for a 345-kV transmission line may occupy a space exceeding 4000 m^3 (140,000 ft^3). The capacitors themselves take up as little as 2% of this space, in spite of the fact that individual capacitor units are rated up to 200-kVAR. The interface spacing and insulation-to-ground requirements account for 98% of the space. The large space required for capacitor banks is even more apparent in modern converter stations, where 30% or more of the converter terminal yard is required for the ac harmonic filter and shunt capacitor installation.

EPRI is jointly sponsoring a project with Consolidated Edison Co. of New York, Inc., (RP996) to develop a compact capacitor bank suitable for ac as well as HVDC stations. The development work is well under way. The contractor, Gould Inc., will build an SF_6-gas-insulated, dead-tank capacitor bank. A steel tank similar to a transformer tank will be used to house the capacitor racks. The capacitors themselves are to be provided by ASEA of Sweden under a subcontract to Gould.

In the new design, the capacitor tank is pressurized to slightly less than 100 kPa (15 psig), and the temperature of the gas is controlled so that the capacitor temperature will always be above 10°C. The use of overpressure and a controlled ambient temperature inside the tank makes it possible to either stress the capacitor units more than a conventional air-insulated capacitor unit could be stressed or to attain higher reliability of the capacitor unit than could be attained with an air-insulated unit using the same stress level. A study to determine the optimal economic design for taking advantage of both of these factors is a part of the project.

The selected capacitor unit contains 48

capacitor elements arranged in three series-connected groups of 16 elements each. Each element has its own fuse, located inside the capacitor can. This is a departure from the current domestic practice of using external fuses. The use of internal fuses is necessary for a compact capacitor unit of this type, because replacement of a capacitor unit will be more difficult when using a gas-filled tank than with an air-insulated installation. By using internal fuses, any faulty element will be isolated without appreciably changing the operating duty for the remaining elements. In other words, one can take advantage of the redundancy built into the capacitor unit. The capacitor unit also makes use of a new insulating fluid that has been developed as a replacement for polychlorinated biphenyl fluid. The fluid is benzylneocaprate, which was jointly developed by Rhône-Poulenc of France and ASEA Kabel Ab of Sweden for use in power capacitors. The fluid is a nonchlorinated, ester-based compound with excellent electrical properties and is suitable for use in high-voltage capacitors. According to the developers, the liquid has proved to be biodegradable by common bacteria.

This new technology will be demonstrated in two different applications of these capacitor banks. One is an eleventh-harmonic filter branch to be installed on the site of the prototype HVDC link, operated by Consolidated Edison Co. of New York, Inc., at Astoria (*EPRI Journal,* December 1976, p. 18). The other application will be a 345-kV, 24-MVAR shunt capacitor application, also to be installed in Consolidated Edison's system in New York City (Figure 5). The stress levels selected for the two capacitor banks will be different in order to verify predicted reliability of the capacitor installation. Hence, the field test should produce sufficient data to make it possible for the designers to produce a capacitor bank with a specified reliability. If successful, the new capacitor bank design will offer utility engineers a compact, rugged, reliable, and economical alternative to the air-insulated rack design. The enclosed capacitors will be protected from environmental hazards ranging from pollution to birds, rodents, and snakes. *Project Manager: Stig Nilsson*

POWER SYSTEM PLANNING AND OPERATIONS

Dispatch center design

Operators in hundreds of U.S. electric utility power dispatch centers are responsible for delivering power to customers economically and reliably. Some recently published articles define and discuss the functions performed in the dispatch center and the equipment that supports system operators (*1–6*). The record of these operators has been impressive. But on a few occasions, members of the dispatching team have been misled by the information presented. Time may be lost in trying to trace missing information or in discounting irrelevant information.

Each member of the dispatching team receives power system information visually and audibly and implements decisions by pushing a button or issuing an order. Technological changes in the dispatch center environment have, over the last few years, increased the amount of information automatically presented to the dispatching team. Supervisory control and data acquisition (SCADA) installations have decreased the number of operators geographically dispersed at subarea control stations that can help diagnose system problems.

An EPRI project is being initiated to study the dispatch center environment, in which the power system dispatching team is expected to make flawless decisions (RP1354). The project has three tasks.

- Survey the design practices used in dispatch centers
- Define the needs for and uses of power system information
- Identify improved methods and techniques for presenting information

During the survey, researchers will collect information on design characteristics of dispatch centers. Particular attention will be given to those factors that affect dispatcher efficiency and those that tend to cause errors. Room lighting, noise levels, work station layouts, concurrent demands for actions, viewing angles, and viewing distances represent the type of factors to be evaluated. Human-engineering criteria and analytic techniques that have been proved in the design of aircraft and manned spacecraft will be applied to the information collected. A basis will be provided for design guidelines that help satisfy human-engineering needs, improve the control center environment, and minimize possibilities for human error.

In the second task, researchers will examine the information requirements associated with various modes of power system operation. Reasons for presenting certain information to dispatch team members during each mode of power system operation will be questioned in depth. Before digital computers were used to support dispatch functions, much information, based on measured parameters, was unprocessed. Computers have been and will be employed in many centers to detect and give warning of false or incomplete data. Researchers will ascertain whether more or less data processing can benefit the dispatcher. An action-oriented point of view will be taken during this analysis. What action is the dispatcher expected to take when a particular set of data is presented? Does the kind of information and the way it is presented elicit the desired dispatcher response? Is too much information presented to the dispatcher, especially during emergency and restorative operations? Information should neither overwhelm the dispatcher nor be insufficient for decision making.

The third task is planned to improve methods of presenting information to the dispatch team by better use of existing hardware and software, the addition of new hardware and/or software, or a combination of these. For example, in some nonutility operating environments, prerecorded voice-alarm messages have been effective. It is possible that they would be effective in the power system dispatch center. Cordless headsets, television projectors, and voice-actuated software are other possibilities to be evaluated.

This research project is just beginning. Utility companies that would like to participate in the survey phase of the project are asked to contact EPRI. Techniques in use at one utility may benefit another. A lot may be learned from a fresh look at present practices. *Project Manager: Donald Koenig*

Power system operations

Two technical planning studies on power system operations have recently been completed. The first was a study of interconnected power systems operations at below-normal frequency (TPS78-784). The principal purpose was to investigate how far frequency can be allowed to deviate from normal during a widespread, sustained capacity emergency on an interconnected power system. One motivation for this study was the repeated capacity deficiencies experienced by the eastern interconnected power systems in January 1977 and January 1978 during extended periods of subfreezing temperatures.

