Protecting Groundwater Quality
A Special Report

ELECTRIC POWER RESEARCH INSTITUTE

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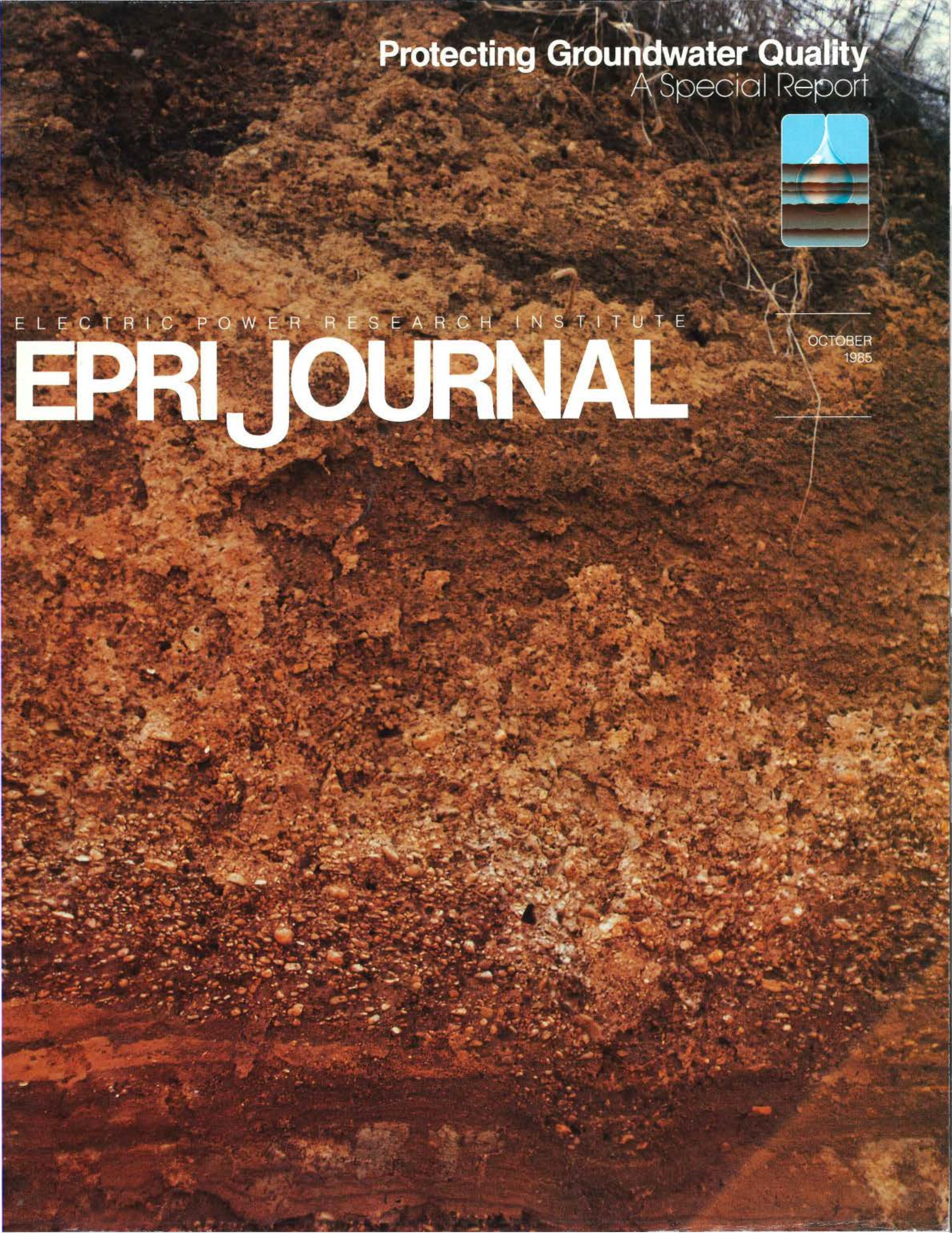

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EPRI was founded in 1972 by the nation's electric utilities to develop and manage a technology program for improving electric power production, distribution, and utilization.

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Cover: Groundwater is normally dispersed through layers of soil and rock called aquifers. In relatively permeable aquifers, such as sand or gravel, the water saturates the spaces between individual grains; in hard rock formations, groundwater travels through a maze of cracks and fractures in the rock.

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Groundwater Preservation: The Utility Role

Although preservation of groundwater quality has emerged in recent years as one of America's preeminent environmental concerns, surprisingly little is known about the general condition of groundwater throughout the country. As a major industry producing large amounts of waste, utilities are obliged to help the nation preserve and assess the status of its groundwater resource, despite the fact that virtually all by-products of fossil fuel power generation are nonhazardous under federal law and have been managed responsibly for decades. Such an endeavor is also in the best interests of the utility industry, for without research, decisions will be made and policies promulgated in the absence of scientific understanding of the problem. The cost to the industry of ill-informed policy would far outweigh the costs of gathering the data needed to support sound regulations. We owe it to ourselves and to our descendants to approach this challenging task with integrity, informed by the most thoughtful, comprehensive analyses our scientific tools can offer.

EPRI and the utility industry have an ambitious research program under way to answer a host of important questions regarding utility wastes and groundwater quality. Field measurements of solute migration through soils are being gathered to form an empirical base for hydrologic models of the leaching behavior of utility wastes. This and similar research will provide state-of-the-art information to guide future waste handling and disposal regulations. Simultaneously, the industry is pursuing an ambitious technology development program to deal with the immediate engineering challenges of expanding utilization of utility by-products, improving disposal practices, and, ultimately, developing new kinds of power plants designed with enhanced by-product use and handling in mind. As in the air quality field, the best long-term approach to mitigating solid-waste problems may be the adoption of clean-coal combustion processes, such as fluidized-bed combustion and integrated gasification–combined cycle.

Groundwater is a vast, slowly changing resource; once contaminated it is very difficult to clean. This realization should predispose us toward caution. It is imperative, however, that our caution be guided by a clear understanding of the risk posed by various levels of contamination and the costs and benefits of reducing that risk.

Part 1 of this special *Journal* issue examines the status of groundwater research in the United States and the effort by EPRI and others to build a scientific framework for cost-effective programs and policies to protect this vital resource. Part 2 focuses on utility wastes and the various programs now under way to put them to productive use and minimize their environmental impact. These stories demonstrate the industry's commitment to R&D that preserves our quality of life as well as the health of our environment.

Richard E. Balzhiser, Senior Vice President
Research and Development Group

Authors and Articles

Concern about industrial wastes and how they can contaminate groundwater supplies reflects a growing reality that so far has resisted a comprehensive, clearcut, and immediate solution. This special report reviews the facts of the situation and the purposeful R&D efforts being sponsored by EPRI on behalf of the electric utility industry.

Groundwater: Examining a Resource at Risk (page 6) describes a vital resource and the many unforeseen mechanisms and pathways of pollution that have come about with the proliferation of synthetic chemicals in our daily uses and daily wastes. The author is Taylor Moore, the *Journal*'s senior feature writer, working in conjunction with five EPRI research managers, two from the Energy Analysis and Environment (EAE) Division and three from the Coal Combustion Systems (CCS) Division.

Utility Solid Waste: Managing the By-products of Coal Combustion (page 20) categorizes and characterizes the major wastes produced by coal-fired power plants. It also reviews research to minimize, isolate, convert, and recycle them. Feature writer Michael Shepard wrote the article with assistance from the same CCS research managers.

Dean Golden and Ralph Komai are project managers in the Heat, Waste, and Water Management Program of the CCS division. They guide research in solid-waste disposal; Komai also works in PCB detection and disposal. Both came to EPRI from Southern California Edison Co., Golden in 1978 and Komai in 1979, after several years in environmental management there. Golden was responsible for the utility's compliance with water and waste regulations; Komai managed technical reviews of those regulations. Golden has two degrees in civil engineering and an MBA. Komai graduated in mathematics and chemistry and earned an MS and a PhD in chemistry.

Thomas Morasky was named manager of the Heat, Waste, and Water Management Program in October 1984, having been a project manager in the Desulfurization Program since he came to EPRI in August 1976. He was formerly with Detroit Edison Co. for 10 years, supervising the design, installation, and operation of several flue gas scrubbers. Morasky graduated in chemical engineering.

Glenn Hilst, manager of the Environmental Physics and Chemistry Program since 1980, joined EPRI's EAE division in October 1977. He formerly was the chief scientist of TRC Environmental Consultants, Inc., and before that, vice president and senior consultant for Aeronautical Research Associates. From 1960 to 1970 Hilst was a vice president of Travelers Research Center and director of its environmental science department. He holds three degrees in meteorology.

Ishwar Murarka, a project manager in Hilst's program, has special responsibility for land and water quality studies. He came to EPRI in October 1979 and first worked in aquatic systems research, building on experience he gained during five years as an environmental scientist at Argonne National Laboratory. Murarka graduated in geography, has two advanced degrees in soil science and statistics, and holds an MBA.


Morasky


Golden


Komai

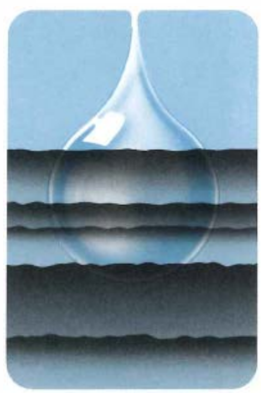

Hilst


Murarka

Part 1 Protecting Groundwater Quality

GROUNDWATER

EXAMINING A RESOURCE AT RISK



Mounting public and regulatory concern over contamination of groundwater has altered the country's view of waste disposal practices. Through an integrated program of fundamental research, EPRI is studying the release, migration, and attenuation of waste products moving through groundwater aquifers.

Water that flows unseen beneath the Earth's surface was long thought of as a pristine resource, filtered and protected from the effects of man's activities by layer on layer of rock and soil. But the accumulated chemical and biologic by-products of a century's worth of industrialization, population growth, and related development are pressing hard on the environment. Incidents of groundwater contamination have occurred in all 50 states and have forced the closing of several thousand public and private wells.

There is no doubt that since World War II the number of chemicals developed and being used in the full spectrum of human activity has multiplied manyfold and that some of these chemicals—including some considered toxic—are finding their way into surface waters and groundwaters. But how widespread is this problem on a national scale? Most experts agree that the percentage of groundwater that is contaminated is small, probably around 1–2%. Others point out that because only a fraction of the total groundwater resource has actually been tested, the extent of contamination may be greater than 2%.

Regardless of what figure turns out to be correct, legislative and regulatory pressure to protect the public and the environment from the perceived risks is growing, as are research efforts to quantify and characterize the real dangers to groundwater quality. The past 15 years have seen the emergence of ever more accurate and sensitive instruments and techniques for detecting substances in water at exceedingly low concentrations—parts per billion, and even lower.

This technical virtuosity has worked both for and against a realistic appreciation of the situation. We now know that a great number of individual chemicals can be detected in the groundwater of some specific areas; but the growing list of trace chemicals has become almost an end in itself, crowding out the more pertinent question of whether hazardous substances are present in concentrations that pose a real threat to groundwater quality or human health.

Unfortunately, our understanding of the mechanisms and pathways for environmental release and the health effects of human exposure to low levels of most of these substances has not kept pace with our ability to detect them. Obtaining this understanding is the present research challenge—to identify and quantify the specific risks so that limited resources can be directed to those areas where they will do the most good.

EPRI has an expanding, coordinated interdivision research effort that is addressing many of the key scientific and engineering uncertainties of the disposal of chemical wastes by the electric utility industry. The overwhelming majority of utility waste is classified as nonhazardous; among industrial producers of toxic and hazardous wastes, utilities rank low on the list, behind petroleum production and refining, chemicals, plastics, steelmaking and metalworking, agriculture, and other producers. Still, the volumes of waste produced by utilities are large and the costs of meeting current regulatory standards have already increased significantly. Some major research questions remain to be answered if utilities are to avoid further, and perhaps unnecessary, regulatory and financial burdens. And this must be done while sustaining a determined effort to preserve the quality of groundwater as a critical national resource.

The groundwater resource

In the United States, experts say, between 33 and 100 quadrillion (10^{15}) gallons of water are contained underground in permeable or porous geologic formations that range from a few feet to several hundred feet thick. The volume of groundwater within one-half mile of the surface in this country is estimated to be four times that of the Great Lakes. An integral part of the global hydrologic cycle—second only to the oceans and seas—groundwater supplies just under a third of the total streamflow in this country and provides most, if not all, of the low water flow in streams during dry periods.

The use of groundwater for all purposes is increasing: total withdrawals grew from 35 to 90 billion (10^9) gallons a day between 1950 and 1980, in parallel with a population that has increased from about 151 million to 227 million over the same period. In addition to

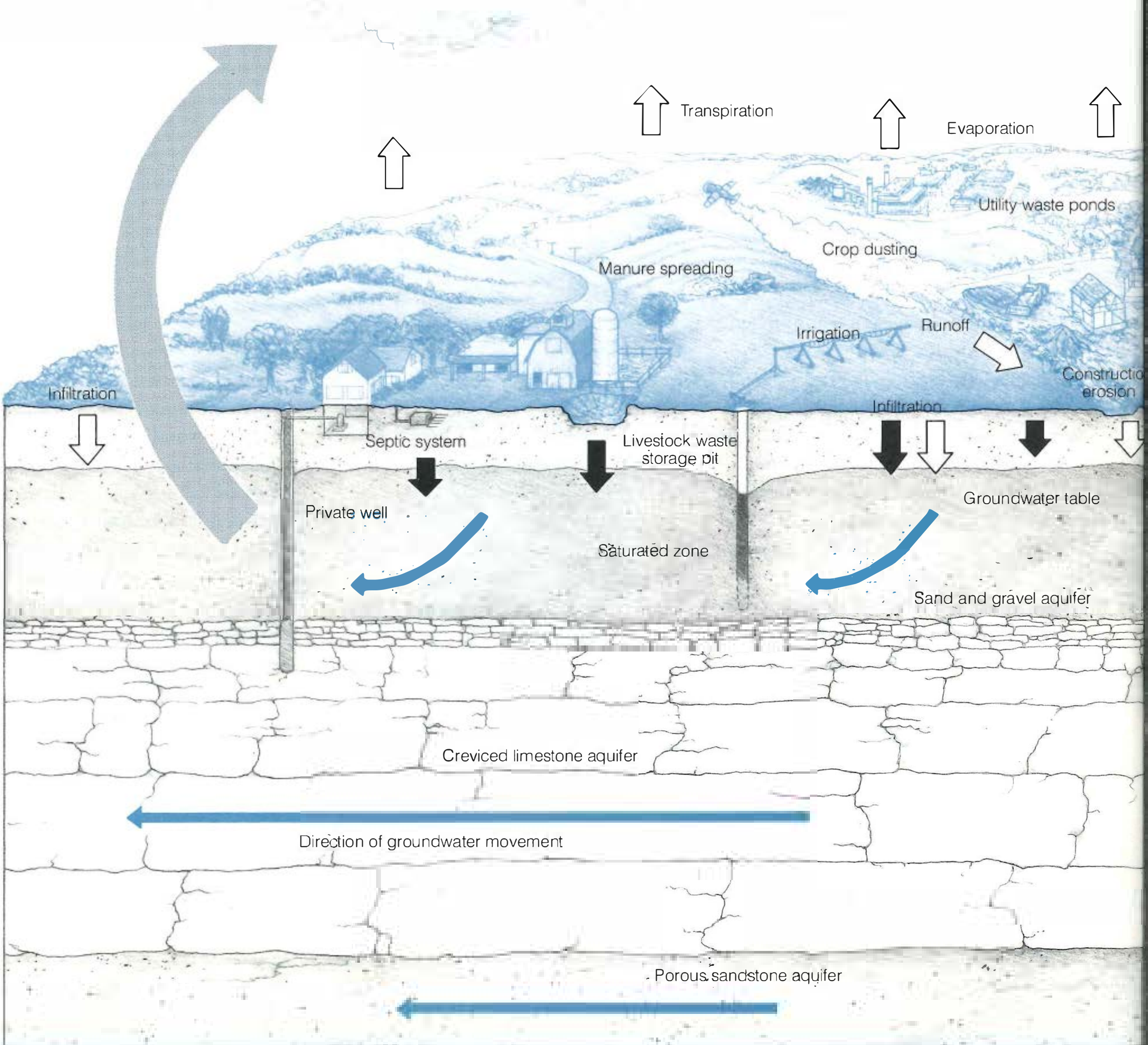
Direction of groundwater movement

Human induced impacts on groundwater

Natural processes

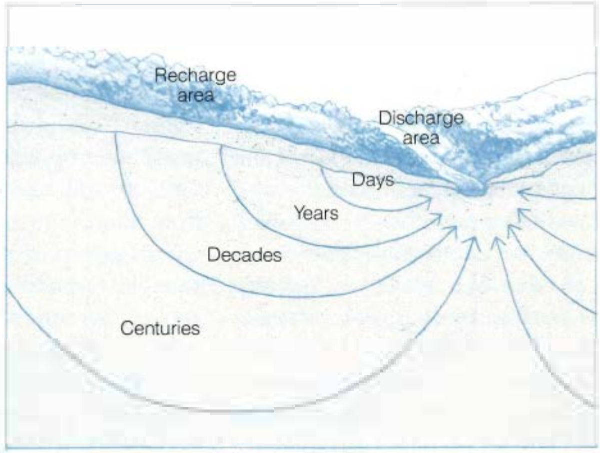
Groundwater in the Water Cycle

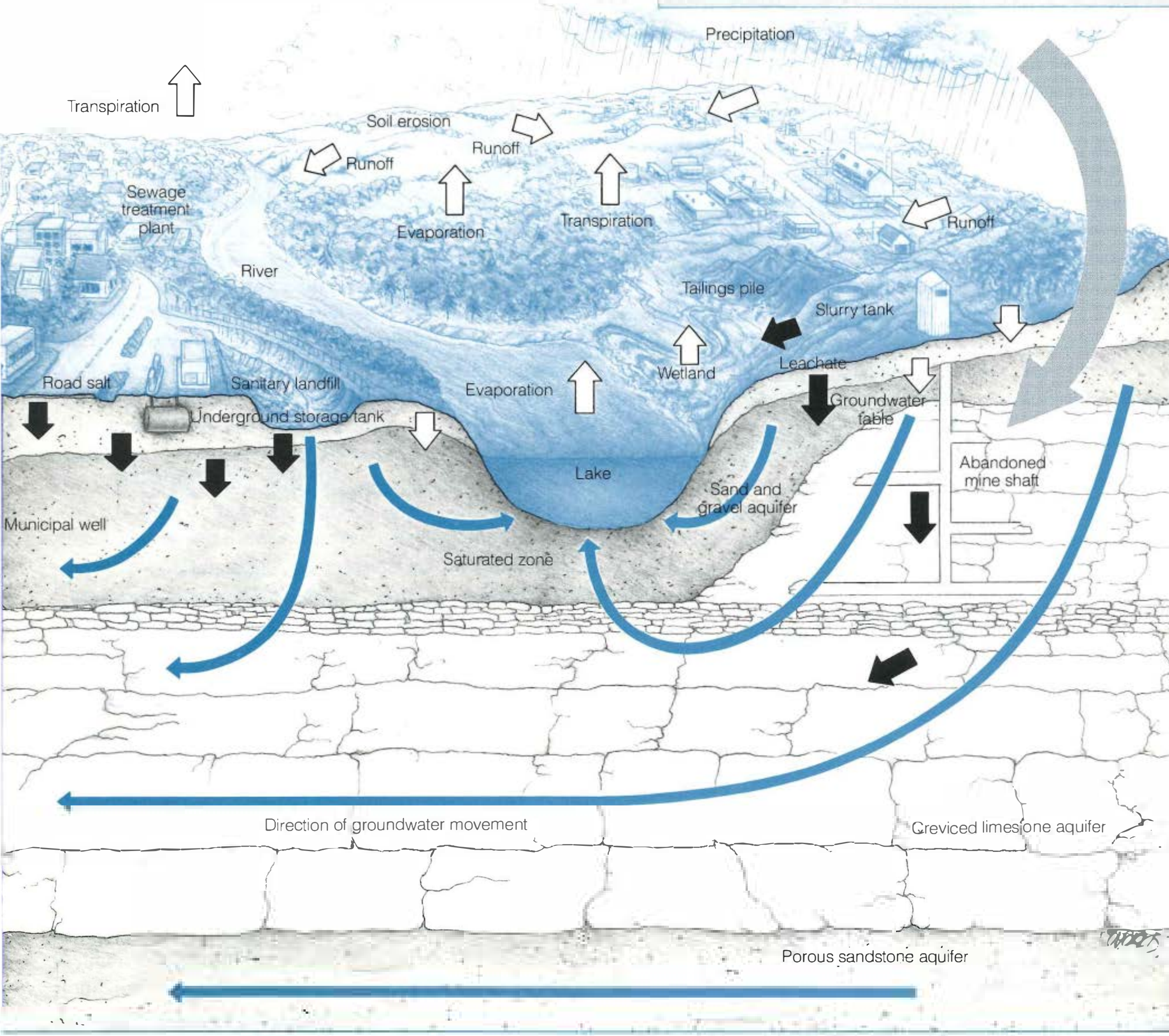
Groundwater—water that saturates soil and rock formations below the water table—plays an integral role in the hydrologic cycle and supplies the drinking water for half of this country's population. Bodies of groundwater stored in underground geologic formations, known as aquifers, may range in thickness from a few feet to several hundred feet and extend in area for many square miles. Shallow aquifers close to the land surface may be recharged by rainfall and surface runoff that percolates through pores and cracks in overlying soil and rock. Deep aquifers may contain large quantities of water, though they typically receive no surface recharge. All groundwater tends to move toward an area of discharge in lowlands where the water table intersects the land surface in streams, lakes, or wetlands. But rates of movement vary greatly depending on the local geology. Groundwater moves more quickly in and through sandy aquifers but is slowed by clay soils or lightly fractured limestone. Threats to groundwater quality can come from the full spectrum of man's activities on or near the surface, including septic tanks, agricultural fertilizer and pesticides, waste landfills and ponds, underground storage tanks, and other sources of soluble material.