The study results show that a frequency change of only 0.5 Hz could be tolerated before large-bladed turbines would be dropped from the interconnected power systems. Many of these turbines cannot be operated continuously below this frequency because of turbine blade resonance and resulting blade fatigue. If an interconnected system were experiencing a shortage of capacity, the additional loss of capacity at frequencies below 59.5 Hz would compound the problem; this could cause parts of the interconnected power system to become isolated from one another. For security reasons, a margin of 0.2 Hz above the 59.5-Hz minimum should be maintained. Although part of the system load is frequency-dependent, the range of allowable frequency excursion is too small to provide any substantial load relief.

The second study was a survey of cyclic load capabilities of fossil-steam generating units (TPS77-732). The purpose was to assess the capabilities of existing units to meet new requirements that may be imposed on them because of increased cyclic operation. The study sought answers to the following questions.

- At what minimum loads can individual fossil units operate for sustained overnight and weekend periods?
- What constraints can be identified that prevent fossil units from operating at lower minimum loads?
- How many fossil units have two-shift cycling capabilities?
- What constraints can be identified that prevent fossil units from being cycled?
- What are the loading and unloading response rates of fossil units, and what constraints can be identified that limit an individual unit's rate of response?

In the survey, detailed questionnaires were sent to over 100 utilities and power pools; 88 of these responded. The final report on this study tabulates the results of the survey questionnaire and includes numerous tables that classify generators by boiler type, fuel, and megawatt capacity. *Project Manager: Charles Frank*

Transient and midterm stability

Large-scale power system disturbances have become of greater concern to the public during the last decade. One way to minimize the effects of such disturbances is to analyze their causes, sequences of events, and consequences and develop mitigation measures from the results. But new system analysis tools are needed to do this effectively.

The goal of an EPRI research project is to develop an analytic method of implementing studies of large-scale disturbances (RP1208). New concepts in computation structure, network simplification, and numerical analysis are the basis for this new tool, which should result in an operating computer program. The contractors will draw on the results of RP670, RP745, and RP763 for improved techniques involving transient stability and midterm stability computations, dynamic equivalents, and numerical methods.

Arizona Public Service Co. (APS), the lead contractor on RP1208, is responsible for coordinating the efforts of the other three contractors. In addition, APS is in charge of computer program coordination, evaluation, and documentation. Arizona State University (ASU) is conducting the research efforts involving network reduction and output analysis. Boeing Computer Services, Inc. (BCS) is providing the numerical integration algorithms and step-size control. Systems Control, Inc. (SCI) is developing algorithms for midterm generator aggregation and generator bus reduction.

This project was started during the first quarter of 1978 and is scheduled to continue through December 1979. As the work progresses, ASU, BCS, and SCI will provide APS with new or revised computer subprograms for implementation and evaluation.

Since transient and midterm stability computations use large amounts of both computer storage and time, parallel processing is also being investigated as an alternative that will provide results with shorter run times and reduced costs. Both BCS and SCI are working on algorithms involving array processors. *Project Manager: John Lamont*

Software center

In the October 1978 *EPRI Journal* the article on the new Electrical Power Software Center (p. 48) included telephone numbers to call for additional information. Please use the following numbers instead of those given in the article: (408) 734-5500 for Leroy Krider at TDC and (415) 855-2832 for John Lamont at EPRI (Electrical Systems). The number for Burt Zolotar at EPRI (Nuclear Power) remains (415) 855-2092.

UNDERGROUND TRANSMISSION

Contaminated-pellet detector

The presence of contaminants within the insulation matrix of power cables is recognized as a serious industrywide problem. Contaminants are defined as foreign bodies that are unintentionally incorporated into the polymeric insulation material, which is generally either a high-molecular-weight low-density polyethylene or a cross-linked low-density polyethylene.

Contaminants disrupt the continuity of the insulation and reduce its integrity. During operation, this leads to inferior dielectric characteristics, which result from increased localized stresses near the contaminant. The ultimate result is reduced cable life and premature failure.

Despite precautions, contaminants may enter the cable insulation via the raw material itself and via material handling during preparation of cables. Although some contaminants can be prevented from entering the cable by screens that filter the extrudate, a way is needed to keep all contaminants out of extruded dielectric cable.

One readily observable effect of contaminants, as seen in microscopic examination of the insulation of failed cables, is the presence of treelike configurations in the shape of bow ties, with the contaminant situated at the center. These trees develop after the cable has been in operation for some time.

Reynolds Metals Co. is looking for a way to remove contaminants from a moving stream of polymeric pellets just before their entrance into the insulation extruder (RP7865). The removal process involves the use of a modified optical detection and air rejection system that has been used in the food industry by Reynolds's subcontractor on this project, Food Technology Corp. of Rockville, Maryland. This project was initiated in early 1977 and involves two tasks.

Task 1 concerns the design, development, and fabrication of the equipment, followed by suitable laboratory testing. The system uses an optical detector that emits a signal and thereby triggers an air ejector downstream from the pellets, which travel along a belt between the hopper and the detector. The defective pellets are blown clear and rejected. A small percentage of good pellets are ejected along with the bad, but the loss is insignificant in comparison with the 113 kg (250 lb) of material processed per hour (Figure 6).

The detector's ability to efficiently reject defective pellets is influenced by the size and location of the pellets and by their orientation in relation to the optical beams. During the testing, a rearrangement of the optical diodes increased the area of the pellets viewed by the beams and essentially resolved the latter problem.

During a final test in Task 1, several hundred kilograms of commercially available resin were used, among which a small number of contaminants were found that had not been detected by any other method.