Flow Within Groundwater Systems

The time required for groundwater (and contaminants that may be in the groundwater) to move through aquifers and reach surface streams or drinking water wells can range from days and years to decades and centuries. Many factors affect the travel time, including distance, hydraulic gradient, the nature of local geologic media, and the chemical nature of the contaminants themselves. Groundwater in sandy or coarse rock formations, for example, may move as much as several feet a day while less-permeable geology may limit the rate of movement to a few inches a year. Water in some very deep aquifers has remained virtually in situ for thousands of years.





supplying half the nation's drinking water, groundwater is the source of all water for 80% of the country's rural population, and it supplies 40% of the total requirement for irrigation (which accounts for two-thirds of all the groundwater withdrawals). About 80% of the nation's community water supplies also come from the ground.

Groundwater aquifers, variously composed of sand and gravel or different types of fractured rock, may or may not be confined by overlying strata of relatively impermeable geologic material. Shallow aquifers, which occur closer to the land surface, are recharged by water from direct rainfall and surface runoff that filters through the cover material. Aquifer size can range from a small area to a large region. An example of the latter is the Ogallala aquifer, which underlies the central United States and sustains most of the agricultural production in six High Plains states.

Once chemicals are released to the underground environment, the speed with which they can travel through the soil to eventually reach underlying aquifers varies according to the permeability and homogeneity of the local geologic media (cracks and fissures, for example, can accelerate the movement), the degree to which soil particles retain the contaminants, the depth of the water table, and the rate and direction of groundwater movement. Depending on the ways local geochemical and hydrologic factors influence specific substances, some chemicals may never reach groundwater.

The direction and rate of movement of groundwater are key variables that must be determined with a fairly high level of accuracy to assess the potential for or degree of chemical contamination. Such fundamental features of a technically complex resource are generally inferred from monitoring well data.

Groundwater velocities in sand and gravel aquifers typically range from 10 to 100 meters per year. The time it takes for groundwater contaminants to disperse and reach a monitoring well hundreds or thousands of meters downgradient can be on the order of decades. For this reason, attempts to restore contaminated aquifers can take many years, cost millions of dollars, and yield uncertain results. Groundwater management practices therefore usually focus on prevention of contamination rather than on restoration.

The quality of groundwater is highly variable. Depending on the surrounding geology, groundwater may have naturally occurring levels of dissolved solids (usually calcium from rocks), salts, trace metals such as arsenic and selenium, and even radionuclides from naturally occurring uranium and thorium deposits. Water treatment systems can usually reduce the levels of natural contaminants to safe drinking water standards, but that task is increasingly complicated by the need to treat contaminants resulting from man's activities.

Sources of contamination

Perhaps the most surprising aspect of groundwater contaminants is the ubiquity of their potential sources. Although highly publicized spills, accidents, and cases of improper management of industrial chemicals are popularly considered to be at the heart of contamination, indications are that groundwater quality has been degraded even more heavily by simple, everyday human commerce and by activities as mundane as flushing a toilet, running a dishwasher, or doing the laundry.

"Contaminants enter groundwater from countless sources—including millions of septic tanks; leaks from hundreds of thousands of miles of underground sewer lines and several million buried tanks; and runoff from agricultural lands, the national network of roads and highways, and commercial, mining, and industrial properties," says James J. Geraghty, a hydrogeologist and principal in the prominent groundwater consulting firm of Geraghty & Miller, Inc. "So far, EPA and state agencies have focused almost all their efforts on only a small percentage of these sources—mainly those owned and operated by industries or other groups that appear to have the financial resources to make the necessary investigations and to institute cleanup procedures."

In its recent comprehensive report, Congress's Office of Technology Assessment points out that of all sources known to contribute to groundwater contamination, septic tanks and cesspools directly discharge the largest volume of wastewater into the subsurface; they are also the most frequently reported sources of groundwater contamination. There are 17–20 million residential sewage disposal systems in the United States; the number of commercial and industrial septic tanks is unknown.

Contaminants from these domestic systems are principally human wastes (e.g., coliform bacteria, viruses) but also include nitrates, chlorides, and various metals (e.g., lead, zinc, copper, manganese, tin, iron). Additives and cleaning solvents, including trichloroethylene, benzene, and dichloromethane, also routinely enter groundwaters through domestic waste disposal systems.

In addition to this category, there are at least 30 other significant categories of potential groundwater contamination sources, including an estimated 140,000 brine injection and enhanced oil recovery wells; several hundred thousand wells for sewage and agricultural waste disposal; 15,000–20,000 open and closed municipal waste landfills; 75,000 active industrial landfill sites; about 200 facilities for disposal of both liquid and solid hazardous wastes; an estimated 180,000 surface impoundments (ponds) for all types of waste; some 2.5 million to 5 million underground storage tanks for petroleum and other chemical products; and about 30 commercial and government radioactive waste disposal sites around the country.

Other sources of potential groundwater contaminants include the millions of acres under agricultural irrigation (which can leach chemicals from the soil into runoff water), lands treated with pesticides and fertilizers, animal feedlots, and land application of treated wastewater or industrial and sewage sludges.

The accounting above gives a strong feeling for the diversity and multiplicity of the potential sources of contamination. It cannot be assumed that any particular site of potential contamination will contribute to groundwater degradation, and certainly only a small percentage of sites are believed to have accounted for incidents in which chemicals in groundwater have reached unsafe levels. Nevertheless, such a catalog of potential problems underscores the practical difficulties in working on the groundwater issue. The institutional problems alone are formidable: Assuming that chemical wastes pose a potential hazard to groundwater quality, which sources do we deal with first? Who is considered responsible? Who will pay for preventive or remedial action?

Regulatory framework

Congress has passed several major bodies of legislation in recent years that form a complex web of regulations and standards related to hazardous waste. The most publicized of these is the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, which established the Superfund program for identifying and cleaning up the worst of the country's problem toxic waste dumps. More than 2000 waste sites now appear on the Superfund list as areas slated for eventual cleanup by EPA.

Cleanup of existing toxic trouble spots is certainly a crucial piece of the federal groundwater effort. But perhaps even more important for the future of groundwater quality are the 1984 amendments to the Resource Conservation and Recovery Act (RCRA) of 1976, which approach the problem more from the prevention side. With the RCRA amendments, Congress issued clear signals to encourage alternatives to land disposal of hazardous waste, including immobilization and volume reduction techniques, as well as incineration.

The amendments provide tough civil and criminal penalties for noncompliance, and they expand the scope of liability of the regulated community. Businesses can be held liable for improper or inadequate disposal of hazardous wastes at sites to which they have merely shipped waste and for recovery of site cleanup costs even if they have contributed only a portion of the waste at a site.

New hazardous waste sites will be subject to much more stringent requirements—such as bottom liners and leachate collection systems—designed to protect groundwaters from contamination, and additional requirements could be placed on existing sites as EPA moves to implement the new mandate. The Congressional Budget Office estimates that the RCRA amendments could double American industry's annual compliance

The Ogallala Aquifer: A Unique Groundwater Resource

One of the world's largest aquifers, the Ogallala encompasses an extensive area in the central United States. The aquifer's average thickness ranges from 200–300 ft (60–90 m) in its southern reaches to more than 1200 ft (370 m) in central Nebraska. For the past 40–50 years, the Ogallala has supplied nearly all the water for irrigation and drinking in the High Plains. About 200,000 irrigation wells tap the Ogallala and withdraw enormous quantities. As recently as seven or eight years ago, more than 3 billion (10^9) acre-feet of water remained in storage in the aquifer; but recharge from surface waters or other nearby aquifers is minimal.

costs for hazardous residuals, pushing them as high as $11.2 billion.

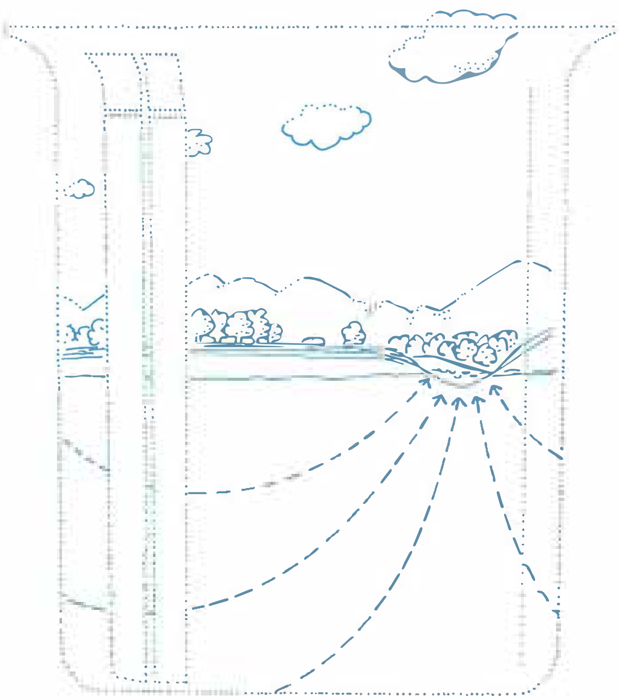
But the solution to groundwater protection is not simply a matter of money. Implementation of new guidelines and procedures can be tedious and slow, as EPA is learning in various programs. Since last year, the agency has pursued a strategy for protecting groundwater from contamination that incorporates a risk assessment approach. It calls for focusing protection and cleanup efforts where groundwater of particular public value is vulnerable to contamination, and it places less emphasis on groundwater that is not a current or potential source for drinking or other purposes. The focus on prevention reflects the fact that aquifers, once contaminated, can be extremely difficult (and in many cases impossible) to completely restore.

EPA's groundwater strategy relies heavily on state management and protection programs (including $7 million for state grants this year), development of a groundwater classification system to guide agency efforts, and EPA coordination of the many federal agencies and programs associated with groundwater problems and analysis. It includes development of waste disposal facility design and siting criteria, improved management practices, facility performance and effluent standards, and expanded groundwater research.

Utilities' combustion wastes have so far been exempted from significant federal regulation under the hazardous waste provisions of RCRA, including the recent amendments. The legal definition of hazardous waste excludes ash and flue gas desulfurization (FGD) sludge, pending completion of a congressionally mandated EPA study expected to be issued next year. EPA's recommendations will depend, in part, on the effects of a technical change in the procedure for measuring the presence and levels of a variety of hazardous substances in waste leachate samples. How the utility solid wastes are characterized under the revised procedure could have important

Protecting Groundwater Quality

EPRI's Solid-Waste Environmental Studies



In 1983 EPRI consolidated several projects in the EAE division related to utility combustion wastes under the single heading of solid-waste environmental studies (SWES) in the Environmental Physics and Chemistry Program. The goal of SWES is to develop methods and associated data for predicting the release, transformation, transport, and ultimate fate of chemical constituents of solid waste at utility disposal sites, according to Ishwar Murarka, a senior project manager for geohydrochemical research.

Murarka now manages over half a dozen related contracts under SWES that are designed to yield both near-term and long-term results. Objectives for the next 4–5 years include the gathering of laboratory and field data on leachate generation, subsurface dispersion, and chemical transformation and attenuation of waste constituents; the development of a quantitative understanding of the mechanisms of leaching and associated geohydrochemical processes; and the development of improved, more-cost-effective field methods for sampling and measuring chemicals in solid waste or in groundwater. SWES investigations are currently focused on boron, sulfate, and seven of the heavy metals of major interest in coal and oil ash and FGD sludge; low-volume chemical wastes (which include boiler cleaning fluids) are not covered in the research.

For the longer term, SWES will focus on the development and validation of improved computer models that can accurately predict the leaching, dispersion, transformation, and attenuation of chemicals from solid-waste disposal sites. Such models will be useful to utilities in designing new disposal facilities, as well as in managing existing ones. "The ability to predict with reasonable precision the nature and extent of effects on groundwater will help define when and to what extent environmental controls need to be applied," adds Murarka.

Most currently available codes for modeling contaminant transport and behavior underground are screening models and thus suffer either from limited applicability to different soil zones and types or from rate coefficients based on unrealistic assumptions about the physical and chemical processes. "We're taking a unique approach to model development in the SWES projects," says Murarka. "Instead of developing new codes by saying 'let's assume this and that,' which most modelers now do, our approach is to first ask 'what is really happening, and why?' To get answers to those questions, we are conducting experiments and field studies—we're doing the applied science to make sure we understand the fundamental processes of the complex system that we're working with. Then we'll know how to properly model the processes; ultimately, we'll validate the models with more field work."

Glenn Hilst, manager of the Environmental Physics and Chemistry Program, says SWES should result in "a hierarchy of models for different applications. But to build the hierarchy, we need to know what the ultimate model is. From the ultimate model we can then produce simpler versions for specific applications."

To generate data for the models, Murarka and a small army of SWES contractors are well along in a number of investigations of leachate chemistry, attenuation, and subsurface transport processes. Battelle, Pacific Northwest Laboratories is responsible for much of the research into attenuation and leaching as well as for the early phases of model evaluation and improvement. Murarka says results from the chemical attenuation studies can probably produce the greatest incremental improvement in methods for predicting solute migration.

Murarka reports that Battelle's research has already produced empirical data of direct use to the industry. "Chromium is one of the nastier chemicals in combustion wastes considered toxic at fairly low concentrations. Understanding the geochemistry accurately is therefore essential. Prior to EPRI's research, the literature suggested that the solubility of chromium would yield solution concentrations that would exceed drinking water standards. But new information we have developed from the attenuation studies shows that actual concentrations will be at least an order of magnitude less. The solubility of chromium hydroxide solids will limit the solution concentrations of chromium to levels well below today's drinking water standards."

Efforts to evaluate and recommend improvements in the accuracy of measurement and sampling methods for wastes, soils, and groundwater are cofunded by EPRI, Wisconsin Power & Light Co., and Pennsylvania Power & Light Co.; Residuals Management Technology, Inc., is the contractor. According to Murarka, "Results of preliminary experiments show that several of the most commonly used sampling devices and techniques seriously alter the chemical integrity of the samples under certain conditions."

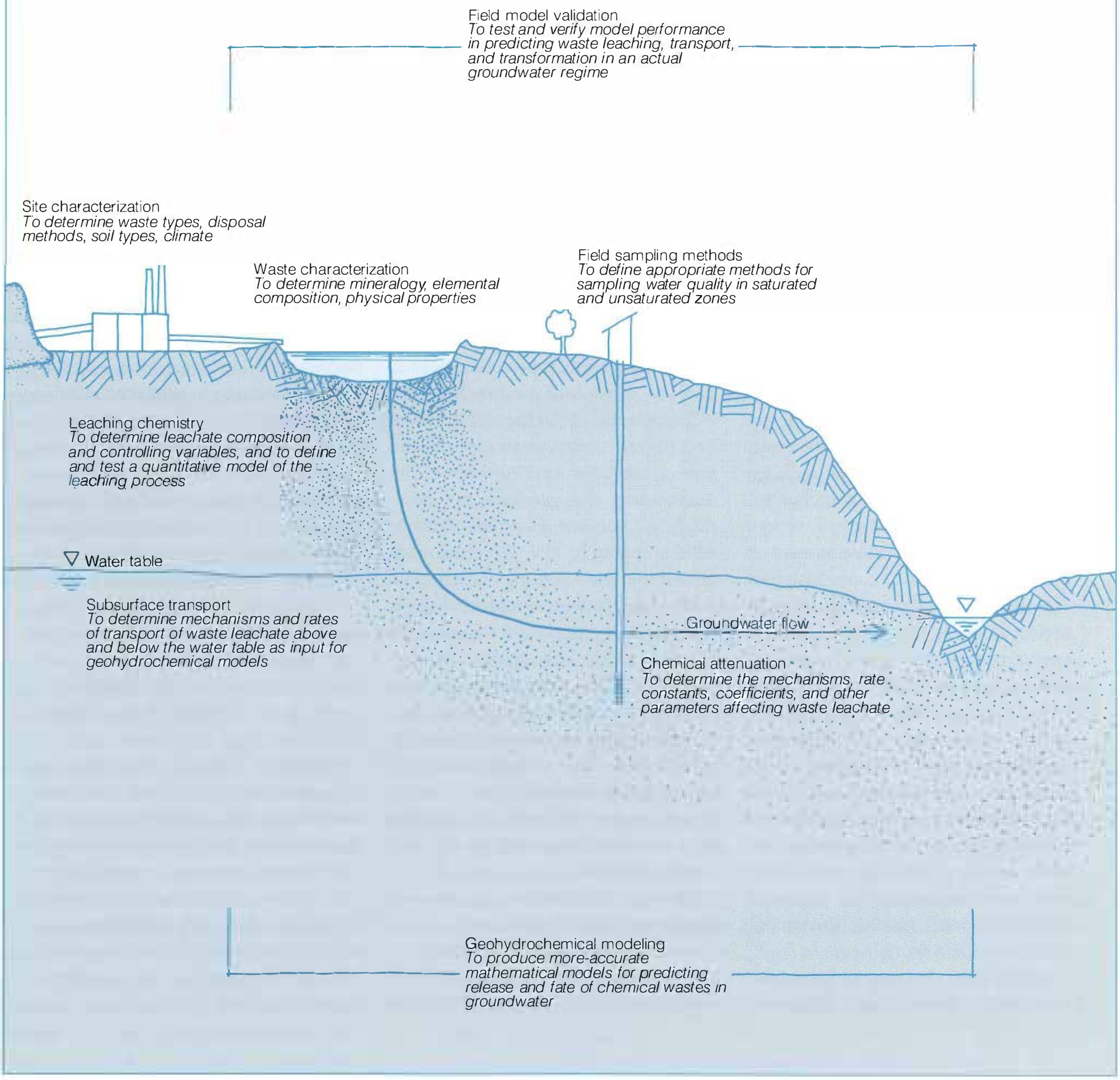
Meantime, EPRI and Southern California Edison Co. (SCE) are cosponsoring studies by the University of California at Riverside on subsurface transport processes in unsaturated groundwater zones, and the Tennessee Valley Authority and MIT's Parsons Civil Engineering Laboratory are pursuing similar studies for saturated zones.

The work on solute transport includes a first-of-a-kind tracer study—the Macrodispersion Experiment, now under way—to track three-dimensional dispersion in saturated subsurface zones. Researchers will release seven different chemical tracers, including tritium and fluorocarbon compounds, into the ground at two and possibly additional sites. The first phase of the tracer experiment was conducted last September on a site at Columbus Air Force Base in Mississippi; two utility solid-waste disposal sites operated by SCE are being considered as locations for repeating the work in a different hydrogeologic regime.

Extensive annual sampling and measurement at 200–400 multilevel sampling wells placed at as many as 30 different depths downgradient from the release points should provide a more complete picture of solute dispersion than has ever been available before. Data from the experiment can also be used in the concurrent modeling efforts. □

Overview of SWES

EPRI's solid-waste environmental studies (SWES) project includes laboratory and field studies of all major geohydrochemical aspects of groundwater. The goal is to develop methods to predict the ultimate fate of chemicals from the utility industry's combustion wastes. The work includes characterization of the types of waste and associated chemical leachate from fossil-fuel-fired power plants, quantitative analysis of the transport and chemical transformation of leachate in the saturated and unsaturated subsurface zones, selection of appropriate methods for measuring groundwater quality, and, eventually, field validation of improved geohydrochemical models.



implications for future disposal practices and costs. In the interim, utility solid wastes are subject to the RCRA nonhazardous waste provisions, as well as to state regulation.