Task 2, which consists of installation and testing of the system in a manufacturing

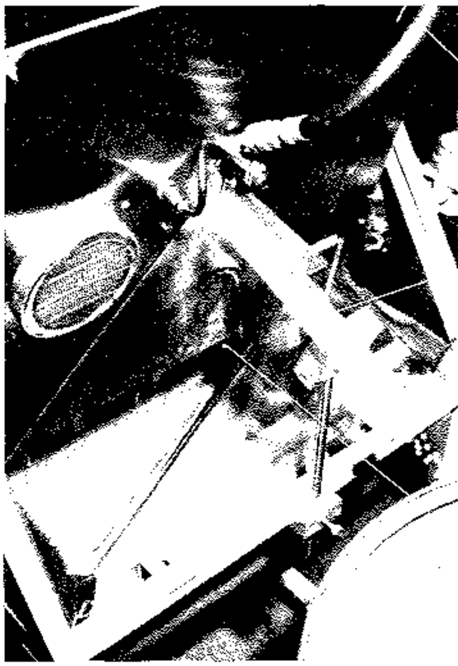


Figure 6 Polymeric pellets pass through an optical detector before entering the insulation extruder. Contaminated pellets, which are darker than clean pellets, impede transmission of light and are rejected by a blast of compressed air.

environment, is under way. *Project Manager: Bruce Bernstein*

Air-cycle cooling of cables

It is well known that the cost of operating underground transmission lines can be reduced by improving cable characteristics and thereby uprating circuit voltage and ampacity. For high-pressure, oil-filled pipe-type cable that is being forced-cooled to obtain larger power capacities, there is another way to reduce system cost—by reducing the cost of auxiliary or refrigeration equipment. This is the option being addressed by the AiResearch Division of Garrett Corp., which is developing an air-cycle cooling system that can be manhole-installed.

Refrigeration units must be spaced about every 4 km (2.5 mi) for cooling the dielectric oil in a 345-kV circuit. Presently two full refrigeration units are placed on a circuit, one to provide backup in case of failure in the other unit.

The land requirement for conventional refrigerators is large. For a 300-t (1.06-MW) capacity refrigerator, approximately 567 m^2 (6100 ft^2) is needed for a refrigerator station with a backup unit. An advanced 300-t air-cycle refrigeration station with full redundancy in refrigerator capacity requires a manhole only 5.2 m wide, 10 m long, and 3 m high (17 ft × 33 ft × 10 ft). Savings in land leasing and land taxes can be realized if manhole-installed equipment is used.

AiResearch has come up with conceptual designs for a 300-t cooling station. The criteria require three refrigeration turbocompressors to cool 8 km (5 mi) of cable from one manhole. Two refrigerators will each cool 4 km (2.5 mi) on opposite sides of the manhole, leaving one refrigeration unit as a backup system. Preliminary cost analyses show the air-cycle, manhole-installed system to be 10–75% cheaper than conventional vapor-cycle equipment over a 20-yr life and 62% cheaper in initial capital cost.

Air-cycle machinery is less costly and more environmentally pleasing (since it is installed out of sight), and noise attenuation is much simpler with higher-frequency components. No precoolers are needed, which eliminates the hard-to-attenuate low-frequency noise components. The objective of this research is to fabricate and proof-test a 45-t (158-kW) air-cycle refrigeration unit. The project is in the tenth month of an 18-month first phase. It is expected that the second phase—the design, construction, and demonstration of a 300-t unit—will begin in 1980. *Project Manager: Thomas Rodenbaugh*

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R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Director

AIR POLLUTANTS AND RESPIRATORY INFECTION

As part of EPRI's continuing investigation of the possible effects on human health of fossil fuel combustion products, groups of rats and mice were exposed first to sulfur dioxide (SO_2) and then to disease-causing bacteria. The animals did not develop pneumonia or die with any greater frequency than groups exposed to the bacteria alone. In this study, no increased susceptibility to disease or death could be attributed to SO_2 air pollution.

Do air pollutants such as SO_2 and sulfates cause harmful health effects in humans by increasing susceptibility to respiratory infection? It is well known that during the acute air pollution episodes of decades past, many older people suffered worsening of their chronic cardiac and pulmonary diseases. For some, death came earlier than would otherwise have been expected. However, with the general reduction of pollution, especially particulates, in urban areas, such episodes are unlikely to recur.

Epidemiologic studies have not yet shown that prevailing levels of SO_2 and sulfates harm healthy persons. However, these compounds may interfere with the way the body defends itself against attack by bacteria or viruses. Respiratory infections account for the vast majority of illnesses experienced by humans, and it is possible that air pollutants cause widespread reduction in resistance to infection but that this effect is difficult to detect.

The School of Medicine at the University of California at Davis is investigating the possible influence of SO_2 and sulfates on the infectivity of bacteria in rats and mice (RP680). Groups of the animals have been exposed to 0.2–0.4 ppm SO_2, which are slightly higher levels than those measured in highly polluted industrial cities. Specially modified aerosol generators were used to add ferrous sulfate (Fe_2SO_4) particles at a concentration of 60–170 $\mu g/m^3$, which is a higher sulfate level than would be encountered in a highly polluted area. These particles were all between 2.1 and 2.7 μm in diameter, permitting easy access to the lung.

The animals were exposed first to this test atmosphere for 17 hours and then to a finely dispersed aerosol of *Staphylococcus aureus* (a common infectious bacterium) and a disease-producing *Streptococcus*. Another group of animals was exposed to the bacterial aerosol without prior exposure to SO_2 and sulfate. A third group was exposed to four hours of SO_2 and sulfate after being infected with bacteria.

Comparison of the lungs of all three groups of animals showed no difference in rate of clearance of bacteria by pulmonary alveolar macrophages (PAMs). It is known that the principal defense of the lung against inhaled bacteria is by phagocytosis, the engulfing of bacteria by scavenger PAM cells, which surround the bacteria and take them into the cytoplasm of the cell. These bacteria-containing cells are then ejected from the lungs on mucus secretion (phlegm), which carries the cells up the trachea by ciliary action. Any interference with this mechanism could result in severe bacterial pneumonia.

The fact that the rats and mice exposed to SO_2 and sulfates at near-ambient and above-ambient levels showed no impairment in ability to clear the lungs of inhaled bacteria suggests that these pollutants at these levels do not compromise the ability of the lungs to fight infection.

The studies will now be repeated with nitrogen dioxide, another pollutant that is produced during combustion at high temperatures. *Program Manager: James McCarroll*

EFFECTS OF TRANSPORTATION SYSTEMS ON UTILITY LOADS

The Demand and Conservation Program is conducting four research projects that examine the relationship between transportation services and energy consumption. These projects deal with energy use in transportation services (RP757), the effect of electric vehicles on utility loads in the period 1985–2000 (RP758), the effect of future transit systems on energy consumption and utility loads (RP1051), and the consumer demand for EVs and the resulting effect on energy use and utility loads (RP1145). The first two projects have been completed and the second two are under way.

Transportation services

Wharton EFA, Inc., has developed an extensive data base and an elaborate model for the demand and supply of transportation services in the United States and the consequent demand for energy (RP757). The model produces conditional forecasts of demand for all types of energy used in carrying freight and passengers by different means during the 1985–2000 time period. These forecasts depend on price levels for competing fuels, economic growth in the United States (as projected by the Wharton long-term model), and a variety of assumptions about government regulation of air pollution, highway speed, and so forth. The forecasts are published in EA-641.

The data base and model are updated annually to provide EPRI with long-term projections of energy use in transportation for several scenarios. The results of the first updating of the model will be published early in 1979 in the Demand and Conservation Program's forecasting document, *Demand 79*.

Electric passenger vehicles

Late in 1977, Mathtech, Inc., completed its study of the effect of electric vehicles (EVs) on utility loads (RP758). Mathtech developed an EV engineering-economic computer model that links capital and operating costs of EVs to their engineering and performance characteristics. An EV demand model, various assumptions about labor costs and material price levels, and assumed trends in gasoline and electricity prices are then combined with this supply model to make projections of EV sales, the stock of EVs on the road, and the consequent electricity demand in the 1985–2000 time period. These projections show a relatively slow but accelerating market penetration of EVs during the next two decades, giving way to rapid penetration by the end of the century.

The Mathtech report (EA-623) assumes that EV batteries will be charged at night at a preferential off-peak rate, resulting in excellent load diversity. Depending on the assumptions made about utility load management, characteristics of battery chargers, and load diversity, the load impact of EVs according to Mathtech's stock projection would be 1–5% of peak load. However, this additional load would occur during off-peak hours and would result in a substantial and perhaps a beneficial increase in nighttime demand for some utilities.

The computer code developed by Mathtech is available to others interested in EV research. So far, the Mathtech projections have been used by SRI International in Palo Alto, California, and by the U.S. Department of Transportation Systems Center in Cambridge, Massachusetts.

Future transit systems

Howard R. Ross Associates is working on Phase 2 of a project that is examining the effect of future transit systems on electric utility loads and energy consumption (RP1051). The research explores automated electrified transportation that combines the best characteristics of passenger automobiles and mass transit. The Phase 1 report (EA-784) focuses on a system that would use existing highways for both heat engine vehicles and EVs. The EVs would draw their operating power and battery-recharging power from a device implanted in the highway. This device would facilitate the use of short-range, battery-powered EVs and permit them to be integrated at a relatively early date in the highway system. Such a system would overcome the range and weight problems that have restricted the development of an economical EV with performance characteristics acceptable to consumers.

The advanced transit system offers several other social and economic advantages, such as reduced air pollution, increased safety, reduced need for new highways, and potential for automation. The Phase 1 report discusses the problem of future personal transportation in detail, develops preliminary scenarios, and sets out the study plan for Phase 2. Results of Phase 2 are expected to be published in late 1979.

Consumer demand for EVs

Charles River Associates (CRA) and the University of California at Berkeley (UCB) are working on a two-part project (RP1145). In the first part, CRA is developing a "hedonic" demand model for EVs, based on data from an extensive survey on personal travel. The hedonic demand model for projecting vehicle choice accounts for the price and performance characteristics of the vehicle, the nature of the trip, and the socioeconomic characteristics of the household. The results of the demand work will be available in mid-1979.

In the second part of RP1145, CRA's demand research will be combined with several institutional and technological scenarios being developed by UCB's Institute for Transportation Studies and with the completed Mathtech research to produce an integrated and sophisticated study of market penetration of EVs and their effect on utility loads. Both the UCB report on scenarios for the introduction of EVs and CRA's new conditional forecasts of the effect of EVs on utility loads should be available in late 1979. *Project Manager: Anthony Lawrence*

New Contracts

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
Fossil Fuel and Advanced Systems Division				
RP411-3	Design Bases for H-Coal Commercial Plant Study	5 months	34.6	Hydrocarbon Research, Inc. *J. Fox*
RP547-5	Alternative Reactor Concepts	19 months	61.9	Science Applications, Inc. *N. Amherd*
RP722-3	Evaluation of 30-MW Rivesville Atmospheric Fluidized-Bed Combustion Facility	4 months	12.0	Combustion Processes, Inc. *T. Lund*
RP725-11	Engineering and Services for Apitron Filter	3 months	44.0	Crescent Engineering Co. *R. Carr*
RP779-21	Evaluation of Two-Stage, Short-Residence-Time Solvent-Refined Coal Process	1 year	37.8	Auburn University *C. Kulik*
RP842-2	4.8-MW Fuel Cell Module Demonstrator at Host Utility	4 years	3478.2	Consolidated Edison Co. of New York, Inc. *E. Gillis*
RP991-2	Penetration Analysis of Fossil Fuel and Advanced Power Generation Systems	6 months	49.6	American Electric Power Service Corp. *O. Gildersleeve*
RP991-7	Penetration Analysis of Fossil Fuel and Advanced Power Generation Systems	6 months	27.3	Philadelphia Electric Co. *O. Gildersleeve*
RP1038-1	Development of an Automated Data Acquisition System for Gasification–Combined-Cycle Pilot Plants	18 months	29.9	Systems Integrated *L. Atherton*
RP1041-4	Adiabatic Reformer Test Program	10 months	305.6	United Technologies Corp. *E. Gillis*
RP1086-3	Economic Comparison of Hydrogen Production Using Solid Polymer Electrolyzer for Sulfur Cycle Water Decomposition and Water Electrolysis	6 months	61.0	General Electric Co. *B. Mehta*
RP1180-2	Evaluation of SO_x Control Systems Combining Coal Cleaning and Flue Gas Desulfurization	7 months	94.9	Bechtel National, Inc. *K. Clifford*
RP1180-7	TVA Economic Evaluation of the Open-Loop Aqueous Carbonate Process	4 months	19.9	Tennessee Valley Authority *S. Dalton*
RP1184-2	Power Plant Performance Modeling	2 years	800.4	Bechtel National, Inc. *J. Dimmer*
RP1188-1	Development and Validation of Reliability Prediction Techniques for Selected Thermomechanical Components of Gas Turbine Combined-Cycle Plants	15 months	222.2	Westinghouse Electric Corp. *J. Weiss*
RP1193-2	Thin-Film Indium Phosphide Photovoltaic Devices	8 months	135.4	Poly Solar, Inc. *E. DeMeo*
RP1199-2	Thermal Energy Storage for Stack Gas Reheat in Coal-Fired Plants With Flue Gas Desulfurization	5 months	28.9	General Electric Co. *T. Schneider*
RP1199-3	Combined Thermal Storage and Transport for Utility Applications	4 months	27.5	General Electric Co. *T. Schneider*
RP1201-6	Technical Study of Hybrid Heat Pumps	7 months	50.7	Science Applications, Inc. *R. Mauro*
RP1235-5	Combustion Demonstration of SRC-II Coal Liquid	4 months	77.9	KVB, Inc. *W. Rovesti*
RP1235-6	Combustion Demonstration of SRC-II Coal Liquid	2 months	100.0	Consolidated Edison Co. of New York, Inc. *W. Rovesti*
RP1255-1	Technology Assessment of Municipal Solid Waste as a Utility Fuel—Part 1	8 months	135.0	Ebasco Services Inc. *C. McGowin*
RP1260-1	Long-Term Stability of Solid-Waste Products From Flue Gas Cleaning	16 months	65.2	Radian Corp. *J. Maulbetsch*
RP1260-5	Confirmatory Drift Measurements on Mechanical-Draft Cooling Towers	3 months	11.7	Calfran Industries *J. Maulbetsch*
RP1263-2	Test Incineration of Capacitors Containing Polychlorinated Biphenyls	5 months	51.8	Acurex Corp. *D. Golden*