Utility industry wastes

Last year, utilities produced about 80 million tons of solid waste—an estimated 90–95% of it produced from the combustion of coal and oil—and were operating over 1000 waste disposal facilities. Fly ash from coal combustion accounted for about two-thirds of the total volume of solid waste. About 19 million tons per year is bottom ash from furnace hoppers, and about 5 million tons per year is sludge from the flue gas scrubbers that remove sulfur. Some three-quarters of all utility solid waste is disposed of in landfills or surface impoundments; the rest is reused as construction or road-building material. Total production of fly ash, bottom ash, and FGD sludge is expected to increase to about 125–150 million tons per year by the year 2000.

Over 90% of coal ash is composed of inorganic compounds of silicon, aluminum, iron, and calcium as unburned mineral matter or rock; amorphous aluminum silicate is the major constituent. But fossil fuels and their combustion residuals also contain trace quantities of naturally occurring radionuclides (radium, thorium, uranium, and strontium), heavy metals (including lead, mercury, cadmium, chromium, zinc, selenium, and arsenic), and polycyclic aromatic hydrocarbons (PAHs) from the leftover carbon in the fuel.

When combustion wastes are disposed of in large quantities, as they are in ponds or landfills, slurry water, rain, or other chemicals present can leach toxic constituents from the wastes and potentially migrate to the groundwater. In response, the utility industry has emphasized research to determine the leachability of its wastes and is closely studying engineering methods for blocking migration, such as the installation of pond and landfill liners.

Solid combustion waste is not the only type of chemical waste generated by the utility industry, although it accounts for the great majority of the waste volume. Utilities have customarily used large amounts of polychlorinated biphenyls (PCBs) as transformer coolant and capacitor dielectric fluid. The use of PCB, a halogenated aromatic hydrocarbon and a suspected carcinogen, is being phased out under federal regulation as equipment is replaced. The Toxic Substances Control Act of 1976 requires groundwater monitoring at PCB disposal sites.

Utilities use several volatile organic compounds as solvents, degreasers, and cleaning fluids. Acids and other chemicals used to periodically clean fossil-fuel-fired boilers have commonly been disposed of in combination with solid combustion wastes. A 1500-MW coal-fired plant can generate some 600,000 gallons of spent cleaning solutions during cleaning, which is performed every 2–5 years. Recent RCRA amendments, however, have added new uncertainties as to whether such liquids must be segregated and disposed of as hazardous wastes.

Other chemicals of concern to utilities include trace metals in runoff water from the estimated 200 million tons of coal in storage piles around power plants; creosote, chlorophenols, and arsenic compounds used as insecticides and fungicides for treating wood utility poles; and herbicides applied around transmission towers to control weeds.

Expanding R&D

The growing focus on chemicals used in industry and commerce has already increased the cost of environmental regulatory compliance. The utility industry's waste disposal costs are now around $800 million a year. More-stringent requirements for liners and groundwater monitoring at disposal sites could more than double this figure.

In response to the changing regulatory environment and the increasing costs of waste disposal, EPRI is expanding its already broad-based research efforts in solid waste environmental studies, waste disposal engineering and analysis, PCB cleanup, and aqueous discharge monitoring and control. The work is centered in the Energy Analysis and Environment (EAE) and Coal Combustion Systems (CCS) divisions, with additional efforts in the Electrical Systems (ES) Division.

EPRI's groundwater protection work is centered in the CCS division and focuses on near-term needs, such as engineering and cost evaluations for the utility waste disposal technology required under existing federal and state regulations. Other long-term research forms a bridge to the future by building a base of scientific data for quantitatively analyzing the behavior of wastes in the natural environment, assessing the environmental risks they pose, and putting these risks in perspective. This part of EPRI's effort, managed by the EAE division, involves laboratory and field experiments on the fundamental mechanisms behind the leaching, dissolution, and migration of chemicals into groundwater; it should lead to a better understanding of how this resource may be threatened. "By the 1990s we hope to have in place the scientific framework for rationally managing environmental risks," says Glenn Hilst, program manager for environmental physics and chemistry in the EAE division.

In addition, new projects under development at EPRI will address the implications of regulations covering underground storage tanks; categorize the full inventory of chemicals in the utility industry; refine techniques for analyzing organic chemicals in solid wastes; assess the issues posed by old coal tar waste sites; expand current low-volume-waste research to include additional chemicals, such as boiler cleaning fluids and wood pole preservatives; and apply risk assessment techniques to the full range of utility chemical wastes.

To coordinate such a wide-ranging and diverse assortment of research projects and ensure that EPRI R&D is providing timely answers to utility industry needs, the Institute has established an interdivision committee on toxic substances, with representatives from all six technical divisions. The committee is headed by Ralph Perhac, director of the Environmental Assessment Department in the EAE division.

"Because of the complexity of the issue, any one division at EPRI would have difficulty in handling the research effectively," explains Perhac. "We can make the most of our limited funds if we develop an Institute-wide research program—one based on interdivision coordination that begins at the planning stage."

Key roles for the committee are to assess the current state of knowledge of toxic substances and organize the information as a basis for research planning; assign priorities to the various elements of the issue and determine whether increased R&D attention is required in specific areas; and foster the transfer of EPRI toxics research results to utilities and industry trade associations, as well as to other interested parties.

According to Thomas Morasky, manager of the Heat, Waste, and Water Management Program in the CCS division and an architect of EPRI's emerging integrated toxics research strategy, "EPRI can play a key role in improving the information base and describing alternatives available to utilities for assessing and managing toxics problems. Any industry using a wide variety of chemicals or producing large volumes of chemical wastes will have to increase its attention to these activities. Electric utilities will certainly be no exception."

Already, EPRI has made major contributions to the information base for utilities to use in addressing chemical waste issues. These include a shelfful of reports emanating from the EAE division's series of solid-waste environmental studies (SWES). Research under these projects represents a major commitment by EPRI over the next 5–10 years to quantitatively analyze the physical and chemical processes involved in controlling the leaching of chemicals from waste disposal sites and the potential of those chemicals for subsequent migration into groundwater.

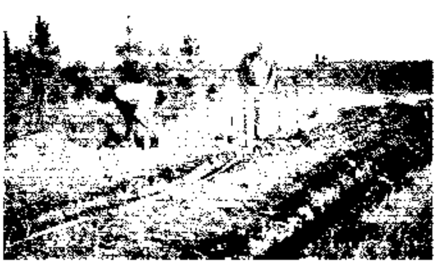
"Once wastes are placed in the environment, the presence or addition of water guarantees there will be some dissolution," says Ishwar Murarka, senior project manager for SWES. "But to understand groundwater contamination or the necessity of controlling the extent of contamination, we have to know such things as the rate of dissolution, the influence of local geochemical and geohydrologic factors in determining what substances migrate through the natural environment, and the distances these substances travel."

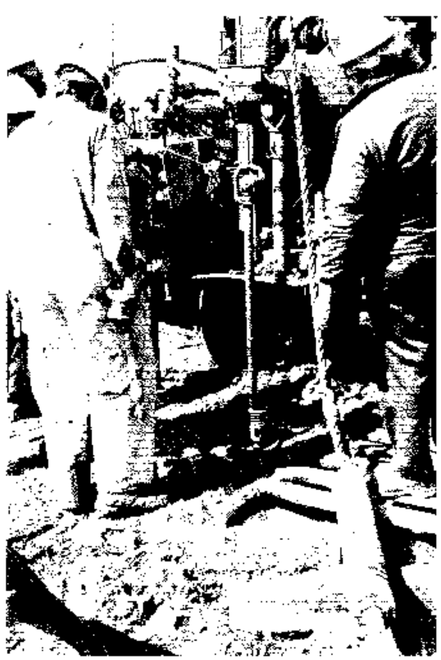
The ultimate products of SWES will be a series of improved models and associated data for predicting the environmental fate of chemicals in utility solid wastes. "The SWES work is addressing the key uncertainties involved in predicting the release, transformation, and transport of constituents from utility solid wastes in the environment," states Murarka. "EPRI has committed $34 million for these projects through 1990."

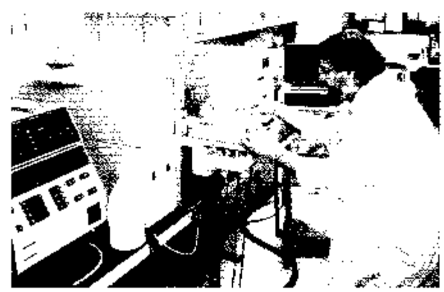
With more-immediate waste disposal engineering concerns in mind, the CCS division sponsored development of a comprehensive three-volume manual on groundwater management that complements extensive reference manuals on ash and FGD by-products disposal and the upgrading of waste disposal facilities. The manual, prepared by Southern Company Services, Inc., the Geological Survey of Alabama, and Weston Geophysical Corp., discusses the full range of utility-related groundwater considerations, including leachate from

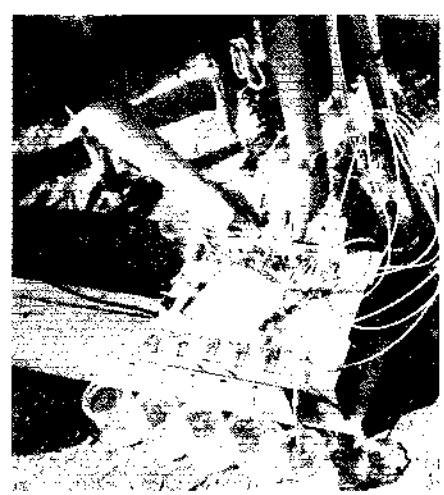
Groundwater Research: From Wells to Laboratory

EPRI's groundwater research includes the drilling of test wells for measuring water quality and conducting groundwater transport studies. Laboratory analysis of samples sheds light on the transformation of chemicals in the subsurface environment.

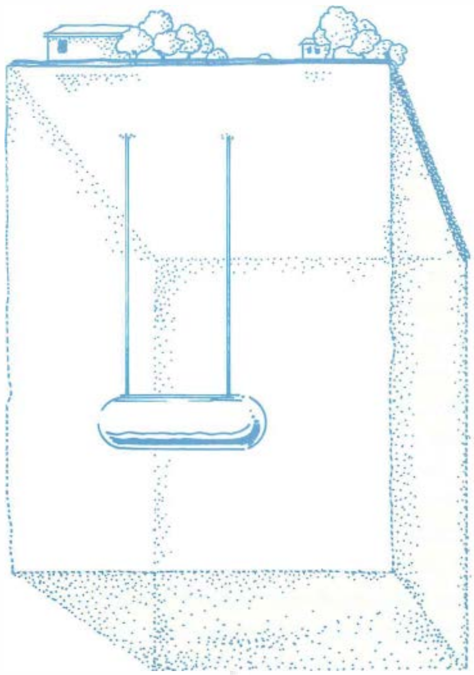








Underground Storage Tanks



Of all the potential sources of groundwater contamination, the category that may pose the most serious risks to human health and the environment, according to EPA, is leaking underground storage tanks. Such tanks are used to store liquids of all kinds, including gasoline, hazardous and toxic chemicals, domestic fuels, process chemicals, and dilute wastes.

There are an estimated 2.5–5 million underground tanks in the United States, as many as half of which contain gasoline. The chemical constituents of gasoline that are particularly troublesome potential groundwater contaminants include lead, toluene, benzene, ethylene dibromide, and ethylene dichloride. About 40% of all underground gasoline tanks belong to major oil companies and their service stations; individual stations, small oil companies, and other industries account for the rest.

Most underground tanks are made of carbon steel and are unprotected (by liners or cathodic treatment) from corrosion; typical design life is 15–20 years. Newer tanks are designed for corrosion resistance or are made of fiberglass or with double liners. But an estimated one million underground tanks are more than 16 years old, and statistical estimates of the number that may be leaking range from 75,000 to 700,000. Cleanup of leaks and spills can typically cost \$20,000–\$150,000, and costs may be in the millions of dollars if groundwater is contaminated.

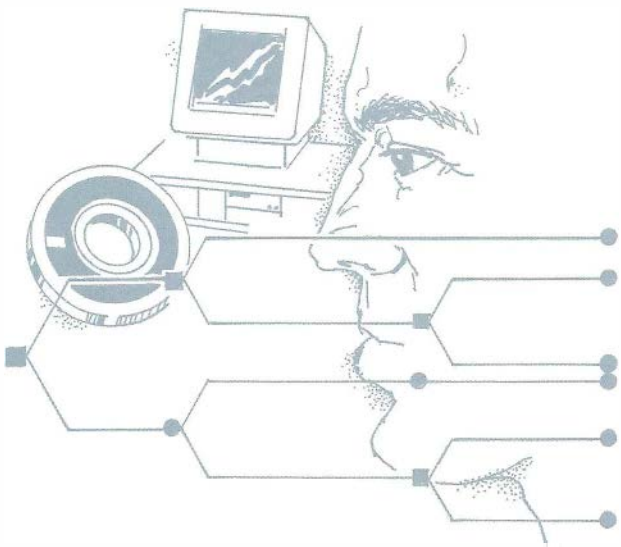
Electric utilities use underground tanks extensively for storage of motor fuels and other fuels. A recent industry survey estimates that utilities operate about 16,000 underground storage tanks nationwide, more than 70% of which are over 5 years old.

"Recent amendments to federal hazardous waste laws pose a major regulatory challenge to the utility industry with respect to detection, prevention, and control of leaks in underground tanks," says Thomas Morasky, manager of EPRI's Heat, Waste, and Water Management Program in the CCS division. EPRI has been asked by utility trade groups to help assess the industry's ability to deal with technical issues posed by the new rules.

As a result, EPRI plans to embark on research projects to evaluate and, if necessary, develop leak detection techniques for underground tanks. "Research is also required on methods for continuously monitoring underground storage tanks and repairing those that leak," adds Morasky. Part of the approach will be an assessment of technical alternatives for site cleanup. One likely product of the planned research will be a document to provide utilities with guidelines on the proper design, construction, operation, and maintenance of new underground storage tanks. □

Protecting Groundwater Quality

Waste and Risk Assessment



One of the ways EPRI can help utilities respond to the challenge of waste disposal and groundwater contamination is by developing new analytic tools that assess the possible environmental and economic risks involved and estimate the relative advantages of various risk management strategies. Such an approach can enable utilities to set priorities for minimizing risks and respond to increasingly stringent regulations in the most cost-effective manner.

Three specific analytic tools, each addressing a particular waste management problem, are now in various stages of development by Environmental and Economic Integration Staff. The furthest along of these tools is a decision analysis framework that can be used to compare the costs and benefits of options for disposing of coal combustion by-products. Created by Decision Focus, Inc., and intended to be incorporated into a package of computer codes, this prototype has recently been verified by using it with data from six utility disposal sites, and it is now ready for field trials at host utilities.

Because of large uncertainties about such factors as a site's groundwater characteristics and geochemical properties, the framework provides for incorporating expert judgments where critical data are lacking. On the basis of these judgments and the available information, a decision tree can be constructed that determines the expected costs of various corrective actions, together with their expected impact on the environment.

The disposal analysis framework has been developed in cooperation with the Utilities Solid Waste Activities Group (USWAG), and an on-site utility case study is now under way. Other host sites are actively being sought, according to Victor Niemeyer, project manager, and interested utilities should contact him directly.

The second analytic tool developed in response to a USWAG request, focuses on the problem of leaking underground storage tanks. The goal of this project, now in the design phase, is to help utilities set priorities for testing and treating the underground tanks used primarily for holding fuel for transportation fleets. When completed, the new methodology will use data on tank age, design, and proximity to important groundwater resources to indicate which tanks are most likely to cause significant environmental impact due to leakage. This tool will also indicate the more cost-effective strategies for managing these risks.

The third problem to be addressed by new risk management tools concerns plant wastes from the long-discontinued production of town gas. In many cases, today's electric utilities have inherited sites where gas was manufactured from coal for local use; these waste sites may therefore be old and poorly characterized. Some sites may contain materials that could be classified as hazardous under RCRA. Despite the risk presented by the presence of such toxic materials, however, human exposure might in some cases be greater if the wastes were dug up for modern disposal than if they were simply left alone.

EPRI is considering a request by utilities to provide a decision analysis framework that can be used to determine the best way of treating the town gas waste sites. This methodology would consider such factors as the structure of the site, the proximity of the site to important groundwater resources, and the nature of the wastes contained. □

solid wastes and coal piles, land subsidence and sinkhole development, and seepage from all types of impoundments. It contains basic geologic and hydrologic background information and government regulations, describes groundwater problems specific to electric utilities, and discusses the techniques and instrumentation necessary to detect, evaluate, monitor, remedy, or prevent groundwater problems at utility sites.

CCS has also funded development by Battelle, Pacific Northwest Laboratories of what is considered one of the best sets of available computer models of groundwater flow for disposal engineering analysis. The UNSAT1D code for unsaturated flow, the VTT code for saturated flow, and the COUPLE code for modeling combined flows were demonstrated with data from Basin Electric Power Cooperative's Antelope Valley generating station near Beulah, North Dakota. The models were used to determine optimal thickness for a clay cap over a waste landfill and to confirm the effectiveness of a grass cover; they also indicated that operation of the disposal system did not significantly affect the hydraulic gradient of saturated groundwater flow.

"In developing engineering approaches to groundwater problems, you often have to make decisions on the basis of limited information," explains Dean Golden, a CCS project manager who has been involved with groundwater research at EPRI since 1978. "To aid the utility that has to make a decision now without extensive data, we can offer information on what the maximum leachate concentrations would be if there were no chemical attenuation," says Golden. "That's how the UNSAT1D and other models are set up: from an engineering standpoint, they provide worst-case analyses to help in making siting decisions and decisions as to whether, for example, you need one foot or ten feet of clay underneath—or whether you need any liner at all." The more comprehensive models developed under the SWES program will complement the engineering models, providing detailed analysis of the movement of substances in groundwater and building the base for longer-term solutions.

Other CCS groundwater-related projects have assessed and documented the proper design of groundwater monitoring wells and the performance of various liner materials for disposal ponds. Ralph Komai is directing a recently begun project to assess remedial measures for dealing with leaking underground fuel tanks; an effort is also anticipated that will explore technical issues posed by land disposal long ago of coal tars from early gasification plants.

A long-term issue

There is wide agreement throughout industry, government, and the environmental community that chemical wastes and the potential threat they pose to groundwater resources represent a major environmental challenge in this decade and beyond. But the multitude of sources of contamination, the limited scientific understanding of underground geohydrochemistry, and the diffuse federal and state regulatory authority ensure there will be no simple or easy solutions.

A rational approach to protecting groundwater as well as other environmental resources demands a risk assessment strategy, one that recognizes that not all risks can be completely eliminated and that for each succeeding increment of risk reduction there is a corresponding increase in cost. An explication of the risk assessment approach (which has evolved since the early 1970s, when it was thought many environmental risks could be reduced to zero) was recently given by William Ruckelshaus, who twice served as EPA administrator.

Writing in *Issues in Science and Technology,* the quarterly of the National Academy of Sciences, Ruckelshaus suggests that "in groundwater protection we should start relating our concern for this resource to its presumptive use. Groundwater is a resource like any other. Obviously we cannot allow our groundwater to be carelessly fouled, but let us cultivate a sense of proportion as well as a sense of outrage. There is a great difference between the careless and casual destruction of a supply of drinking water and the demand that a vast pool of groundwater lying beneath an industrial metropolis be scrubbed as clean as it was when a dozen farmers lived above it.

"The hazardous waste problem boils down to specifying where we want the waste to go. In the last analysis, after we have reduced production and have recycled and treated as much as we can of our waste, we have three choices as to where to put it: the land, the air, or the water. Congress has never analyzed the total risk associated with a certain hazardous waste policy and the total cost of eliminating it and then used the analysis as the basis for legislation. However, that is what we will increasingly have to do if our national environmental policies are to retain any contact at all with the day-to-day realities they are supposed to influence." ■

Further reading

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Groundwater Manual for the Electric Utility Industry. Vols. 1–3. Final report for RP2301-1, prepared by Southern Company Services, Inc., Geological Survey of Alabama, and Weston Geophysical Corp. March 1985. EPRI CS-3901.