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1264-2	Technical Assistance in Retrofitting Titanium Blades in a Steam Turbine	23 months	25.0	Battelle, Columbus Laboratories *R. Jaffee*
RP1271-1	Assessment of Distributed Wind-Power Systems	2 years	399.8	General Electric Co. *E. DeMeo*
RP1336-1	Hot Gas Cleaning for Pressurized Fluidized-Bed-Combustion Power Plants	1 year	446.1	Westinghouse Electric Corp. *W. Slaughter*
RP1402-1	Economics of Dry Flue Gas Desulfurization–Particulate Removal Systems	7 months	85.8	Bechtel National, Inc. *N. Shah*
RP1404-1	Development of an Ash Disposal Reference Manual	9 months	99.7	GAI Consultants, Inc. *D. Golden*
RP1406-1	Model of Subsurface Transport of Leachate From Flue Gas Desulfurization Sludge Disposal Sites	2 years	96.7	Battelle, Pacific Northwest Laboratories *D. Golden*
RP1409-1	Corrosion Detector for Steam and Combustion Turbines	18 months	199.6	Consolidated Controls Corp. *J. Parkes* and *A. Dolbec*
RP1411-1	Solids Separation Data Analysis	4 months	22.4	University of Houston *N. Stewart*
RP1412-1	Combustion Tests of SRC-II With Dual-Register Burner	3 months	87.6	Babcock & Wilcox Co. *W. Rovesti*

Nuclear Power Division

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
S129-1	Thermal-Hydraulic Evaluation of Steam Generators	18 months	178.2	Combustion Engineering, Inc. *D. Steininger*
RP771-4	Analysis of Reliability-Availability Data Systems	1 year	129.4	The S. M. Stoller Corp. *W. Lavallee*
RP885-6	Support in the Distribution and Maintenance of Computer Codes	6 months	19.7	Nuclear Associates International, Inc. *B. Zolotar*
RP885-7	Verification and Validation Techniques for EPRI Software Models	8 months	49.6	Science Applications, Inc. *B. Zolotar*
RP1167-4	Thermodynamics of Aqueous Transition Metal Salts at High Temperatures	1 year	25.0	University of Delaware *T. Passell*
RP1172-2	Multifrequency Eddy-Current Test Demonstration and Evaluation	3 months	6.0	Combustion Engineering, Inc. *G. DeYoung*
RP1176-3	Study of Fission-Gas Release—Phase 1	6 months	10.0	Battelle, Pacific Northwest Laboratories *A. Roberts*
RP1248-1	Environmental Cracking Margins for Carbon Steel Piping	30 months	900.0	General Electric Co. *R. Smith*
RP1321-3	Analytic Methods for Predicting Transient Fuel Behavior	8 months	90.6	Intermountain Technologies Inc. *R. Oehlberg*
RP1333-1	Kinetic Bonding of Condenser Tube to Tubesheet	13 months	253.4	Lockheed Missiles & Space Co., Inc. *R. Smith*

Electrical Systems Division

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1048-7	Investigation of a Moisture-Detection Instrument for Coal—Phase 1	5 months	48.1	Science Applications, Inc. *C. Frank*
RP1288-1	Accuracy Improvement in Prediction of Electrical Machine Constants	42 months	566.0	General Electric Co. *J. Jackson*
RP1290-2	Metglas Magnetic Material for Transformer Cores	4 years	1112.0	Westinghouse Electric Corp. *E. Norton*
RP1359-1	Substation Control and Protection System	1 year	518.5	Westinghouse Electric Corp. *S. Nilsson*

Energy Analysis and Environment Division

Number	Title	Duration	Funding ($000)	Contractor/ EPRI Project Manager
RP1009-2	Updating, Modifying, and Computerizing the EPRI Coal Mining Cost Models	9 months	92.1	NUS Corporation *T. Browne*
RP1015-3	Model Verification and Assessment	1 year	150.0	MIT Energy Laboratory *R. Richels*
RP1224-3	Development, Modeling, and Experimental Manipulation of a Thermal Microecosystem	2 years	50.6	University of Georgia *R. Kawaratani*
RP1292-1	Adjusting Energy-Using Capital Stock in the Manufacturing Sector	2 years	74.9	Carnegie Mellon Institute of Research *L. Williams*
RP1294-1	Intermediate-Term Uranium Supply Curve Estimator	5 months	47.4	International Energy Associates Ltd. *J. Searls*
RP1295-1	Acquisition and Modification of SRI Energy Models	7 months	235.3	SRI International *A. Halter*
RP1366-1	Relationship Between Energy and Economic Growth: An Input-Output Approach	2 years	300.0	Resources for the Future, Inc. *A. Halter*
RP1369-1	NO_x Transformation in Power Plant Plumes	25 months	356.9	Battelle, Columbus Laboratories *G. Hilst*
RP1371-1	Chemical Affiliation of Trace Metals in Ash	10 months	60.0	University of Southern California *R. Perhac*
RP1373-1	Effects of Pollutants From Various Energy Technologies on Cardiopulmonary Functions	3 years	1654.8	Mount Sinai Medical Center (Miami) *J. 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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ENERGY ANALYSIS AND ENVIRONMENT