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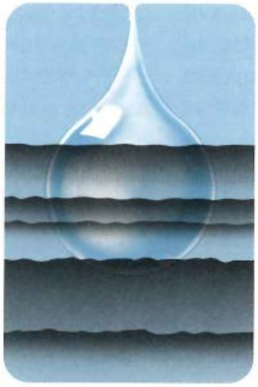
This article was written by Taylor Moore. Technical background information was provided by Glenn Hilst and Ishwar Murarka, Energy Analysis and Environment Division, and Dean Golden, Ralph Komai, and Thomas Morasky, Coal Combustion Systems Division.

Part 2 Protecting Groundwater Quality

UTILITY SOLID WASTE

MANAGING THE BY-PRODUCTS OF COAL COMBUSTION



The utility industry is continuing to explore new technical solutions to groundwater protection in the way it produces, uses, and disposes of waste from fossil fuel power generation. Regulatory uncertainty has compounded the challenge.

More than one-half of this nation's electricity is generated from coal, a fuel that produces solid wastes when it burns. By-products of coal combustion are nothing new; utilities have been dealing with them for over half a century. What is new is the volatility of the regulatory climate in which the industry must handle these and other power plant wastes.

Coping with the uncertainty created by changing environmental regulations is one of the greatest challenges facing utilities today. For example, for some time regulatory agencies have used certain methods to assess the hazardousness or toxicity of waste products. The procedures used to judge toxicity are now being modified, as are the rules governing handling, disposal, and use of utility wastes. In compliance with current federal tests and standards, well over 99% of power plant residues are classified and handled as nonhazardous waste. Because these tests and standards are changing, the future status of utility by-products is unclear. EPRI and the utility industry are working to ensure that future regulations are grounded in a comprehensive scientific understanding of the nature of utility wastes and the options available for dealing with them.

Although the vast majority of utility wastes are relatively benign, they are produced in large quantities—roughly 80 million t/yr. About 90% of this volume is fly and bottom ash and flue gas desulfurization (FGD) sludge from coal-fired plants. The remaining 10% includes hundreds of low-volume wastes, including wash waters and spent solvents used to clean boilers and other equipment, cooling-tower sludge, coal pile runoff, ash from oil-fired plants, sludge from geothermal fields, and the like.

Utilities also must manage wastes from technologies no longer in use, such as the coal tars from turn-of-the-century coal gasification plants. Even advanced coal combustion technologies now under development, such as integrated gasification–combined-cycle generation (IGCC) and fluidized-bed combustion (FBC), will produce some wastes. In fact, nearly all methods of electricity generation produce by-products. Consequently, waste handling and disposal are issues that will be with us as long as we use electric power.

Sizing up the issue

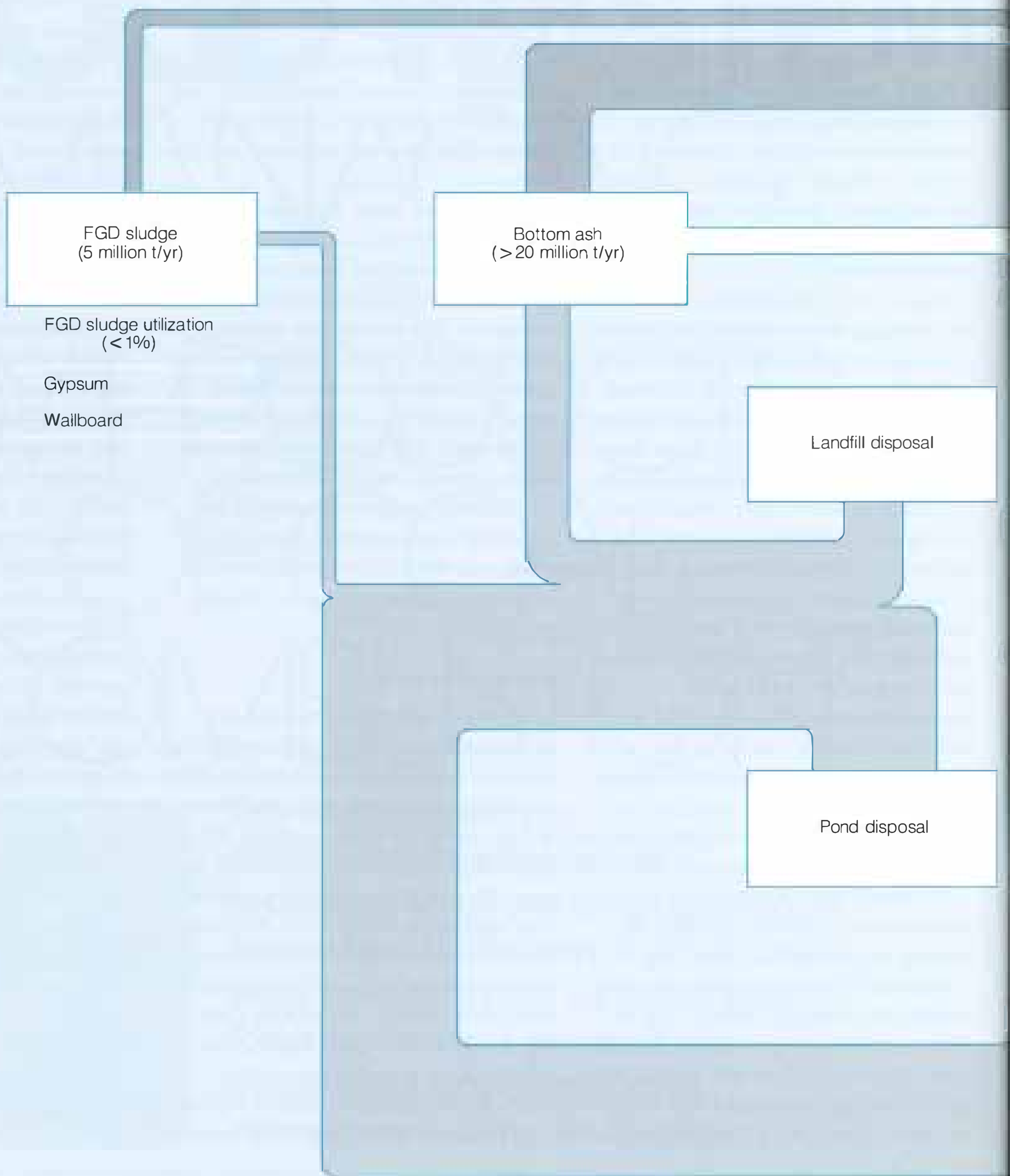
The utility solid-waste problem is a multifaceted and complex subset of the broader waste challenge faced by all industrial societies. Handling the sheer volume of utility waste requires engineering skill, money, and lots of land area. As power companies run out of inexpensive, available land, they are studying ways to produce less waste, to recycle more of it, and to compactly and safely dispose of those by-products they cannot use or sell. Historically, utilities have found markets for as much as 25% of their coal ash (mostly as a cement additive and as fill material in road embankments and bases) but for almost none of their other wastes. The bulk of the unused material has been placed in utility-operated ponds and landfills, most of which are immediately adjacent to power plants. The size of such a facility depends on the size of the plant it serves, but ponds generally range from 30 to 400 acres, whereas landfills average about 45 acres and are sometimes four times this size. Ponds were more popular in the past because less labor is required to sluice wastes with water than to scrape, shovel, and haul dry material.

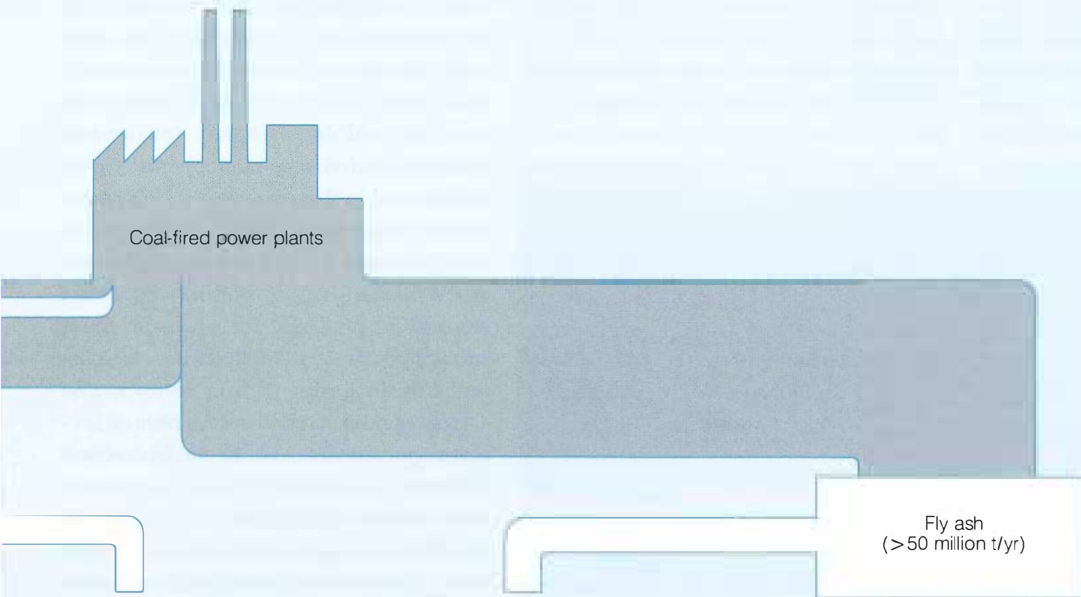
Today, about two-thirds of the ash and sludge produced are transported as wet slurry from power plants to nearby ponds. The rest is hauled dry or else dewatered and then disposed of in landfills. The trend is toward dry disposal because landfills are generally viewed as being environmentally safer and consume only 40% as much space, per unit of waste, as ponds. Eventually, however, all waste impoundments fill up. Acquiring new disposal sites close to power plants, particularly in crowded urban areas, can be expensive and politically difficult. Some utilities are converting existing waste ponds to landfills for lack of additional disposal space.

Not only is there a lot of material to be dealt with, but the public is increasingly concerned that wastes be handled in ways that protect human health and environmental quality. The most important concern is that wastes be isolated from drinking water supplies—particularly underground aquifers,

Current Fate of Coal Combustion By-products

Fly ash, bottom ash, and FGD sludge account for more than 90% of the over 80 million t/yr of waste generated by coal-fired power plants. Currently about 17% of the fly ash, 33% of the bottom ash, and less than 1% of the FGD sludge is reused. Of the remainder, roughly two-thirds is disposed of in ponds and one-third in landfills. The trend, however, is toward dry disposal. Most new utility waste facilities are landfills, and some existing disposal ponds are being dredged and drained to convert them to land disposal sites.





Bottom Ash Utilization (%)		Fly Ash Utilization (%)
1.3	Aggregate	0.7
24.5	Blasting grit	NA
9.7	Cement additive	18.6
2.5	Concrete admixture	35.6
0.9	Concrete block	3.6
0.0	Dam construction	1.8
13.8	Fill material	4.5
NA	Grouting	6.2
NA	Hazardous waste fixation	0.7
11.4	Ice control	0.5
11.8	Road construction	2.6
13.6	Roofing granules	NA
10.4	Miscellaneous uses	25.1

which are nearly impossible to clean once they are contaminated. Such contamination can occur when water runs off waste impoundments into adjacent surface waterways or percolates through the bottom of ponds or landfills, carrying leached materials into underground aquifers. The contribution of utilities to groundwater contamination nationwide appears to be extremely small in comparison with other pollution sources, such as chemical dumps, refineries, and sewage facilities. Nonetheless, utilities are continually studying better ways to keep their wastes from escaping into the environment.

Although most utility by-products are relatively benign in comparison with the hazardous wastes that have made headlines over the last decade, utilities do handle and produce many substances, the environmental effects of which are not well understood. The low-volume utility wastes were (and still are, in many cases) disposed of in combination with high-volume wastes. Codisposal of low- and high-volume wastes will very likely continue to be an acceptable method in most instances. In cases where fairly benign materials, such as ash and sludge, have been mixed with low-volume wastes that fail government toxicity tests, there is the possibility that the government could view the entire waste volume as toxic. Special disposal techniques (such as incineration, solidification-fixation, and treatment in hazardous waste facilities) may be required in the future for those utility wastes that fail mandated toxicity tests. In such instances, utilities may find that off-site commercial treatment and disposal by professional waste management firms is the most economical disposal option.

Studying the wastes

EPRI and the utilities have devoted millions of dollars over the last several years to physical and chemical analysis of dozens of utility by-products. One of the most important questions was whether utility wastes are potentially hazardous.

To answer this question, EPRI's Coal Combustion Systems (CCS) and Energy Analysis and Environment (EAE) divisions funded evaluations of coal and oil ash, FGD and geothermal sludges, and nine categories of low-volume waste, using EPA's extraction procedure and standards for judging toxicity. The wastes were submerged for 24 hours in a mildly acidic solution adjusted to pH 5 with acetic acid or ammonium hydroxide. The leachate was then analyzed for eight elements regulated by the National Primary Drinking Water Standards—silver, barium, cadmium, chromium, arsenic, mercury, lead, and selenium. If the leachate exceeded NPDWS for any of these elements by more than a factor of 100, the waste would be classified as hazardous. (The rationale behind allowing the leachate to exceed the standard by 100 times is that wastes are diluted as they pass through soil. Thus substances will be at much lower concentrations if and when they reach groundwater than they are at the time they escape from an impoundment.)

Coal ash and scrubber sludge were found to be nonhazardous under current federal standards, with a margin of safety (in all substances for which standards exist) of one to three orders of magnitude. Of all the low-volume wastes tested, only one—a single kind of untreated acidic boiler cleaning solution—exceeded federal standards for cadmium, chromium, and lead. Additional sample analysis is being conducted on similar wastes from other boilers. Cleaning the boilers of a 1500-MW coal-fired plant generates about 600,000 gallons of spent cleaning solution and rinse water. Because boilers are cleaned infrequently (only every two to five years), the cleaning waste could be given special treatment, if necessary, with little effect on the rest of the plant's routine operation.

One might think that utilities could breathe a sigh of relief now that their major wastes have been found to be nonhazardous under federal law. The situation is not that simple, however, because the tests and criteria used to judge toxicity are changing. In November 1985 EPA is scheduled to publish a new test called the toxicity characteristic leaching procedure (TCLP). Public comment on the test will be accepted for several months, and the agency plans to promulgate a final version about one year later. It is expected that the new test will use a sodium acetate–buffered solution as the leaching agent and that the leachate will be analyzed for up to 50 more substances than are looked for in the current test, including organic compounds.

Coal and oil ash do contain minute levels of polycyclic aromatic hydrocarbons and other polycyclic organic compounds that are potentially toxic. In addition to the metals currently tested for, it appears likely that the new procedure will test for boron, vanadium, and manganese, all of which appear in coal ash in trace quantities. Basically, the rules of the game are changing, but utilities do not yet know what those changes will mean.

Regulatory uncertainty

This type of regulatory change has complicated utility waste programs for the last decade. In 1976 the federal government enacted the Resource Conservation and Recovery Act (RCRA). RCRA charged EPA with the monumental task of promulgating regulations to classify as hazardous or nonhazardous tens of thousands of substances discarded by the full range of American industry and to develop guidelines for treatment and disposal of these materials.

Recognizing that industry could not stop operating while EPA studied the problem, the government issued interim rulings on a number of materials, including electric utility wastes.

In 1980 Congress temporarily classified utility ash, slag, sludges, and codisposed low-volume fossil fuel combustion byproducts as nonhazardous waste, and delegated their regulation to the states. The federal nonhazardous classification of utility wastes applies only until EPA completes its study of the environmental characteristics of these materials and recommends how they should be managed. EPA could propose to permanently classify any or all utility wastes as nonhazardous or as hazardous. It could rule that current disposal practices are adequate, or it could require that utility wastes be disposed of in the same manner as other hazardous industrial wastes. No one knows what the agency will do or precisely when it will act, but EPA expects its long-overdue report to Congress on utility wastes to be released in the first half of 1986.

The stakes are high in waste classification. Under RCRA, hazardous wastes must be handled from cradle to grave under strict guidelines; requirements range from record keeping and 24-hour site surveillance to installation of pond and landfill liners, leachate collection, and groundwater monitoring. RCRA leaves regulation of nonhazardous wastes largely to the states. Depending on the rigor of state laws, current disposal requirements can be significantly more involved and expensive than pre-1970s practices. In California, for example, wood power poles are classified as hazardous waste because of the toxicity of the preservatives with which they are treated. The classification raises their disposal cost more than tenfold.

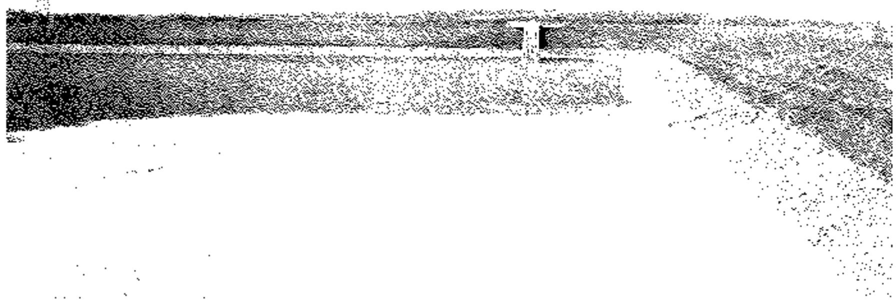
In response to laws in some states and in anticipation of possible future federal regulations, utilities have equipped new landfills with liners, groundwater and leachate monitoring instruments, surface run-on and run-off control systems, and other means of preventing and detecting migration of substances out of impoundments. Hundreds of old, unlined disposal sites still exist, however, and little is known about their environmental impact. What is known is that upgrading old impoundments to modern standards is technically difficult and very costly.

For example, a 1982 EPRI-funded study calculated that if all the states strictly interpreted and enforced the RCRA guidelines for nonhazardous

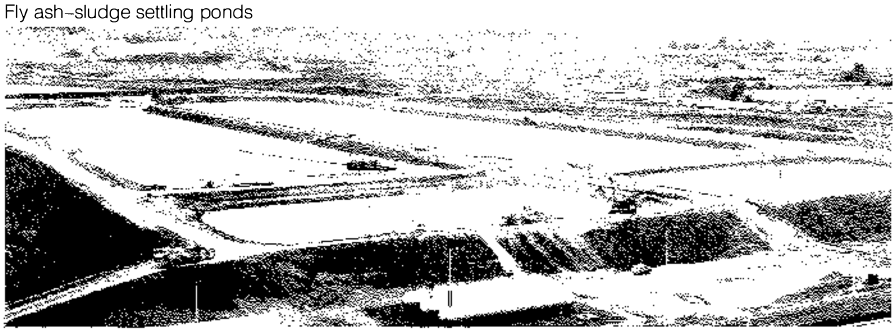
Disposal Practices

Because of economic and environmental considerations, utility waste disposal is shifting from ponds to dry landfill disposal. More material can be stored in landfills than in ponds, as dry solids are denser and can be stacked to over 100 ft (30 m) in height. For dam safety reasons, waste disposal ponds are rarely more than 20 ft (6 m) deep. Because of poor structural properties, sludge is usually stabilized before it is deposited in a landfill.