U_3O_8 Production Cost Analysis Study

EA-730 Final Report, Vols. 1, 2, and 3 (RP803-1)

The objectives of this study by Bechtel National, Inc., were to research, formulate, develop, and test a model for estimating the production cost of conventional uranium mining (Vols. 1 and 2). The model evolved from a base-case underground mine of 1000-t/d output at a nominal depth of 274 m (900 ft) and from base-case open-pit mines of 2000-t/d output at depths of 9, 36, and 72 m (30, 120, and 240 ft). In addition, an alternative production method employing heap leaching was partially investigated. Vol. 3 presents the user's manual for the computer program. *EPRI Project Manager: Thomas Browne*

Modification of Local Weather by Power Plant Operation

EA-886 Final Report (TPS76-660)

J. Laurmann of Stanford, California, assessed the present state of knowledge on inadvertent weather modification and identified current research activities on the subject. Research indicates that although conventional power plants may play a role in the formation of acid rain and in reducing visibility, the probability of their causing significant weather changes is slight. Large concentrations of power plants (>10,000 MW) have the potential to initiate thunderstorms; however, much research is needed before inadvertent weather effects can be predicted quantitatively. *EPRI Project Manager: Ralph Perhac*

Fuel Utilization in Residences

EA-894 Final Report (RP137-1)

Ohio State University used a mathematical model and a computer program to establish an accurate procedure for determining the monthly and seasonal energy requirements of all types of residential structures. The response factor technique was used to calculate the dynamic load responses of a residential structure. The model and the program take into account all the external and internal dynamic loads imposed on the structure, such as changes in weather conditions, appliance usage, and occupancy. *EPRI Project Manager: Robert Crow*

User's Guide to an Environmental Information Resource for Thermal Power Station Cooling Systems

EA-901 Interim Report (RP877)

A bibliographical computerized data base related to cooling system impacts on aquatic environments was compiled by the Information Center Complex at Oak Ridge National Laboratory (ORNL) and the Atomic Industrial Forum, Inc. (AIF). The data base covers four major subject areas: thermal effects, chemical effects, impingement, and entrainment. The ORNL portion of the project covers published literature, including government and university reports, conference proceedings, and trade journals. The AIF portion covers previously inaccessible "gray" literature and data—utility environmental reports, impact statements, Federal Water Act sections 316(a) and (b) demonstrations, state agency water quality reports, and the like. Data base products and services are described. *EPRI Project Manager: John Reynolds*

FOSSIL FUEL AND ADVANCED SYSTEMS

Structural Design Concepts for Increased Reliability and Safety in Power Plant Condensing Systems

FP-507 Final Report, Vols. 1 and 2 (RP372-1)

The University of Pennsylvania undertook a series of structural analyses of power plant condensers. Vol. 1 presents the results of an evaluation of the effect of the condenser tube bundle, acting as a foundation support, on the compressive-load-carrying capacity of tube support plates. Vol. 2 describes research in these areas: stress analysis of rectangular tubesheets, stress analysis of U-tube heat exchanger tubesheets, limit design of condenser hotwell floors, and tubesheet stress analysis using beam strip models. *EPRI Project Manager: John Dimmer*

Geothermal Heat Exchanger Test at Heber, California

ER-572 Final Report (RP846-1)

The Ben Holt Co. conducted a test of a tube-in-shell counterflow heat exchanger to measure long-term corrosion and fouling rates. The test used geothermal brine from the Nowlin No. 1 well at the Heber geothermal field in California. Two sections of the heat exchanger were tubed with steel and two with titanium so that data on both materials could be obtained from a single test. *EPRI Project Manager: Gary Underhill*

Electrostatic Precipitator Rapping Reentrainment and Computer Model Studies

FP-792 Final Report, Vol. 3 (RP413-1)

Using a mathematical model based on the physical principles of the electrostatic precipitation process, the Southern Research Institute analyzed the performance of electrostatic precipitators at six coal-fired power plants. Overall collection efficiency and collection efficiency as a function of particle size were measured with the collecting electrode rappers energized and deenergized. Samples of coal, fly ash, and flue gas were chemically analyzed, in situ and/or laboratory measurements of dust resistivity were performed, and secondary voltage-current relationships were obtained from the precipitator transformer-rectifier sets. The measurements of fractional efficiency indicated that efficiency losses due to electrode rapping occurred primarily for particles greater than 2.0 μm in diameter. *EPRI Project Manager: Walter Piulle*

Coal Slurry Feed Pump for Coal Liquefaction

AF-853 Final Report (RP775-1)

Rockwell International Corp. conducted a study to determine the feasibility of a high-volume, high-pressure centrifugal coal slurry feed pump for coal liquefaction. The study consisted of three tasks. Task 1 was an engineering study to define material erosion in centrifugal pumps and to select for experimental evaluation metals, hardfacings, coatings, and inserts capable of withstanding coal-oil slurries at high temperatures and pressures. Task 2 involved the testing of candidate materials with coal-oil slurries at the solvent-refined coal plants at Battelle, Columbus Laboratories and Wilsonville, Alabama. Task 3 was a design study of candidate centrifugal pump concepts in various configurations. An engineering evaluation of the pump concepts and their application in a pumping system was also made. *EPRI Project Manager: H. H. Gilman*

Solvent-Refined Coal Process: Operation of Pilot Plant at Wilsonville, Alabama

AF-867 Annual Report (RP1234)

This report by Southern Company Services, Inc., presents operating conditions and results for the 6-t/d solvent-refined coal (SRC) pilot plant at Wilsonville, Alabama, for October, November, and December of 1977. It also presents a general summary of activities at Wilsonville for the 1977 calendar year.