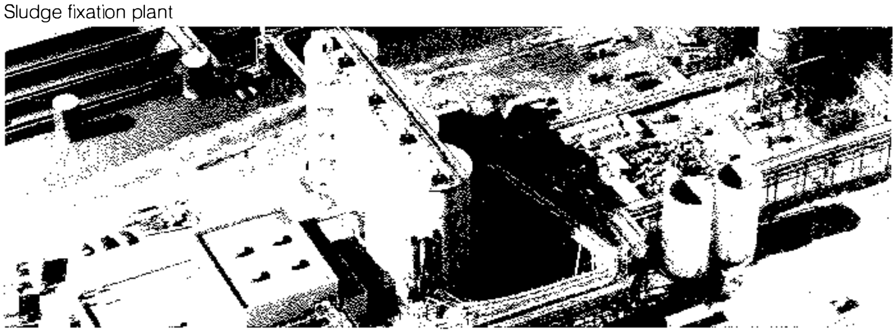
Sludge disposal pond



Fly ash–sludge settling ponds



Sludge fixation plant

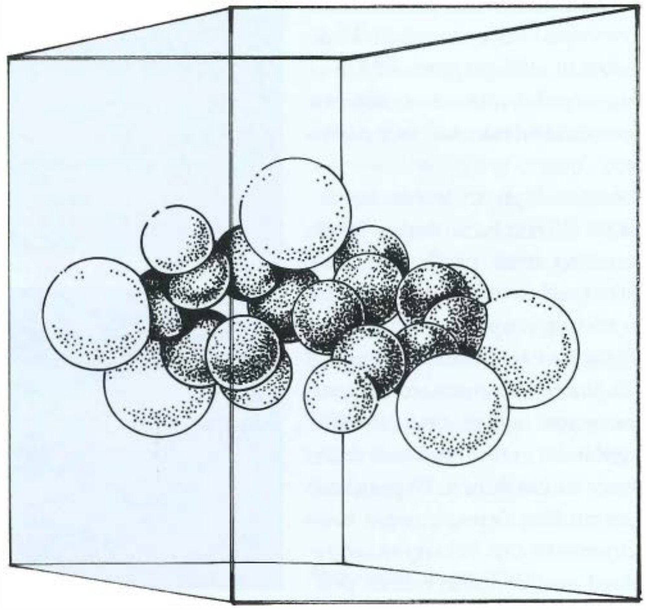


Stabilized sludge landfill

Gypsum storage pile

Protecting Groundwater Quality

Handling PCBs



Despite uncertainty about the health effects of PCBs, Congress singled them out for regulation under the Toxic Substances Control Act of 1976. In 1979 EPA banned further production of the compounds, which have been used for nearly 50 years in a variety of industrial and commercial applications. Utilities were allowed to continue to use existing transformers and capacitors containing PCBs for the duration of their normal service life, although certain uses have since been eliminated. All PCB-containing transformers and capacitors will be replaced eventually by equipment that uses alternative insulating and cooling fluids. Under new rules issued by EPA in July 1985, utilities must phase out the use of PCB transformers in or near buildings by 1990. Ultimately, the power companies must destroy all 200 million pounds of PCB in utility equipment and in addition must clean or contain any PCB-contaminated sites that are environmental hazards.

Most utility PCBs (over 160 million pounds) are contained in capacitors and transformers purchased before 1977. (Capacitors are permanently sealed; transformers can be opened, drained, and refilled.) Utilities generally know which equipment contains pure PCB fluid and which contains other insulating fluid, such as mineral oil. But because the same pumps and hoses were used routinely over the years to replace fluids in different types of transformers, traces of PCBs were carried from the servicing equipment into an estimated 10% of the 20 million mineral-oil-cooled transformers. EPA standards classify as contaminated any fluid containing from 50 to 500 parts per million PCBs; fluids exceeding 500 ppm are classified as PCBs. Of those mineral oil transformers tainted with PCBs, 90% fall in the 50–500-ppm range.

Transformers containing 50–500 ppm PCB can be used until retired, drained and refilled with non-PCB fluid, or drained, and sold for scrap metal. PCB-contaminated liquid must be either chemically treated or burned in one of three approved PCB-incineration facilities (Texas, Arkansas, and Illinois) or in a high-efficiency utility boiler. Retired devices holding fluid with over 500 ppm PCB must be drained, filled with solvent for 18 hours, and then emptied. The contaminated fluid and solvent must be incinerated in an approved facility. If transformers contain over 500 ppm PCB when they are retired from service, their shells must be put into a landfill at a hazardous waste facility.

Some utilities have initiated programs to replace PCB-filled capacitors and transformers with equipment that uses other fluids. Other power companies are waiting to remove known PCB-containing equipment as it reaches retirement age, although the new phase-out regulations will require that some of this equipment be replaced (or drained, cleaned, and refilled with non-PCB fluid) by 1990. A few utilities are systematically testing all their in-service mineral oil transformers for PCB contamination. More commonly, mineral oil equipment is tested for contamination only after it is removed from service. When utilities remove PCB-filled equipment, they can store it for up to one year before disposing of it. This equipment must be stored in specially designed facilities. In addition, utilities must label all PCB equipment and keep detailed records on its removal, storage, and disposal.

The greatest potential hazard with PCBs arises when they are exposed to fire. Because they do not burn readily, PCBs can form partial oxidation products, including polychlorinated dibenzofurans (PCDFs), which animal tests have shown to be more toxic than PCBs. The rules issued in July by EPA are designed primarily to reduce the risk of fires in structures that involve PCBs.

There are several reasons, however, why it may be impractical or potentially risky to replace PCB-insulated building transformers with equipment that uses other fluids. Some transformers fill entire rooms and are situated in relatively inaccessible areas of buildings, which makes safe removal difficult. Further, non-PCB transformers often are bulkier than those that use PCBs. In some cases there is not enough space to replace PCB-filled equipment. And whereas it is dangerous to expose PCBs to fire, mineral oil and other substitute fluids are generally more flammable. Thus, switching from PCBs may reduce the risk of toxic by-product contamination once fires begin, but it may allow more and larger fires to occur.

The potential toxicity of the PCDFs formed during PCB incineration and fear of PCBs themselves have raised the public's concern about the siting of PCB incineration facilities close to population centers. Alternatives to incineration were therefore sought in two EPRI-funded projects. EPRI is studying arc pyrolysis as a means of destroying PCB capacitors. The arc pyrolysis system will melt capacitors (a capacitor is typically about the size of an attache case) and break down the PCBs to simpler compounds without producing PCDFs or other partial oxidation products. If arc pyrolysis works well on capacitors, it may be scaled up to handle moderate-size transformers. An EPRI study on chemical detoxification of PCB capacitors was carried through preliminary design work but did not receive follow-up funding. A final report on this project is due later this year.

In addition to exploring better disposal techniques, EPRI has spent $1 million to develop improved PCB field measurement devices. These new testing methods are expected to save utilities about $750 million over the years it will take to locate and clean or destroy contaminated equipment. Faster, less-costly tests will also help utilities to measure contamination from PCB spills. When such releases occur, whether they are caused by failure of utility equipment or mishandling by hired waste disposal firms, utilities may be required to clean the sites. Site cleanup can sometimes involve digging up soil or asphalt on which PCBs have been spilled, cleaning and disposing of the contaminated material, and restoring the site to its original condition.

EPRI has also funded research on washing contaminated soil and evaluating biologic agents for detoxifying PCBs. EPRI will demonstrate the soil-washing process in 1986 at a PCB-contaminated utility site. According to Project Manager Ralph Komai, "Soil washing is expected to significantly reduce PCB cleanup costs." Komai adds that "because this process will reduce the need for landfilling of PCB-contaminated soil, it will minimize the likelihood that utilities will be held liable for future landfill cleanup efforts." □

disposal then being considered for implementation by EPA, nationwide utility disposal costs would rise from $800 million a year to a levelized cost of $2.6 billion a year. (Sulfur dioxide emission controls placed on new power plants are costing the industry about $6 billion a year.) The same study estimated that the cost of upgrading all utility waste sites to hazardous waste standards and handling all utility wastes according to hazardous waste requirements would cost $3.4 billion a year.

Improving waste disposal

Whatever shape the environmental laws ultimately take, utilities and the government agree that the electric power industry can improve its disposal methods. EPRI has sponsored a number of research projects with this goal in mind. The CCS division has published the comprehensive, three-volume *Groundwater Manual for the Electric Utility Industry* (EPRI CS-3901). The manual describes the hydrogeologic phenomena involved in the migration of substances under the earth and provides guidance to utilities on preventing, detecting, and mitigating groundwater problems. Designed for use by utility personnel of widely varying technical backgrounds, the groundwater manual is rich in practical advice on all types of utility activities that could conceivably affect groundwater.

"For most utilities with potential or real groundwater problems, the first decision that has to be made is whether to call in outside contractors or to handle the engineering analysis themselves," says Dean Golden, a CCS project manager. "The groundwater manual can be very valuable in helping them make that determination, as well as in guiding the work after it begins."

The manual contains a section on mitigation strategies for coal pile leaching. Techniques discussed range from minimizing the exposure of coal to air and water (by storing less coal on site and keeping it in well-compacted, covered, or sealed piles with sloped sides for quick runoff) to installation of catchment ditches and ponds, liners, and subsurface drainage equipment.

The CCS division also has published manuals that provide state-of-the-art recommendations to utilities on the disposal of ash and FGD sludge and the upgrading of existing disposal facilities, including the conversion of ponds to landfills and the siting and design of new waste facilities.

Some research is directed toward modifying the processes that create wet waste. Most FGD units, for example, are wet scrubbers that capture sulfur dioxide by reacting boiler exhaust gas with slurries of calcium-based materials, such as limestone. The sulfur dioxide in the flue gas reacts with these agents and precipitates out of the exhaust as a cumbersome, semisolid material. The utility industry is developing sulfur dioxide removal techniques that generate smaller amounts of gypsum or other dry, powdered by-products. With the exception of gypsum, these highly alkaline, dry by-products harden like concrete when exposed to water. Few dry scrubbers are currently in operation, but they are expected to be more widely used in the future. Anticipating this shift in scrubbing technology, EPRI is funding research on disposal techniques for dry scrubber by-products.

Additional CCS research focuses on the dewatering and stabilization of wet wastes to prepare them for dry disposal. Wet FGD sludge, for example, is often treated before it is deposited in a landfill. Treatment consists of various combinations of dewatering, thickening, and fixation or stabilization. Dewatering and thickening are accomplished by sluicing sludge to temporary holding ponds or mechanical settling basins, where the heavier solids sink and the liquid effluent is drawn off, either to be evaporated or to be returned to the scrubber as process water.

FGD sludge is typically 5–15% solids when it emerges from the scrubber. Most dewatering techniques thicken the sludge to 30–60% solids. Even with this much water removed, FGD sludge is too mudlike and physically unstable to be put into a landfill. But mixing the sludge with fly ash, soil, lime, or one of several commercially available fixating agents will solidify it to the degree that it becomes a stable landfill material.

Most coal ash is still removed from power stations with water, but utilities are moving toward disposing of their ash in dry form. As with sludges, ash is generally dewatered by allowing solids to settle in a holding pond and then draining off the liquid. The liquid is then either recycled to sluice more ash out of the plant, evaporated in a holding pond, or treated and discharged. Another approach is to apply the ash slurry to a drying bed, which has a bottom of porous sand or wire mesh. The liquid percolates through the bottom into a drainage catchment. The solids, which are too coarse to pass through the sand or mesh, remain on the surface, where they can be mechanically removed for dry disposal. Unlike scrubber sludge, ash compresses very little and has good shear strength, making it an ideal landfill material.

Although it is a relatively straightforward task to design a new facility for dewatering and subsequent dry disposal of utility wastes, hundreds of existing power plants rely on ponds for waste disposal. "Because of space constraints and regulatory pressures for landfill disposal," states Golden, "there is a growing trend to convert existing ponds to dry disposal systems." A recently completed EPRI study documents one such effort at a Pennsylvania Electric Co. ash disposal pond. The basic approach used in this case was to drain the liquids from the pond, dredge and further dry the solids, and then dispose of them on land.

Although land disposal is generally favored by regulators over pond disposal, a number of strategies should be employed to ensure that landfill wastes do not leach into water supplies. The key message of the EPRI waste disposal manuals is that the wastes should be kept as dry as possible and the material under the waste should be relatively impermeable.

Embankments, diversion ditches, and drainage systems are recommended to prevent nearby surface water from running onto the landfill and to allow precipitation that falls on the landfill to run off quickly rather than percolate down through the wastes. In keeping with current regulatory guidelines, the EPRI manuals recommend that as sections of landfill reach capacity they be capped with clay or some other low-permeability material to keep rainfall from soaking into the wastes.

Measures should be taken not only to control run-on but also to minimize the amount of water escaping from the bottom and sides of the landfill. This can be accomplished by siting the facility over nonporous subsoil and bedrock and/or lining the bottom of the landfill with clay, impermeable waste, or a synthetic liner. Liners were seldom used in the past but are being employed today with increased frequency. A recent survey of 61 coal-fired power stations, which represent a cross section of the industry, indicated that 40% had lined impoundments. Two-thirds of these plants use compacted soil or clay and the rest use synthetic liners. To help resolve the debate over the relative merits of synthetic and natural liners, EPRI has funded the testing of 14 lining materials (6 soil-based and 8 synthetic) that were exposed to various wastes generated by coal-fired power plants. The results of these tests will provide much-needed empirical evidence for decisions on liner application and design.

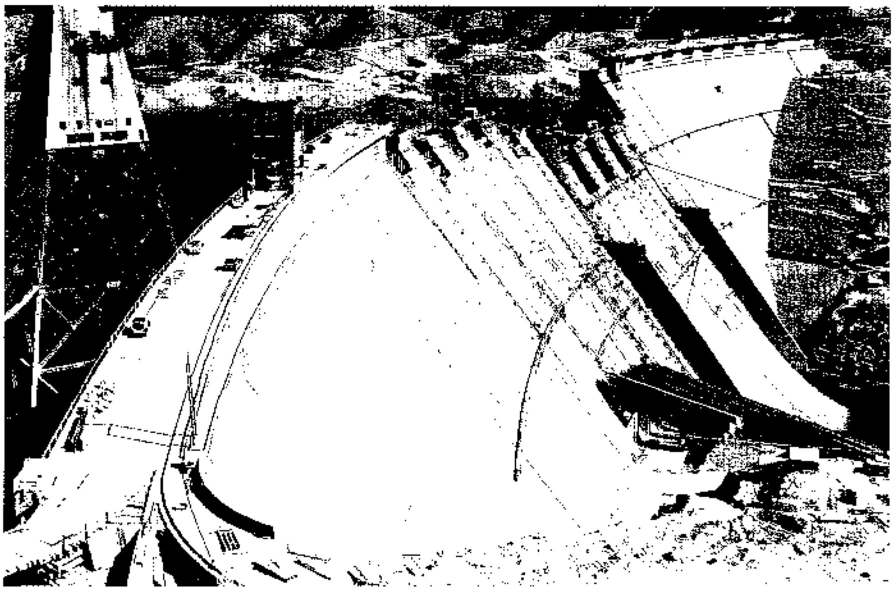
There is considerable debate between regulators and the electric power industry as to whether liners are needed for utility wastes and, if so, what kinds of liners should be used. EPA extraction tests show coal combustion ash and FGD sludge to be nontoxic; these wastes pose little or no threat to public or environmental health. On the basis of currently available information, therefore, the high cost of liners ($20–$40/t of waste per year) does not seem warranted. With utility waste production projected by some analysts to reach 125–150 million t/yr within a decade, the potential cost of liners looms very large. Also, there are technical questions regarding the need for liners. Because of its pozzolanic (cementlike) properties, much fly ash is self-sealing when wet, serving as its own liner and becoming less permeable to water with time.

Many utilities contend that if liners are to be used, clay (rather than synthetic materials) should be the material of choice. In theory, synthetic liners are virtually impervious; in practice they are readily punctured and their seams can fail, potentially leading to major leaks. Clay, on the other hand, naturally restricts water flow to about 1 in/yr, and its

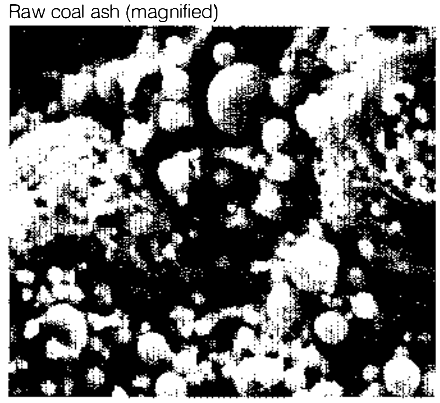
Today's Uses

High-volume, low-technology applications (such as road and embankment fill, blasting grit, and cement additives for dams and other structures) dominate the current market for coal combustion by-products. As in the sale of any bulky product with a low value per ton, the commercial potential of typical coal ash hinges on local demand because that keeps transport costs to a minimum. In the future, coal ash separated into refined by-products may enter higher-value markets in commercial and industrial applications, including strategic metals. The spherical shape and uniform size distribution of beneficiated ash particles provide excellent structural properties for filler in cement and plastics. Easy size separation of the spheres makes them particularly useful in pigments, which rely on specific ranges of particle diameter.

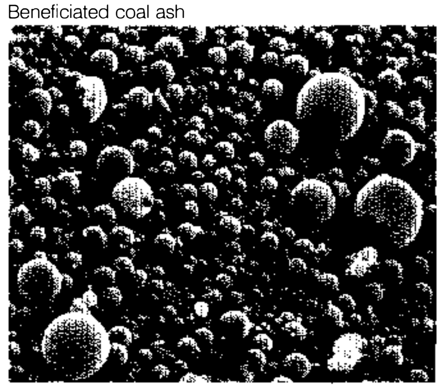
Dam construction



Raw coal ash (magnified)

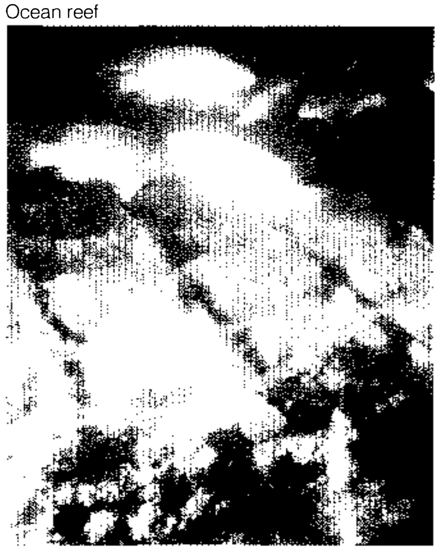


Beneficiated coal ash

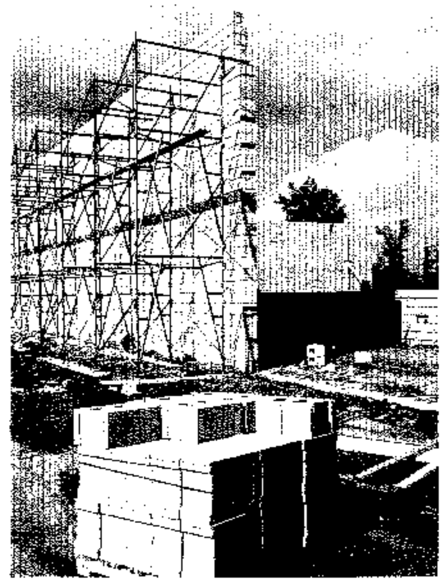


Road base

Ocean reef



Concrete block



molecular properties are such that it adsorbs metal ions, the elements of greatest concern in sludge and ash leachate.

Monitoring wells situated downgradient from waste sites offer a means of judging whether and to what degree materials are leaching out of impoundments. Federal law recommends that utilities install groundwater monitoring systems in nonhazardous landfills that have the potential to discharge into an underground drinking water source. States and localities can institute more stringent requirements.

One technique required at hazardous waste disposal sites but rarely applied at nonhazardous waste facilities is leachate collection. Essentially, a leachate collection system is a network of pipes buried below and around the sides of a disposal site. If monitoring wells detect that unacceptable levels of material are escaping, pumps can draw leachate out of the ground through the collection system before it has a chance to migrate into the groundwater.

Increasing ash use

Utilities are constantly improving their waste disposal techniques; they are also looking for ways to use or sell some of their by-products rather than throw them away. Ash, the most abundant utility waste, has a long history of use. The Romans recognized the pozzolanic properties of volcanic ash and used it as mortar in the Colosseum and in aqueducts. In the 1930s and 1940s fly ash was added to the cement that formed Hoover Dam and other large construction projects. Ash solved a problem civil engineers had been struggling with for some time. As cement cures, it releases heat, which can build up in large slabs of concrete and weaken the structure; fly ash bonds in a manner that does not release heat, so it is an ideal substitute for some of the cement in concrete.

Over the past 50 years, the largest use of fly ash has been as a cement additive. Of the 52 million tons of fly ash produced in 1983 by American utilities, just over 14% was used. Half of the fly ash put to use went into concrete and cement products, and the rest was divided among structural fills, road bases, grout, and mining applications. Even if all cement used fly ash to the maximum practical extent, however, the ash supply would not be significantly diminished. According to an EPRI-funded study, only 27% of the fly ash generated in 1983 would have been consumed if all cement produced in the United States that year had been 20% fly ash (a rich mix). Expanding the use of ash is an important challenge. If current utility predictions that coal use will double within a decade hold true, ash utilization will have to grow at least fivefold in the same period just to keep the demand for disposal space at the current level.

The largest opportunity for ash use is as a high-volume construction material in fills, embankments, and pavement base courses and for stabilizing soils. Some contractors and agencies that lack experience with fly ash are reluctant, however, to substitute it for more familiar materials. To help overcome this hesitance, EPRI's CCS division is publishing a survey of current high-volume ash utilization. The survey found over 250 projects throughout the United States in which fly ash was used in large quantities. The most popular applications were as pavement base course and for subgrade stabilization.

The federal government is also encouraging ash use. The Federal Highway Administration, with support from EPA, issued a directive in January 1985 that ordered state highway departments to revise their procurement and construction guidelines to allow the use of fly ash whenever it is technically and economically feasible. States that do not comply risk the loss of federal funds. John Gillis, of the American Ash Association (formerly the National Coal Ash Association), believes that there is a huge market for ash in highway construction. He predicts that nearly one-third of utility fly ash will be used in 1986, which amounts to twice the fraction used in 1983.

One of the principal factors limiting the use of fly ash has been the variability of its composition. To be more effective at recycling wastes to productive uses, utilities have to know more about the composition and properties of their by-products. To this end, EPRI funded extensive chemical and physical analyses of utility wastes over the past several years. This work revealed that fly ash is composed principally of tiny spheres containing compounds of silicon, aluminum, iron, and calcium. Adhered to or mixed in with these spheres are trace levels (in the parts-per-million range) of some two dozen elements, including a number of trace metals. Bottom ash and slag generally contain the same constituents as fly ash, though in different proportions.

In the late 1970s, when it appeared that coal ash might be classified as hazardous waste, EPRI reasoned that it might make sense to remove the potentially toxic materials from the ash and treat them with special care, leaving the bulk of the ash to be handled under conventional methods. Moreover, because most of the potentially toxic components of ash are metals, some of which are quite valuable, researchers began to view these hazardous wastes as potential resources and their extraction efforts as a mining operation. Earlier attempts had been made to mine ash for metals, but these efforts used complex and expensive techniques and failed. EPRI research in this area now is aimed at identifying and developing relatively simple and inexpensive processes that get enough of the metals out of the ash to keep the bulk material from being classified as hazardous. One metals extraction technique, in particular, looks promising because it produces marketable quantities of by-products and cleans the ash as well.

The heart of the proposed metals extraction technology, the direct acid leaching (DAL) process, was developed under EPRI sponsorship at Oak Ridge National Laboratory. Fly ash is leached in 100°C hydrochloric acid, which pulls the metals out of the ash into solution. The leachate—rich in aluminum, iron, and such trace metals as silver, titanium, and gallium—is then passed through anion exchange columns, which convert the metal salts to chlorides. These chlorides are precipitated and then converted by various separation, leaching, crystallization, and calcination processes into alumina, iron oxide, and other metal oxides. The insoluble, inert ash spheres that remain are classified by size and washed. These spheres have excellent loading and stress properties, making them an ideal filler in plastics. Plastics that contain leached ash filler shrink and warp far less and are more durable and more chemically resistant than plastics that use conventional fillers.

In 1983, having demonstrated the scientific feasibility of the process, EPRI funded a study by Raymond Kaiser Engineers, Inc., to determine the cost-effectiveness of a commercial-scale plant for extracting metals and other by-products from ash. The study found that for a million-ton-per-year DAL facility, rates of return on equity would range from 20% to 36% for 18 of the 20 ash samples tested. The minimal feasible plant would process 300,000 t/yr of the more attractive fly ash resources.

The DAL coal ash mineral recovery technology is a series of relatively simple operations that would use, for the most part, proven commercial processes and equipment. EPRI's CCS division is seeking cofunders to join it in building and operating a $10 million DAL pilot plant at a host utility site. This facility will confirm the integration of the technology and afford an opportunity to thoroughly test ash by-products and their markets. According to Golden, "The principal advantage of the process is that it converts essentially all of the fly ash waste into useful by-products. Although it isn't economically feasible to mine a million tons of ash to get 50 tons of gallium or 1000 tons of titanium, these strategic metals are extracted as a bonus in the process

Selected Laws and Regulations Affecting Utility Waste Management

1976: Resource Conservation and Recovery Act (RCRA) expands federal role in hazardous waste disposal and management. Regulation of nonhazardous waste delegated to states. Utility waste is not officially classified at this time.

December 1978: EPA proposes hazardous waste management regulations under RCRA, including a "special wastes" category containing fly ash, bottom ash, and FGD sludge. If judged hazardous by toxicity tests, utility wastes would be subject to more-stringent disposal requirements than in the past.

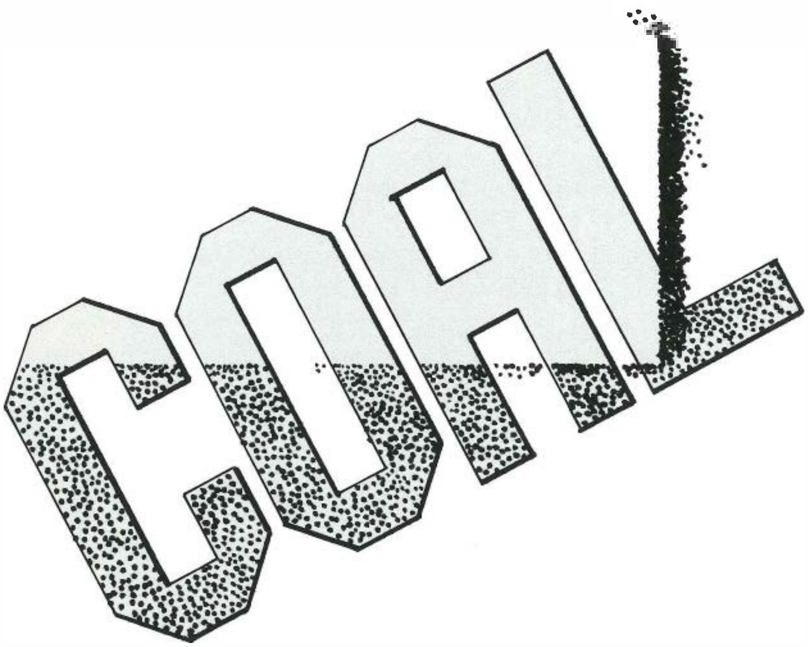
May 1980: "Special wastes" category abandoned; large-volume utility wastes classified as nonhazardous pending further study by EPA.

November 1984: RCRA reauthorization—Congress requires EPA to implement some 200 specific waste management provisions over the next five years, including upgrading of hazardous waste landfills with double liners and leachate monitoring and collection. All land disposal of hazardous wastes is to be phased out by 1990, replaced by such alternatives as incineration, chemical detoxification, and solidification. Potential future effect on utilities is uncertain at this time, pending EPA review of utility wastes, which are currently classed nonhazardous.

November 1985: EPA scheduled to release for comment the new toxicity test procedure and standards.

1986–1987: EPA expected to deliver report to Congress with recommendations on classification and management of utility wastes.

Wastes From Clean Coal Technologies



A new generation of processes is emerging that promises to make electricity from coal with less environmental impact than ever before. Notable among these approaches are enhanced physical coal cleaning, IGCC power generation, and FBC. Known as clean coal technologies, these techniques clearly will minimize air pollutant emissions. There's no getting around the fact, however, that coal contains impurities, including sulfur and various ash-forming minerals. In keeping these materials from entering the atmosphere, the clean coal technologies generate solid and liquid by-products, as do current coal technologies.

About 30% of utility coal is now subjected to some sort of cleaning process to remove rocks, minerals that cause boiler slagging, and sulfur, which contributes to air pollution. Most of the 500 U.S. coal-cleaning facilities are operated by mining companies near mine mouths. To the extent that the impurities are removed and remain behind when the coal is shipped to power plants, the cleaning facilities become responsible for waste disposal. These wastes are voluminous: as of 1978 there were about 3.5 billion tons of accumulated coal-cleaning refuse, and an additional 100 million tons were being generated annually.

Potential environmental problems related to coal-cleaning wastes include air pollution from blowing dust and debris, as well as smoke from burning refuse piles. Water quality problems may also arise because precipitation and coal-cleaning wastewater can leach metals, minerals, and organic compounds out of the wastes. Federal regulations require that the leachate from coal-cleaning wastes be nonacidic and contain minimal suspended solids. Current regulations also prohibit aqueous discharge from cleaning processes.

Safety issues are also important in regard to coal-cleaning wastes. There have been several accidents in which impoundment dams constructed of solid coal refuse failed, releasing large amounts of coal-cleaning wastewater and debris. These incidents led to strict regulations on the use of coal refuse in dam construction.

One of the promising new technologies for deriving energy from coal is IGCC, in which coal is reacted with oxygen and steam in a high-temperature vessel to produce a combustible gas composed mostly of carbon monoxide and hydrogen.

EPRI joined with seven other firms and contributed nearly $70 million to the development of a 100-MW (net), $260 million IGCC demonstration plant at Southern California Edison Co.'s Cool Water station. The depth and diversity of support for this project reflect widespread interest in environmentally clean ways of using coal to produce electric power. And the Cool Water plant is remarkably clean. The exhaust from the gas combustion turbine—without any particulate or sulfur controls—meets California's strict air pollution standards.

Although IGCC offers a virtually air-pollution-free way to use coal, it does produce solid and liquid byproducts. Roughly 300 t/MW-yr of slag is produced in a gasifier. This rate of slag and ash production is comparable to that in conventional coal-fired plants. IGCC slag is an inert mixture that consists almost entirely of mineral matter from the coal. EPRI is studying leaching characteristics of slag from a number of coal gasification processes. Slag from the Cool Water plant has been shown to be nonhazardous in both EPA and California leaching tests.

Because Cool Water's slag is so resistant to leaching, the state exempted it from the stringent disposal procedures that are required for hazardous wastes. The Cool Water project is now exploring commercial outlets for this by-product.

Coal gasification plants also recover elemental sulfur from the coal-derived fuel gas. IGCC sulfur by-product is sold commercially either in solid form or, in the case of Cool Water, as a liquid.

IGCC facilities generate liquid discharges in the form of cooling-tower blowdown and process water blowdown. At Cool Water the process water blowdown (by far the smaller of the two streams) is first stripped of residual ammonia and hydrogen sulfide and then routed with the cooling-tower blowdown to a lined on-site evaporation pond. Several other IGCC wastewater treatment processes are being investigated. These methods will be used at non-zero-discharge sites to treat gasification blowdown water before it is released from the plants.

In FBC limestone reacts with coal inside the combustion chamber, converting over 90% of the sulfur dioxide produced in combustion to dry, powdered calcium sulfate. Coupled with baghouses for particulate capture and with low-temperature firing, which produces less nitrogen oxides than do typical boilers, FBC offers a way to burn all grades of coal and still minimize air pollutant emissions.

The amount of calcium sulfate by-product generated by FBC depends on the sulfur content of the fuel and the Ca:S ratio (typically between 1.5:1 and 2.5:1) of the limestone-fuel mix. Dry-sorbent capture of sulfur in fluidized-bed units requires about twice as much limestone per pound of sulfur captured as do the most efficient wet-sulfur scrubbers now in use. Because FBC plants do not mix water with their limestone, however, the total volume of dry-sulfate FBC waste will be about the same as the volume produced in wet scrubbers.

The particulates formed in FBC plants are similar in quantity and composition to the ash formed in conventional pulverized-coal boilers, although FBC ash is generally more alkaline and contains more sulfates. FBC ash has a higher electrical resistivity than does typical fly ash, which means that baghouses will be more effective than electrostatic precipitators for FBC particulate control. Because FBC ash is collected with calcium sulfate, the potential for using this ash is reduced.

EPRI's CCS division is sponsoring research to study the chemical and physical characteristics of wastes from FBC, coal cleaning, and several other advanced sulfur dioxide control technologies. This project will also examine disposal and utilization options for the by-products of these technologies.

Physical coal cleaning, IGCC, and FBC have the potential to reduce emissions of air pollutants in coal-fired electric power generation without increasing solid and liquid wastes. Creative waste management, treatment, and use—in concert with the inherent air quality advantages of these emerging processes—will help make the next generation of coal-fueled plants the cleanest in history. □

of removing alumina, iron oxide, magnetite, gypsum, and beneficiated ash."

Putting sludge to use

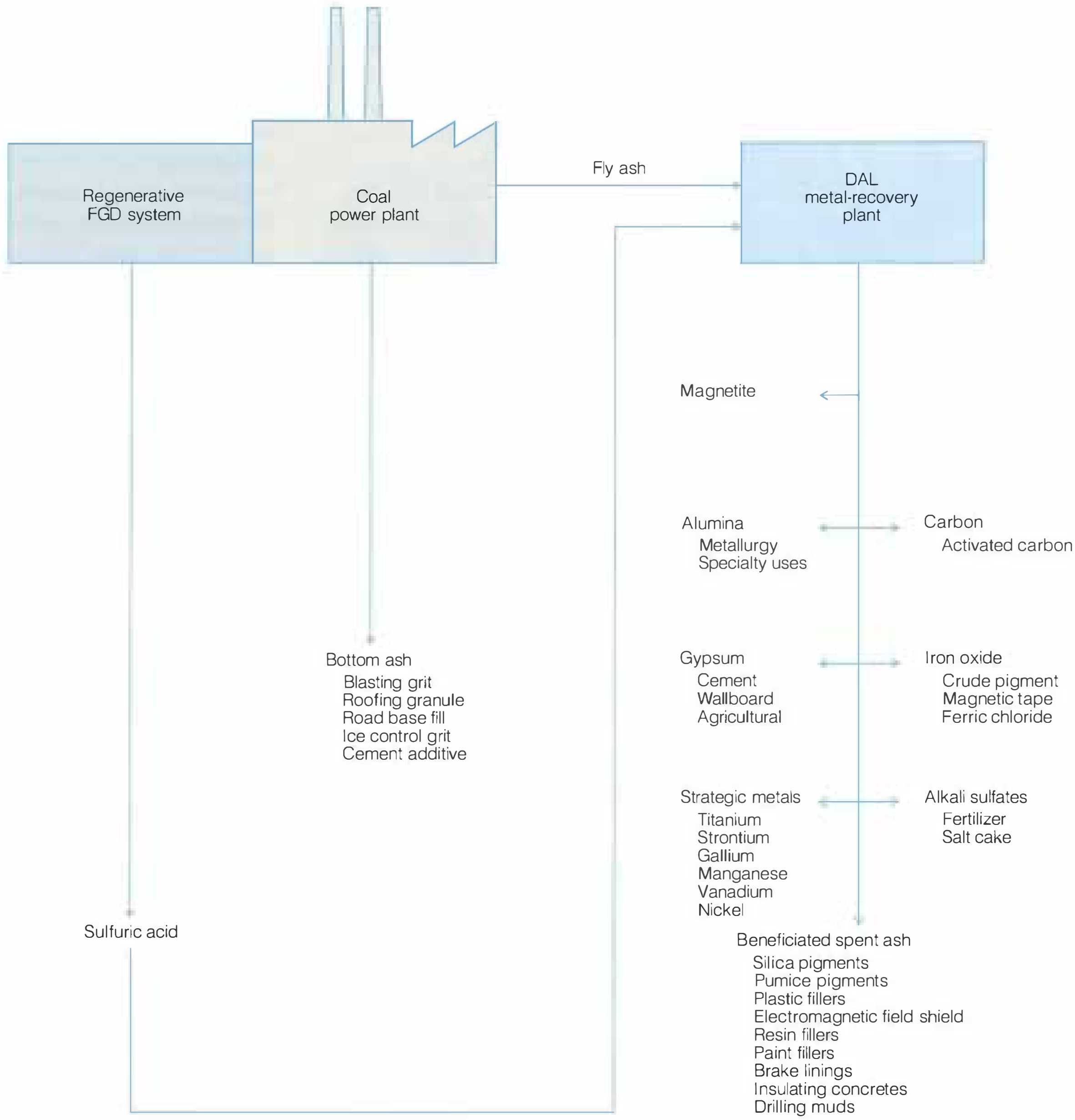
If coal use doubles within the next 10–15 years, as some analysts predict, the rate of production of FGD sludge will grow even more dramatically because new coal-fired plants must be equipped with scrubbers. The primary constituents of scrubber sludges are sulfates, sulfites, and carbonates of calcium. Sludges typically contain some unreacted scrubbing agent; varying amounts of fly ash; oxides of silicon, aluminum, and iron; and trace levels of many of the same elements found in coal ash.

Scrubber sludge holds less promise for use than does fly ash. A 1983 EPRI manual on FGD sludge disposal stated that there are no prospects for large-scale utilization of scrubber by-product in the United States. A few research projects have examined the prospects of scavenging sulfur from FGD sludge, but no cost-effective technique for doing so has been found. Gypsum (a primary component of FGD sludge) has a large market in the wallboard, cement, and agricultural industries. Many industries that use gypsum own their own mines, however, and thus have little interest in buying gypsum from other sources. Further, such contaminants as fly ash and chlorides in many cases prevent scrubber gypsum from competing effectively with naturally occurring gypsum. Where natural gypsum is not available (in Japan, for instance), sludge-derived gypsum is widely used. And in parts of the United States that lack local gypsum supplies, FGD by-product gypsum has regional market potential. In response to just such a situation, an FGD gypsum wallboard plant is now being built in Texas.

Because there are few economical uses for FGD sludge, most of this material will continue to be disposed of in landfills. If the cost of FGD sludge disposal continues to increase, FGD processes that recover sulfur in a marketable form may

Potential Future By-product Utilization

As the costs of waste disposal rise, utilities will find new ways to utilize the by-products of coal combustion. This diagram describes a hypothetical future scenario in which an increasing proportion of the major by-products from coal-fired plants are put to use. The direct acid leaching process (DAL) developed under EPRI sponsorship to separate fly ash into metal oxides and other commercially valuable products is the heart of this scenario. Marketing research indicates that a DAL facility capable of processing one million tons per year of fly ash would be profitable. EPRI is now seeking cosponsors to build a pilot-scale DAL facility. To avoid costly sludge disposal, FGD systems that produce recyclable sulfur compounds will become more common. Bottom ash, with particles too large and a surface area too small to be cost-effectively processed for metals recovery, will continue to be sold in its traditional markets.

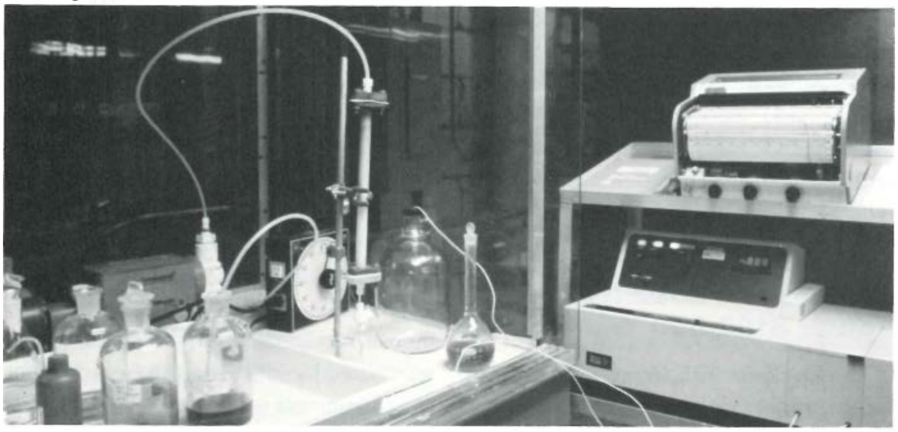


Testing and Research

EPRI and the utility industry are conducting extensive research to characterize the chemical and physical properties of their wastes. Using government-developed procedures, EPRI research has tested dozens of kinds of utility wastes for leaching of metals and organic compounds. These tests have shown that virtually all utility wastes are nonhazardous under current federal and state standards. Nevertheless, the utility industry is actively developing improved waste disposal technologies. This effort includes testing of soil-based and synthetic liners, as well as studies on landfill design and waste stabilization, fixation, and dewatering. Disposal research is complemented by an aggressive effort in by-product utilization.

Liner testing

Leaching tests



Metals extraction

become economical. A few such facilities are already in operation. Philadelphia Electric has installed devices to recover elemental sulfur from the flue gases of two of its plants. Public Service Co. of New Mexico has an FGD system on its San Juan generating station that produces marketable sulfuric acid.

A new era

The days of "out of sight, out of mind" are long gone. Utility wastes, like the by-products of any modern industry, are now subject to an unprecedented level of scrutiny. This attention has raised the utilities' awareness of the need to understand and carefully manage their wastes. Uncertainty created by changing regulations makes the industry's job more difficult, but the basic challenges remain: to minimize waste production, expand utilization, and ensure safe, economical disposal. EPRI is helping utilities meet these challenges by providing the electric power industry, the government, and the public with the information needed to build sound policies and practices. ■

Further reading

Characterization of Utility Low-Volume Wastes. Final report for RP2215-1, prepared by Radian Corp., May 1985. EPRI CS-3737.

Dewatering to Stabilize Fly Ash Disposal Ponds. Final report for RP1260-36, prepared by Pennsylvania Electric Co., May 1985. EPRI CS-3863.