The effects of various process variables on SRC yield and quality were determined. These variables included process solvent boiling range, dissolver volume, accumulated-solids concentration, and hydrogen sulfide partial pressure. The effects of operating variables on the overall plant solvent inventory balance are also given. *EPRI Project Manager: Norman Stewart*

The Impact of RCRA (PL 94-580) on Utility Solid Wastes

FP-878 Final Report (TPS78-779)

The Resource Conservation and Recovery Act of 1976 (RCRA) created federal and state regulatory authority over solid and hazardous wastes. Most utility solid and liquid wastes fall under definitions in RCRA.

This technical planning study, conducted by Fred C. Hart Associates, Inc., provides an initial data base on potentially hazardous constituents in each solid-waste stream. The data, assembled from both open and industry literature, show that almost all the major solid-waste streams contain measurable levels of compounds or elements for which limits have been set by primary or secondary drinking water standards. *EPRI Project Manager: Dean Golden*

Environmental Effects of Normal and Off-Normal Releases of Tritium From CTR Systems

ER-879 Topical Report (RP236-2)

Controlled thermonuclear reactors (CTRs) will use the deuterium-tritium reaction. Researchers at the University of California at Los Angeles sought to quantify the hazard presented by major tritium release mechanisms. This report describes the method they developed for determining doses to the public from releases of tritium in the form of tritiated water vapor or tritiated lithium compounds. *EPRI Project Manager: Noel Amherd*

Preliminary Design Study for an Integrated Coal Gasification–Combined-Cycle Power Plant

AF-880 Final Report (RP986-4)

This report by The Ralph M. Parsons Co. presents the preliminary design, implementation schedules, and cost data for a fully integrated coal gasification–combined-cycle power plant using the oxygen-blown Texaco coal gasification process. The plant will have a net electrical output of 92 MW and will be located at Southern California Edison Co.'s Coolwater Generating Station near Barstow, California. *EPRI Project Manager: Michael Gluckman*

Development of Standard Laboratory Resistivity Apparatus

FP-885 Final Report (RP464-1)

Recommended procedures for measuring particulate resistivity have been available for some time. Denver Research Institute reviewed three general types of laboratory resistivity cells: a coaxial cell with guard rings, a parallel plate cell without guard rings, and a parallel plate cell with guard rings. Because of the necessity of collecting and processing a large quantity of data in the study and the desirability of imposing reproducible conditions for testing, a completely automated system incorporating a minicomputer was designed. *EPRI Project Manager: Walter Piulle*

Application of Acoustic Agglomeration for Fine-Particle Emission Control

FP-887 Final Report (RP539-1)

Flue gases are routinely purged of their suspended fly ash burden by being passed through an electrostatic precipitator, a scrubber, or a fabric filter. All these devices remove the coarser particles more efficiently than they do the finer. If the dusty gas were first passed through a sonic agglomerator so that most of the finer particles were agglomerated into coarser ones before the gas entered the collector, the overall collection efficiency would improve.

This report by the State University of New York at Buffalo considers the economic feasibility of such an approach. The project combined a theoretical investigation and laboratory-scale experiments to evaluate sonic agglomeration constants attained with particles of various substances, including polystyrene latex particles, dioctyl phthalate particles, Fe_2O_3 particles, and others. *EPRI Project Manager: Walter Piulle*

EPRI-Radian Particle Balance Concept Study

FP-889 Final Report (RP630-3)

Radian Corp. undertook a project to demonstrate the effectiveness of a patented process control concept for lime/limestone scrubbing systems. If the mechanism governing new particle generation is controlled in an operating scrubbing system, the average size of the product sludge particles can be increased. This report describes the resulting impact of this change on the characteristics of the scrubber sludge generated by Louisville Gas and Electric Co.'s Paddy's Run No. 6 flue gas desulfurization system. *EPRI Project Manager: Thomas Morasky*

Fluidized-Bed Retrofit Study on Consolidated Edison's Arthur Kill No. 3 Generating Station

FP-893 Final Report (RP717-2)

Combustion Engineering, Inc., studied the feasibility and cost of retrofitting a utility boiler to fire coal by atmospheric fluidized-bed combustion. The retrofit study was conducted at the 500-MW Arthur Kill Unit No. 3, operated by Consolidated Edison Co. of New York, Inc. The fluidized-bed design parameters were based on those established for the Rivesville unit. *EPRI Project Manager: Shelton Ehrlich*

Experimental Investigation of the Removal of Hydrogen Sulfide From Geothermal Steam

ER-896 Final Report (TPS76-656)

In geothermal steam power production, such corrosive compounds as hydrogen sulfide have to be removed; it is most desirable to accomplish this removal upstream of the turbine. Earlier work with the high-intensity ionizer suggested that high-intensity corona might be adopted to remove hydrogen sulfide from geothermal steam. The purpose of this experimental investigation by Air Pollution Systems, Inc., was to examine the technical feasibility of this process. *EPRI Project Manager: Vasel Roberts*

Computational Method for Fluid Dynamic Analysis of Electrostatic Precipitator

FP-898 Final Report (RP531-2)

Flow Research, Inc., investigated new approaches to improving the design and performance of electrostatic precipitators (ESPs). Through the use of a finite-difference computation scheme, the turbulent flow field and fine-particle trajectories around an ESP collecting electrode were described. This analytic technique was used to evaluate the turbulent flow characteristics of four collecting-electrode geometries. A possible new development, the fluid dynamic collector, was also investigated. *EPRI Project Manager: Walter Piulle*

Turbine Cycle Performance Improvement Through Titanium Low-Pressure Blades

AF-903 Interim Report (TPS77-746)

Westinghouse Electric Corp. conducted thermodynamic, mechanical, and economic analyses of the application of long titanium blades in low-pressure steam turbines. Improvements in turbine cycle heat rate of 1% for fossil units and 2% for nuclear units were indicated for machines whose last-row blade lengths are increased by 30–40%. *EPRI Project Manager: Robert Jaffee*

NUCLEAR POWER

Clean Critical Experiment Benchmarks for Plutonium Recycle in LWRs

NP-196 Final Report, Vol. 2 (RP348)

In order to provide benchmark information for testing fuel-cycle analysis methods and nuclear data libraries, EPRI supported a series of critical lattice experiments at Battelle, Pacific Northwest Laboratories' plutonium recycle critical facility. These experiments involved water-moderated uniform uranium oxide and mixed (uranium-plutonium) oxide critical lattices. The work was described in the first volume of this report (NP-196, Vol. 1). The present volume presents the foil activation data obtained from this experimental program. *EPRI Project Manager: Odelli Ozer*