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Combustion By-products Utilization Manual. Final report for RP1850-1, prepared by Michael Baker, Jr., Inc., February 1984. EPRI CS-3122.

Physical-Chemical Characteristics of Utility Solid Wastes. Final report for RP1487-12, prepared by Tetra Tech, Inc., September 1983. EPRI EA-3236.

FGD By-product Disposal Manual. Final report for RP1685-4, prepared by Michael Baker, Jr., Inc., January 1983. EPRI CS-2801.

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Manual for Upgrading Existing Disposal Facilities. Final report for RP1685-2, prepared by SCS Engineers, August 1982. EPRI CS-2557.

This article was written by Michael Shepard. Technical background information was provided by Dean Golden, Ralph Komai, and Thomas Morasky, Coal Combustion Systems Division.

New Polisher Procedures Cut Blade Corrosion

When Southern California Edison Co. discovered that several turbines in its once-through steam units were corroding severely, the utility at first suspected intrusion of seawater into the condensers was responsible for overtaxing the ability of the condensate polishers to filter contaminants. Then, in a joint study with EPRI, SCE conducted laboratory and field investigations of the turbine steam and found that the corrosion was caused mainly by chloride from impure sodium hydroxide used to regenerate polisher resin. The study revealed that leakage of this chloride from individual polishers can often exceed contamination from outside sources. By modifying its polisher regeneration procedures, the utility was able to reduce chloride contamination 10-fold and reduce turbine blade corrosion by 80%. ■ *EPRI Contacts: Barry Syrett (415) 855-2956; Thomas McCloskey (415) 855-2655*

Oklahoma Utility Finds Ground-Coupled Heat Pump Best Performer

Two years of tests by Oklahoma Gas and Electric Co. show that ground-coupled heat pumps are better at reducing both summer and winter energy use than are competing heat pump designs. On the basis of these tests, OG&E estimates that it could save $70 annually in avoided costs for every unit installed in place of a comparable air-coupled design. The tests used three single-family homes in Perkins, Oklahoma, to compare the performance of air-coupled, solar-assisted ground-coupled, and unassisted ground-coupled heat pump systems. Even though the test period was marked by two unusually cold winters, the unassisted ground-coupled unit shaved peak demand by 50% and total energy use by 29% compared with the other systems, and it needed no backup resistance heating. The closed-loop system requires no external water source, so scaling and corrosion problems are avoided and pumping requirements are reduced. ■ *EPRI Contact: Gary Purcell (415) 855-2168*

MMS Saves Duke Power $100,000 Yearly

Duke Power Co. found it difficult to simulate or predict dynamic plant performance by using traditional diagnostic tools, a problem it shared with many other utilities. So when research cofunded by two EPRI divisions produced a modularly structured computer code that could be used to simulate the actual dynamics of plant performance, Duke volunteered to take part in a 10-utility test of the code. Called the modular modeling system (MMS), the code contains 40 modules that represent all major components used in conventional fossil fuel and nuclear plants; it can be used to predict dynamic performance, to analyze power plant control systems, or to perform scoping analyses of major nuclear accidents. Duke used MMS to model the control systems in its new Catawba-1 nuclear plant and has applied the code in a number of ways at both its McGuire and Oconee nuclear plants. The utility estimates that by using MMS it can avoid various power plant disruptions and save a minimum of $100,000 yearly. ■ *EPRI Contacts: Frank Wong (415) 855-8969; Murthy Divakaruni (415) 855-2409*

LOMI Decontamination Licenses Awarded

EPRI has recently awarded licenses for the LOMI (low-oxidation-state metal ions) chemical decontamination process to Bechtel National, Inc.; IT Corp.; and London Nuclear Services, Inc. Developed through research cosponsored by EPRI and the Central Electricity Generating Board of Great Britain, the LOMI decontamination process has already been used successfully by Bechtel on four steam generators in a PWR; the process is currently being applied by London Nuclear to Commonwealth Edison Co.'s Dresden-3 unit. Earlier, Northern States Power Co. used the LOMI process before replacing corroded piping in the core recirculation system of its Monticello nuclear plant. The utility is pleased with the results: decontamination factors of 21 and 24 in the two cooling loops, a reduction in personnel exposure of 800 man-rem for the pipe replacement project, and a saving of at least two weeks in outage time. NSP estimates total overall savings of nearly $3 million for the project. ■ *Contact: Bechtel National, Inc. (615) 482-1552; IT Corp. (615) 690-3211; London Nuclear Services, Inc. (716) 282-6912; EPRI Contact: Chris Wood (415) 855-2379*

Sigma Research Awarded License for Holographic Imaging Technique

The SDL-1000, a new acoustic holographic imaging system developed by EPRI, has just been licensed by Sigma Research, Inc., of Seattle. A high-speed unit that can be operated on horizontal or vertical surfaces at speeds up to 12 cm/s, the SDL-1000 is a versatile nondestructive evaluation (NDE) test system capable of performing in both holographic and pulse-echo modes for ultrasonic imaging. It can also be interfaced with conventional eddy-current instruments to perform electromagnetic inspections and will generate data that can be used to form B- and C-scan images. The system can also be operated in the immersion mode for underwater imaging. The SDL-1000's exceptional spatial resolution—inherent in holographic imaging—enables it to accurately size flaws and other anomalies in pipe welds, heavy-section metals, concrete, and other applications where focused beams are impractical for attaining resolution. This highly portable NDE system is computer-based and, within seconds after completing a scan, can present the data needed for making finished images. ■ *Contact: Sigma Research, Inc. (206) 575-9324; EPRI Contact: Mohamad Behravesh (415) 855-2388*

Licensed DC Fault Locator Improves Predictive Ability

Although existing systems for locating faults on high-voltage dc lines are very expensive (close to $200,000 per unit), their use is nevertheless critical to a utility hoping to avoid the even higher costs of patrolling long stretches of dc lines. Now a fault detection device developed by EPRI can help utilities inexpensively and accurately locate troublesome fault sites. Recently licensed by Schweitzer Engineering Laboratories of Pullman, Washington, this new locator relies on a simple, passive reflectometer approach. It takes information from just one end of the transmission line, then analyzes the times between the multiple reflections of fault-induced traveling waves to locate stationary voltage minima. Key to its improved prediction capability is a four-sample triangulation–interpolation algorithm: without the algorithm, the normal location accuracy of such a system would be about 4 mi (6.4 km), but use of the algorithm improves the accuracy to about 1 mi (1.6 km). In fact, tests of the system on the Bonneville Power Administration's 800-mi (1300-km) Pacific Intertie showed that it could accurately predict faults to within about a 1-mi span of line. ■ *Contact: Schweitzer Engineering Laboratories (509) 332-1890; EPRI Contact: Harshad Mehta (415) 855-2293*

Newly Licensed Electrode Monitors Corrosion in BWRs

EPRI has licensed NWT Corp. of San Jose, California, to manufacture a high-temperature electrochemical potential reference electrode to measure the corrosion potentials of metals and alloys in high-temperature water environments. Several of the electrodes have already been sold to BWR plants, where they are being used to determine the corrosion potentials of structural alloys (such as stainless steel piping material) that have operated for long periods of time under BWR conditions. Reliable information on the corrosion potentials of stainless steels is essential for BWRs that use or plan to use hydrogen injection in feedwater for controlling the intergranular stress corrosion cracking (IGSCC) of reactor piping systems. IGSCC of stainless steel can occur in BWRs during normal operation because corrosion potentials tend to be high; the addition of hydrogen can mitigate the effect by decreasing the steel's corrosion potential below a critical level. Thus the long-term monitoring of the electrochemical potential of structural alloys in BWR plants can serve as a tool for assessing corrosion-related plant changes that are not reflected by plant chemistry data. ■ *Contact: NWT Corp. (408) 281-1100; EPRI Contact: Daniel Cubicciotti (415) 855-2069*

Partial Discharge Detection Device Licensed by AE International

A division of The Hartford Steam Boiler Inspection and Insurance Co., AE International, recently entered into a licensing agreement with EPRI to manufacture a portable instrument that uses acoustic emission techniques to detect partial electrical discharges in transformers. Generally associated with the degradation of transformer insulation systems, partial discharges are routinely detected in laboratory or factory environments by using conventional electrical sensing techniques. But such techniques do not perform successfully in the field because of high levels of background noise emanating from transmission lines and other equipment. The acoustic emission device, however, can be used in the field to locate even low-level sources of partial discharges, allowing engineers to make an on-site determination of the severity and extent of the problem. This early detection means that a scheduled and less costly repair of the transformer unit can be made, either in the field or at the factory. Further, the early detection of an incipient fault on an operating transformer could prevent a catastrophic failure, such as a short circuit, saving a utility much downtime and money. ■ *Contact: AE International (203) 722-5671; EPRI Contact: Stig Nilsson (415) 855-2314*

CRS: Answering Congressional Queries

A department within the Library of Congress, the Congressional Research Service (CRS), is charged with providing direct reference and research services to members of Congress, congressional committees, and staff.

What does a half million research requests divided by 858 staff members equal? The answer is not as mathematically precise as 582.75 research requests per person. But the equation does give some indication of the annual workload of a unique organization devoted exclusively to serving the vast information needs of the United States Congress. In name, the CRS has existed only since Congress passed the Legislative Reorganization Act of 1970. In actuality, the service originated nearly two centuries ago when Congress created its own library as a resource for legislative issues.

Originally a general reference support group staffed by a handful of librarians, CRS today is an official department of the Library of Congress and is staffed by a pool of diversified professionals possessing expertise in the many areas that are of interest to members of Congress and their staffs. Its real growth has occurred since 1970 with the passage of the Legislative Reorganization Act. The act expanded the service's mandate for analytic research capabilities, gave it greater fiscal and administrative independence from the Library of Congress, and allowed its staff and budget to keep pace with the increasing demand for its services.

For example, the CRS budget, which was about $5 million in 1970, has grown to nearly $40 million for FY85. And the CRS staff, which totaled 323 in 1970, today stands at 858 and includes librarians; information specialists; economists; engineers; attorneys; political, physical, and behavioral scientists; public administrators; and a host of other experts.

Gilbert Gude, director of CRS since 1977, is a former representative from Maryland who served on several congressional committees during his five terms in Congress between 1967 and 1976. Those years, together with his time as CRS director, gave Gude a keen awareness of the service's specialized role.

"There is really no equivalent research organization anywhere," he emphasizes. "CRS represents the largest legislative research organization in the world. We cover all subjects of interest to Congress, which is practically the universe, and we endeavor to transmit our information in formats that can be most easily obtained and used in the context of Capitol Hill. As a result, much of our material is produced in print form, but audio, slide, and video presentations are increasingly used."

Work at CRS requires timeliness and speed. Responses must meet congressional deadlines, particularly when the material is being supplied for scheduled hearings or floor debates. One of the reasons CRS products reach their congressional destination with little delay is that there are few bureaucratic roadblocks to impede the review process. After a written response to a congressional query is completed, it undergoes section and division reviews before reaching the review office, a group of four staff members who must pass on all CRS material. "When material gets up to the review office, it ought to be ready to go," says Gude. "We don't want the review staff heavily involved in rewrite. And this is very much in keeping with our mission."

He emphasizes that material is able to move very quickly through the review office because CRS's concern for accuracy and objectivity begins long before that stage is reached. "The most important safeguard we have for the high-quality work we expect is recruitment," he explains. "We recruit people who have a scholarly, academic approach. If they are advocates, they don't belong here. There are certainly many places in the world for advocates," he concedes, "but CRS is not one of them. The idea is to instill in the analyst and researcher a pride and interest in serving Congress."

One way this is accomplished is to acknowledge the contributions of individual staff members. Thus another CRS hallmark is that credit is always given to the person who prepares a response, whether it is a report, memorandum, statistical compilation, or some other form of communication. With that credit, however, comes the responsibility to lay out a project from the start so that the requirements for balance, quality, and objectivity are met.

Because of Congress's great need for large amounts of diverse information, the research inquiries CRS must address run the gamut from the quick turnaround, factual question to the request for more in-depth scientific, economic, legislative, or policy analysis. Likewise, the answers can range from verbal responses requiring only a few minutes to extensive written reports requiring a few weeks to over a year of study.

Quick Turnaround Response

Of the 858 staff members at CRS, well over half (526 employees) work in the service's seven research divisions. Another 175 staff members work in the reference and library information divisions, 101 work in the senior specialists and the client services offices, and 56 work in various administrative and support offices. Among these groups, the Congressional Reference Division (CRD) ranks highest for the sheer volume of inquiries it handles, about two-thirds of the 450,000 requests received each year. This group, composed of librarians and information specialists, provides quick turnaround answers to members, committees, and staff.

CRD delivers its services in various ways. On-site reference service is provided in two congressional reading rooms and in CRS reference centers conveniently located in four nearby congressional office buildings. The division has also established two information distribution centers, one for each House of Congress. These centers contain preassembled packets of information covering more than 150 topics that are of continuing interest to congressional members and staff. In the centers, congressional staff can browse among towering stacks of the bright yellow packets (Info Packs) for subjects ranging from acid rain, groundwater, and nuclear proliferation to enterprise zones, cable TV, and terrorism.

According to Gude, these Info Packs are a key to preventing the reinvention-of-the-wheel syndrome. When an issue is likely to spur repeated congressional inquiries, the CRD staff moves quickly to save everyone's time by assembling the material in advance. "Our reference division works with our research divisions in crafting these Info Packs," he explains. "They draw on the best of what we've done and the best of what's available outside CRS, including the popular press. The goal is to present a concise overview of a subject to someone who knows very little or nothing at all about that particular topic."

In-depth Analyses

When a request comes in that cannot be handled by the CRD staff, it is directed to one of the seven research divisions. Typically, such a request might require an analytic report or a detailed discussion of the pros and cons of an issue. The seven divisions cover American law, economics, education and public welfare, government, science policy research, foreign affairs and national defense, and environment and natural resources policy. Of the seven divisions, three handle, to varying degrees, inquiries related to energy concerns.

The Environment and Natural Resources Policy Division responds to requests that cover a wide range of policy concerns. Environmental questions, for example, can deal with such issues as toxic- and solid-waste management and disposal, and marine oil pollution and spills. Various energy-related questions can concern such topics as oil, gas, and gasoline supply and production; fuels allocation; and energy conservation. In addition to providing materials in these areas, the division prepares responses for a host of natural resource management and agricultural queries.

In the Economics Division, energy is only one of many topics given attention by staff members. Although the division has no specific group specializing in energy, there are several analysts who work on energy-related economic questions that for the most part involve electric utilities.

Energy inquiries that deal primarily with technical questions are directed to the Science Policy Research Division. This division concerns itself with a wide range of issues and subjects emanating from all fields of science and technology. In the energy arena the staff studies the technical side of the production and use of synthetic fuels, nuclear power, and a broad spectrum of alternative energy technologies. The division's approach is to study a topic, such as conservation, from the standpoint of determining what the technologic capability is for cost-effective application in the United States.

"Energy is not the big profile issue it was a few years ago," comments Gude, "but it is still very much present. Our specialists might not feel the pressure as much, but they still have plenty to do on energy-related issues."

He explains that a single issue can move in and out of the spotlight, depending on various factors, but adds, "What's extremely important here at CRS is that we have an institutional memory. Energy may not be the number one issue on today's front page of *The Washington Post*, but we continue to have staff here who can cover the subject for those in Congress who are concerned about it. And there is always the concern that the oil supply from the Middle East will be cut off once again."

Gude Kaufman

Senior Specialists

One of the ways CRS manages to retain an institutional memory is through its staff of senior specialists. Each specialist is a nationally recognized expert who provides a variety of services in his or her area of expertise. Senior specialists furnish Congress with oral or written analyses, assist directly in the coordination of special congressional studies, serve as staff consultants or project directors for various committees, plan hearings, and assist in preparing reports for hearings. Within CRS, senior specialists also help to coordinate projects that cover interdivisional and interdisciplinary topics.

Alvin Kaufman is a senior specialist working almost exclusively on projects involving electric utilities and natural gas regulation. Kaufman explains that for some requests he conducts studies on his own and at other times gets involved in a project that "might contain pieces that I either haven't followed lately or don't know much about." In such instances, he recruits a group from various divisions and together they work as a team. Conversely, the research division staff will come around to him with a request and ask for help, so he may take on a piece of the work, coordinate it, or take it over entirely. "It is a very free-wheeling organization," he says and adds, "Although there is a chain of command for most of the troops, it's a very loose chain."

How long does the typical project run? "Anywhere from one day to two or three months," Kaufman responds. "We're a short-order house. If we spend three months on something, we've invested a tremendous amount of time. And when it involves a team of, say five people, we could have a total of 15 staff-months invested in that three-month study, which is an enormous amount of time for us. Even so, while it might cost CRS $20,000 to $30,000 to do the study, a federal agency might spend $2 million doing essentially the same thing."

Kaufman emphasizes that CRS is unique in yet another way. There is no overall program where money is expressly appropriated to carry out a specific study over a given period of time. "Around here you have to get used to an issue popping up repeatedly and then going away. Finally, it becomes time for somebody to take action, and the issue takes off. Regional utility regulation is one of those issues that rears its head once in a while, then goes back into its hole. And I think it will continue to come and go."

Current Energy Issues

According to Kaufman, the first half of 1985 has been slow, characterized more by back- burner issues than any real sizzlers. "Congress has been preoccupied with the budget, but the pace is starting to pick up. At the moment, acid rain is big business and will be around for quite a while. We've also had some questions recently on tall stacks, a topic that ties in with our acid rain work. In addition, we are again working on the Fuel Use Act." He notes that CRS involvement with this legislation is a perennial task that is determined by whether or not Congress is thinking of changing the act. "And then," he continues, "we always have questions on the adequacy of generation capacity, which has resulted in a study each year for the past several years.

"Wheeling is another issue that Congress asks about repeatedly," Kaufman says. He notes that the topic generates all kinds of questions that have not been fully addressed as yet. Pointing out that the number of industrial cogenerators is growing around the country, he predicts that the issue of wheeling will heat up even more. He sees cogenerators becoming quite vocal on the issue. "They would like to broaden their market beyond their own utility so that they can peddle the extra electricity to whoever will buy it. To do that, they need the ability to move the electricity around."

This and related issues, Kaufman emphasizes, are really a subset of the deregulation question. He has pegged deregulation as the sleeping giant. "I think we just really haven't taken on the issue of deregulation yet. People are thinking about it, but really haven't come to grips with it."

A particularly sticky area to be considered, he warns, is what is to be done about state regulation and how that, in turn, is going to affect the future evolution of electric utilities. "We have ideas, which we've published, but my crystal ball is as cloudy as everybody else's."

Another project that Kaufman and his colleagues have been pursuing is the development of an electric utility model. In the past, CRS has relied on outside projections as a basis for analyzing issues related to electricity supply and demand. Although it is not a crystal ball, as Kaufman acknowledges, the model now allows CRS to do some of its own forecasting. "I think we are on the verge of a revolution here in terms of our ability to respond and the kind of response we can provide for such requests." With the advent of microcomputers and the development of its own set of models, Kaufman is confident that CRS can increasingly respond very quickly to complex requests. "We always compare our results with those of outside organizations," he continues, "but I think what we'll see is much less dependence on what other researchers are doing or saying and a lot more dependence on our own in-house capability."

Other Resources for Congress

Even though CRS may become less dependent on data supplied from the outside, many of its services build on outside information. For instance, CRS provides Congress with a service called CRS Stats Line. The stats line is a recorded phone message, updated weekly, that gives current figures for selected economic indicators like current unemployment, housing starts, the prime rate, the public debt, the federal deficit, the consumer price index, the gross national product, and the U.S. merchandise trade balance.

CRS also provides a forum for information exchange between the private sector and Congress by sponsoring workshops and seminars on current issues. Experts from research organizations around the country are invited to serve as panelists, and a CRS analyst serves as moderator. According to Kaufman, those workshops that are limited to members of Congress generally focus on policy-related issues and feature two panelists who advocate radically different positions. Those open to staff may have four or more panelists, selected to represent the many sides of an issue. These workshops often help to clarify who supports, opposes, or remains undecided about an issue. They also provide panelists with an opportunity to explain whether they feel they are going to win or lose and why.

Occasionally the seminars serve a dual purpose by providing material for committee prints. Congress will ask CRS in advance to put together a one-day seminar as a vehicle to gather experts. The seminar is then recorded, transcribed, and published as a part of a committee print.