Flaw Evaluation Procedures: Background and Application of ASME Section XI, Appendix A

NP-719-SR Special Report

Appendix A, "Evaluation of Flaw Indications," of *ASME Section XI, Rules for In-service Inspection of Nuclear Power Plant Components,* contains procedures acceptable to the Boiler and Pressure Vessel Code Committee for establishing the acceptability of flaw indications found in nuclear pressure boundary components. This report contains a series of sample problems that illustrate the evaluation procedures contained in Appendix A. These sample problems cover all operational and test conditions, considering such factors as flaw location, flaw size, flaw growth due to normal and abnormal loads, degradation of properties as a result of neutron fluence, and the application of linear elastic fracture mechanics. In addition, the technical basis for the fracture analysis methods of Appendix A is provided, with documentation of the material properties shown for reference in the appendix. *Edited by Theodore Marston*

Study to Define Nondestructive Evaluation Research for Inspection of Stainless Steels

NP-797-SR Special Report (TPS75-620)

Following BWR stress corrosion cracking incidents on 10- and 25-cm (4- and 10-in) stainless steel piping, EPRI organized a round-robin ultrasonic examination of piping removed from service. Five inspection teams participated in this program, with each using both a standard procedure and the individual team procedure. *EPRI Project Manager: Eugene Reinhart*

Self-Actuated Shutdown System for a Commercial-Size LMFBR
NP-846 Final Report (RP897-1)

A self-actuated shutdown system (SASS) is defined here as a reactor shutdown system in which sensors, release mechanisms, and neutron absorbers are contained entirely within the reactor core structure, where they respond inherently to abnormal local process conditions by shutting down the reactor independently of the plant protection system (PPS). It is argued that an SASS, having a response time similar to that of the PPS, would so reduce the already very low probability of a failure-to-scram event that costly design features, derived from core-disruptive accident analysis, could be eliminated. However, this report by Combustion Engineering, Inc., focuses on the feasibility and reliability of the in-core SASS hardware to achieve sufficiently rapid shutdown. A number of transient overpower and transient undercooling responsive systems were investigated, leading to the selection of a primary candidate and a backup concept. *EPRI Project Manager: Bal Raj Sehgal*

CCB, A Two-Dimensional Diffusion Theory Continuous-Cross-Section Burnup Code for Fast-Reactor Analysis
NP-847 Final Report (RP349-1)

In this report by Purdue University, burnup calculation procedures for fast breeder reactors are briefly reviewed. Disadvantages of the procedures are discussed, and several improvements are outlined and implemented. Microscopic group constants, which are usually considered time-independent over each burnup interval, are replaced by time-dependent expressions. These time dependencies are evaluated in terms of polynomials of the actinide number densities with predetermined coefficients. The burnup equations are solved with time-dependent (instead of the usual time-independent) one-group cross sections. As a result, one-group flux calculations can replace most of the multigroup flux calculations for updating the power distribution. Use of these improvements reduces the computation time by more than a factor of 2 for a six-group problem, with very little inaccuracy in the predicted material inventory. *EPRI Project Manager: Bal Raj Sehgal*

Retirement for Cause: A Workable Approach for Structural Life Extension and Response to In-Service Problems
NP-855 Topical Report (RP700-1)

Retirement for cause (RFC) is a procedure by which turbine rotors and other life-limited components are retired from service because of measurable fatigue, creep, corrosion, or wear damage rather than because of subjective interpretation of problems with similar equipment or because a calculated design life has expired. In examining the economic gain resulting from the RFC procedure, Failure Analysis Associates studied the effects of analysis errors and inspection errors, single and repeated applications of the procedure to an individual turbine disk, and use of a conventionally calculated stress (independent of observed cracks) rather than an inspection-based stress. This publication includes two separate but technically complementary reports: "A Workable Approach for Extending the Life of Life-Limited, Inspectable, Expensive Components," and "A Workable Approach for Extending the Life of Turbine Rotors With Subsurface Defects." *EPRI Project Manager: Floyd Gelhaus*

Large Pool LMFBR Design
NP-883-SY Executive Summary (RP620-26)

Westinghouse Electric Corp. conducted a project to refine the design status of components conceptually designed in a prior phase, to complete the conceptualization of the remainder of the nuclear island unique to the pool-type system, and to identify any conceptual feasibility problems of pool-type liquid metal fast breeder reactors. *EPRI Project Manager: Grant Baston*

EPRI Steam Turbine–Related Research Projects
NP-888-SR Special Report

The purpose of this report is to provide a perspective of EPRI projects that relate to steam turbine reliability. Compiling status information is a part of the planning effort for continuing projects on turbine rotor reliability, turbine chemistry monitoring, and materials behavior, and for the proposed project related to cracking of shrunk-on disks in low-pressure nuclear steam turbines. *EPRI Project Manager: Floyd Gelhaus*

Operating and Testing Experience During Startup and Initial Operation at the Fort St. Vrain HTGR
NP-890-SY Summary Report (RP457-1)

The Fort St. Vrain Nuclear Generating Station was designed and constructed as the first commercial-size high-temperature gas-cooled reactor (HTGR) plant. The S. M. Stoller Corp. developed detailed documentation of the significant experiences at the plant from construction through the early phases of rise-to-power testing. *EPRI Project Manager: James Kendall*

An Ultrasonic Pattern Recognition Study of IGSCCs Versus Weld Crown Reflectors in Stainless Steel Piping
NP-891 Interim Report (RP892-1)

Ultrasonics International applied pattern recognition techniques to discriminate between geometrical and crack reflector signals (obtained during ultrasonic inspection of the weld zone in type-304 austenitic stainless steel piping) for one set of data. Seven welds from four different 4-in-diam (10-cm-diam) pipe specimens containing intergranular stress corrosion cracks (IGSCCs) were examined ultrasonically. *EPRI Project Manager: Eugene Reinhart*

Transition-Boiling Heat Transfer in a Vertical Round Tube
NP-895 Interim Report (RP688-1)

The University of Cincinnati obtained heat transfer coefficients for transition boiling in water. The water flowed inside a 1.2-cm (0.5-in) OD tube and was heated by hot mercury flowing in an annulus around the tube. Thermocouple pairs placed on the outside of the central tube and outer pipe at several axial elevations allowed the rate of heat transfer to be determined. *EPRI Project Manager: David Cain*

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