In addition to its workshops, CRS sets up courses, or institutes, for congressional staff. These institutes provide in-depth background on almost any subject taken up by Congress. CRS analysts serve as faculty for the institutes, which also train congressional staff to conduct their own legislative research and to use the wealth of information sources available to them. The institutes have become an excellent device for increasing the points of contact between CRS and Hill staff while training congressional staff to become more self-sufficient.

"Everybody's interest is served by such a formula," Gude notes. "Members of Congress think their staffs are brighter and more intelligent the quicker they can respond; the congressional staff members are a lot happier being productive and not having to depend totally on

CRS PUBLICATIONS AVAILABLE TO THE PUBLIC

Major Legislation of the Congress provides summaries of congressional issues and the major legislation introduced in response to those issues. This book is published approximately 10 times during each two-year congressional period. Subscriptions cost $39 for domestic addresses, $48.75 for foreign addresses.

Congressional Research Service Review is a professional journal for Congress and its legislative staff. It is intended to provide the congressional community with analytic articles on substantive public policy issues. Subscription service normally consists of 10 issues per year and is available for $19 to domestic addresses and $23.75 to foreign addresses.

Digest of Public General Bills and Resolutions summarizes the essential features of public bills and resolutions introduced in a session of Congress. It also indicates committee and floor action and includes sponsor, short title, and subject indexes. It is published during each session of Congress in two cumulative issues (with occasional supplements) and a final edition at the conclusion of the session. Subscription service per session of Congress is available for $55 to domestic addresses and $68.75 to foreign addresses.

CRS Studies in the Public Domain lists those Congressional Research Service studies and reports that have been printed in some form by the U.S. Government Printing Office and that have been made available generally during the latest six-month period. When ordering, refer to S/N 030-000-00132-0; the price is $2.75.

To obtain an order form for any of these publications, request a copy of GPO brochure 900-185, *CRS Publications Available to the Public*, from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

someone else to provide them with answers. It also gives us more time to do a better job."

Additional support provided by CRS includes a variety of publications. A series of issue briefs on over 400 topics is updated routinely to provide a quick analysis on major issues of congressional concern. The *Digest of Public General Bills and Resolutions* summarizes legislation receiving action during a single session of Congress. CRS also prepares bibliographies, research guides, a monthly magazine, audio briefs of conferences or panel discussions on active legislative topics, and overviews of national issues compiled from editorial comments and public opinion polls.

Gude points out that one of his priorities as CRS director is to improve congressional awareness of the many CRS products that are available. "When I came here nine years ago, Congress received various lists of publications in different forms at different times; there was really no clear organization. Now we have everything in one place. We publish *Update* monthly, which is essentially a list of all the information products and services available from CRS."

Public Access

CRS works exclusively for Congress, and hence its products are published exclusively for Congress. "One of the concerns that arises periodically is what the public gets out of its tremendous investment in this organization," says Gude. Although members of the general public cannot request a CRS study directly, they can request a copy through their congressional representative or from the committee that prompted the study. Congress not only publishes some of the CRS material in committee prints but will sometimes enter it into the *Congressional Record* as well. In addition, four publications are available to the public on a subscription basis.

"Those documents we do publish, together with what goes into committee prints and the *Congressional Record*, not only make a substantial amount of our material readily available but also represent most of what would really be of interest to the public. To publish everything that CRS does," Gude explains, "would be a waste of the taxpayers' money and would quickly result in an information overload.

"In fact," continues Gude, "given the ever-growing information needs of Congress and our continuing efforts to find new ways to make information more readily available to the members, we sometimes wonder how we manage to keep up. The fortunate thing," he adds with a smile, "is that all the members of Congress don't ask questions at the same time. If they did, the roof might just fall in." ■

This article was written by Mary Panke, Washington Office. Technical support was provided by Michael Tinkleman, Washington representative, Energy Analysis and Environment Division.

High-Voltage Test Facility Now Owned by EPRI

EPRI sees a new mission for its recently acquired High-Voltage Transmission Research Facility: to provide an expertly staffed, practical problem-solving laboratory for member utilities.

A dedication ceremony held in mid September formalized the transfer of ownership of the High-Voltage Transmission Research Facility (HVTRF) from General Electric Co. to EPRI. As a result, the facility, which was formerly known as Project UHV, is adopting a new mode of operation designed to produce more short-term benefits for EPRI member utilities.

Richard Kennon, EPRI program manager, emphasizes that HVTRF will keep the same excellent staff and will continue long-range research into improved transmission line designs, both HVAC and HVDC. But its new emphasis will be on providing a state-of-the-art laboratory that can help EPRI members solve their day-to-day practical problems. Now, whether utilities seek to qualify a line for environmental acceptability, test insulators for a particularly complex application, or check the switching surge performance of a tower design, they can come to HVTRF for a quick response to their problem. Kennon notes that the laboratory's line qualification tests will be especially useful to utilities working on licensing problems associated with new lines.

"Once EPRI established a new research emphasis for the HVTRF," says Kennon, "it recognized that the facility would need expert oversight by experienced utility technical managers." Such a group has been formed and has already held its first meeting. John Dunlap, the EPRI project manager in charge of work at HVTRF, will work closely with this advisory group to make sure the facility is responsive to the members' needs.

During the last three years, EPRI-sponsored research and testing have concentrated on HVDC transmission lines. "HVAC transmission line design is a mature technology," comments Dunlap, "whereas relatively little is known about dc lines. The design information being developed at HVTRF will be very useful to the many utilities planning or considering dc lines."

Other work at HVTRF includes evaluating insulator performance, corona phenomena, electric and magnetic fields, and all electrical aspects of transmission line design and performance. Two full-scale test lines that duplicate the voltage, conductor geometry and height, and phase spacing of operating lines are used to evaluate a wide range of transmission line performance parameters. In fact, the facility's main test line, which is 523 m long and has a suspension span of 340 m, can simulate any HVAC or HVDC line using voltages up to 1500 kV ac or ±1500 kV dc. Hybrid configurations, combinations of ac and dc lines on the same structure, can also be tested to help develop hybrid-line guidelines.

Additional HVTRF equipment performs an array of other kinds of line, insulation, and voltage tests, including those to assess the nonbiologic field effects of induced voltages and currents, to investigate ways of reducing both radio and audible noise emanating from high-voltage lines, to evaluate the electrical strength of insulators subjected to surface contamination, and to determine the effect of tower geometry on air gap insulation strength.

Located in the Berkshire mountains of western Massachusetts, the high-voltage test facility is well situated to assess the effects of a wide range of weather conditions on high-voltage lines. Surrounding hills shelter the site from strong winds and their severe vibrational effects, but the facility experiences ample fog, rain, snow, and temperature variation for electrical and environmental studies. Indoor experimental equipment also plays an important role in the facility's testing systems. For example, a cyclindrical fog chamber, 24.4 m high and 24.4 m in diameter, is used to determine the flashover voltage of contaminated insulators for both ac and dc lines.

Because transmission line research calls for the continuous acquisition of all-weather data, HVTRF requires a sophisticated monitoring system. A digital computer is used to sample each of its many data-input channels once every minute; the computer then stores the data on disks and magnetic tape for future analysis. Separate instrumentation systems use the latest technology to monitor test line performance under a variety of conditions.

"Utilities can draw on HVTRF's reservoir of data and computer programs from previous projects," notes Dunlap, "and this helps them avoid duplication of effort." He adds that HVTRF also conducts seminars that communicate research results to utility personnel and provide them with field experience. HVTRF, he reminds EPRI users, serves utilities on a first-come, first-served basis and grants priority to their practical requirements.

For additional information, contact Luciano E. Zaffanella, manager, HVTRF (413) 494-4356; or John Dunlap, EPRI project manager, Electrical Systems Division (415) 855-2305. ■

EPRI Cosponsors International Tech Transfer Symposium

EPRI and SRI International were sponsors of the Technology Transfer Society's 10th annual meeting and international symposium for technology transfer held recently in San Francisco, California. Acknowledging the importance of efforts to commercialize the fruits of R&D, the conference devoted three days to an examination of the theme, technology transfer to commercialization.

Elaborating on this subject, Milton Klein, EPRI vice president for special projects, opened his keynote address by linking strengthened technologic competitiveness in world markets with success in the technology transfer process. Klein stressed that commercialization of technology involves innovation and that innovation is a risky business. "It's not possible to have vibrant innovation without people and institutions willing to take risks. The challenge of tech transfer to commercialization," Klein pointed out, "is to bring the risk into reasonable range and be sensitive to the balancing act between prudence and innovation."

Over 150 participants from universities, private businesses and industries, R&D centers, consulting firms, government agencies, and venture capitalist groups took part in the symposium. "The mix of attendees," says Wayne Seden, EPRI's manager of research applications and general chairman of the conference, "reflects the diversity of the many institutions that have a stake in the creation and transfer of new technology."

That diversity was also reflected in the number of topics highlighted during the conference's general sessions. A group of 85 speakers and panelists assembled by Scott Taper, program chairman and EPRI licensing analyst, addressed a wide range of subjects. Included were the commercialization of government and/or space spin-offs; the international transfer of technology to developing countries, to the Far East, and to Europe; managing computer software development; technology and computer productivity; technology transfer's role in Silicon Valley (California); and the effect of venture capital and entrepreneurship on the technology transfer process. A talk entitled "Technology Exchange With Pacific Basin Countries," by Albert Solga, international trade administrator, U.S. Department of Commerce, underscored the strong interest in West–Far East technology transfer.

The Technology Transfer Society is a nonprofit international organization; its worldwide membership includes professionals from industry, research, education, and government. "The symposium marks the organization's first decade of growth and achievement," explains Thomas Anyos, society treasurer and EPRI commercial development manager, "and the symposium theme is in keeping with the society's commitment to accelerating the movement of technology to ultimate application. That is the real goal of most R&D, getting the product to an appropriate market."

Contributing sponsors to the symposium were the Berlitz Translation Services and the International Technology Institute. Other contributions were made jointly by Associates in Technology

Transfer and the California Council for International Trade. Conference proceedings are available for $35 from the Technology Transfer Society, 7033 Sunset Boulevard, Suite 302, Los Angeles, California 90028.

CMF Offers Subscription Service

Twelve utilities have joined a new EPRI-sponsored program to help their customers in the metals fabrication industry improve productivity and energy efficiency. Developed and run by EPRI's Center for Metals Fabrication (CMF) at Battelle, Columbus Laboratories, the utility subscription service (USS) began early this year. USS helps subscribers and their industrial customers learn more about the potential applications for such new electric-based technologies as lasers, robotics, and induction heating.

Utilities are finding that membership in USS provides them with a number of benefits. For example, the subscription service acts as a clearinghouse for information on specific manufacturing processes, provides a telephone hot line for technical and economic information on metals fabrication and manufacture, and furnishes computer profiles listing major manufacturing processes in a utility's service area; the profiles give the number of fabrication plants, company size, and product line. In addition, USS distributes *TechCommentaries* (four-page publications describing current developments in metals fabrication) to a utility's industrial customers.

Another service it provides are the one-day seminars presented by USS staff to utility subscribers. These seminars, which take place at the utility, focus on the manufacturing processes most widely used by that utility's customers and on ways to promote plant modernization. All these USS services are augmented by an annual management briefing that the USS staff holds for each subscribing utility. The briefings cover the changes affecting future electricity demand by metals fabrication customers.

Explaining that USS provides an important link between utilities and their industrial customers, Thomas Byrer, CMF director, says, "With this service, utilities can better assess customer demand, and as a result, they can focus on specific programs to better serve their industrial customers."

The 12 utilities now making up USS are Boston Edison Co., Commonwealth Edison Co., Florida Power & Light Co., Kansas Gas and Electric Co., Los Angeles Dept. of Water & Power, Niagara Mohawk Power Corp., Pennsylvania Power & Light Co., Public Service Electric & Gas Co. of New Jersey, The Dayton Power and Light Co., Tennessee Valley Authority, The Toledo Edison Co., and Wisconsin Electric Co.

For more information about USS, contact I. Leslie Harry, EPRI project manager, Energy Management and Utilization Division (415) 855-2558; or Laura Cahill, CMF operations coordinator (614) 424-5828.

CALENDAR

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

NOVEMBER

5–8
Workshop: Fossil Fuel Plant Cycling
Miami, Florida
Contact: Frank Wong (415) 855-8969

7–8
Reactor Physics Software Users Group Meeting
Palo Alto, California
Contact: Walter Eich (415) 855-2090

12–14
Conference: Fabric Filter Development and Optimization
Scottsdale, Arizona
Contact: Walter Piulle (415) 855-2470

13–15
2d Annual Seminar: Demand-Side Management
Albuquerque, New Mexico
Contact: Ahmad Faruqui (415) 855-2630

13–15
Solid-Particle Erosion of Steam Turbines
Chattanooga, Tennessee
Contact: Thomas McCloskey (415) 855-2655

13–15
Symposium: Coal Pulverizers
Denver, Colorado
Contact: David Broske (415) 855-8968

14–15
2d Annual Conference: Utility Investments Risk Analysis
New Orleans, Louisiana
Contact: Stephen Chapel (415) 855-2608

20–21
7th Annual NDE–Structural Mechanics Information Meeting
Palo Alto, California
Contact: Soung-Nan Liu (415) 855-2480

20–22
Municipal Solid Waste as a Utility Fuel
Madison, Wisconsin
Contact: Charles McGowin (415) 855-2445

DECEMBER

3–4
Workshop: Generator Reliability
Scottsdale, Arizona
Contact: Dharmendra Sharma (415) 855-2302

9–11
International Conference and Exposition: Load Management
Chicago, Illinois
Contact: Veronika Rabl (415) 855-2401

10–11
Seminar: Advances in Liquid Radwaste Processing
Orlando, Florida
Contact: Patricia Robinson (415) 855-2412

R&D Status Report
ADVANCED POWER SYSTEMS DIVISION

Dwain Spencer, Vice President

IMPROVED RELIABILITY OF NEW GAS TURBINE POWER PLANTS

Historically, the method of improving the reliability of gas turbine power plants has been to discover and solve problems as they occur in the field. The loss of availability of these power plants during repair periods has represented a significant cost to the utilities operating them. The majority of gas turbines have traditionally been used in peaking or intermediate-duty service, but it is anticipated that the next new models will be used in baseload service—in the coal gasification–combined-cycle power plants expected to be ordered by utilities in the 1990s. Further, it is recognized that the high cost of reliability improvement will also apply to the new models unless they can be made more reliable at the design stage.

The Power Generation Program has identified objectives and undertaken a number of research projects aimed primarily at improving the reliability of new gas turbine models, but the results will also be applicable to currently operating models (Table 1).

RP2467 is one of the most innovative approaches to improve the reliability of the new gas turbine because it fundamentally changes the way the design process is carried out by the turbine manufacturer. Although this project does not fund the engineering design of the controls and accessories (C&A) systems, it does sponsor the development of an organized, structured method for incorporating and performing reliability analyses and assessments within the design process.

Performing a reliability analysis during the design of a component is analogous to performing a stress analysis of that component. In other words, reliability analysis can be performed along with the analyses generally conducted (e.g., stress, temperature, vibration, corrosion, and fatigue) and thus becomes part of the design process.

The methods and procedures used in this project were drawn from many sources; some have been used successfully in aerospace design. The procedures include the following.

- Assigning reliability goals to systems and components
- Developing a failure rate data book
- Establishing parts profiles (e.g., history, critical areas, failure modes)
- Performing block diagram modeling and analysis of system and component reliability
- Performing failure modes and effects analyses (FMEAs)
- Performing fault tree analyses (FTAs)
- Defining the protocol, including configuration control methods (e.g., identification and tracking of the effect of design changes on reliability)
- Verifying critical systems or components
- Compiling problem-avoidance checklists
- Estimating life-cycle costs

Table 1
IMPROVED RELIABILITY: NEW GAS TURBINES

Project No.	Focus of Research
RP1319	Advanced cooled transition piece
RP1801	Multinozzle combustor
RP2101	Control system reliability demonstration
RP2102	Instrumentation field test
RP2388, 2465	Bucket coatings
RP2421	Life management system
RP2467	Controls and accessories reliability
RP2531	Improved maintainability
RP2774	Durability field test

Over 20 C&A systems are included in this project, and not all these methods apply to each system or component. A portion of the work is concerned with identifying the appropriate reliability tools and techniques to be used for each system.

Although the project is not nearing completion, a number of significant accomplishments have already been made. Design engineers are assessing the reliability of current designs and the effects of modifications to them (a computer-based reliability assessment tool has been developed). At the same time, reliability is becoming one of the quantitative criteria in new design, and the components that cause the most unreliability in a system are being identified. Further, comparative analyses are being made of parts supplied by various vendors, with the result that higher-reliability parts are being selected (one comparison has shown a startling factor of 10 to 1 in failure rate). Design features that will improve reliability are also being discussed with vendors during the design process and incorporated into specifications.

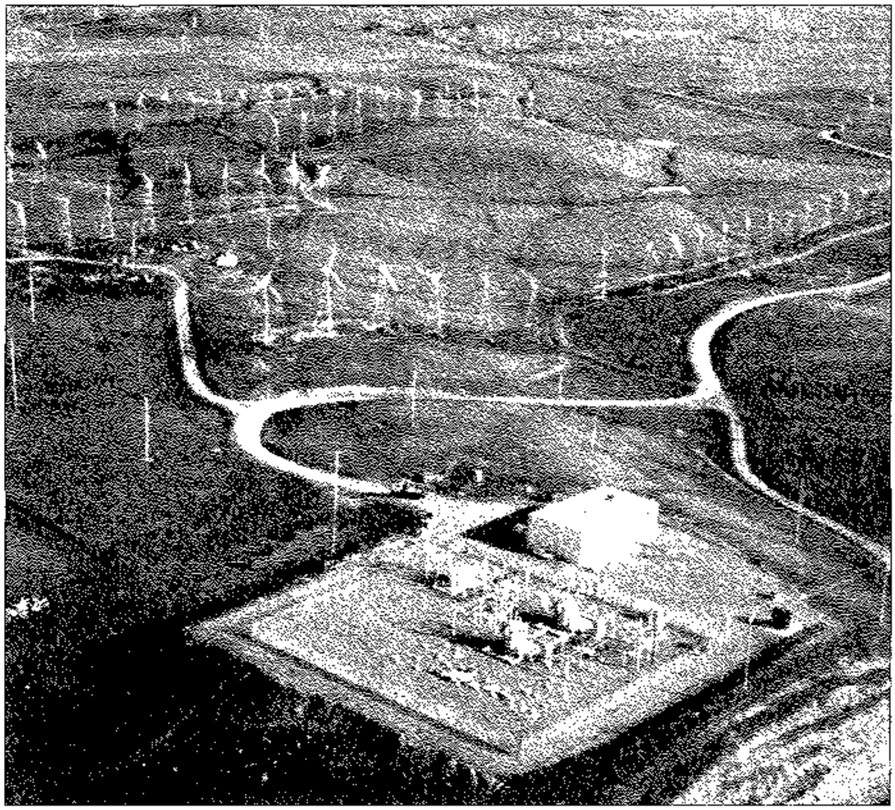
This project represents a transfer of technology in that the one-time funding by EPRI results in incorporation of these reliability methods into continuing design procedures. *Project Manager: Clark V. Dohner*

TRENDS IN WIND POWER TECHNOLOGY

During the past three years an industry has rapidly emerged to supply wind turbines for bulk power applications. This rapid growth was principally due to federal and state investment incentives. The primary market for the industry's products has been private developers, financed by various partnerships formed to take advantage of the incentives (the incen-

tives are not available to the utility industry). The developers have installed wind power stations in several states, with California the major area of development. The station developers and turbine suppliers were usually separate entities, each taking a share of the profits from successful projects. The turbine suppliers include both domestic and foreign sources, and nearly all available turbines were small (rated less than 100 kW).

Figure 1 Wind power station. The control center and electrical substation are in the foreground. Numerous 100-kW wind turbines are in the background. (Photograph by Steve Proehl of U.S. Windpower, Inc.)



Dramatic changes have begun to take place in the industry; the most significant is the trend to midrange machine ratings (nominally 100–600 kW). The transition to higher ratings is occurring within the existing technology base, which evolved collectively in the private and public sectors over the past 10 years; thus these new, larger machines did not require major advances in technology. They retain the inherent design simplicity of their predecessors, which should improve their chances of success because reliability maturation can be achieved more rapidly if designs remain simple (Figure 1). The only technical uncertainties concern the wind turbines' long-term reliability (including component life) and the fundamental limitation of areas with high wind availability and satisfactory average speeds. The variations in wind speeds, even on a microgeographic scale, have been shown to be a key uncertainty in proper siting of wind machines.

The rationale for the industry trend to midrange ratings is that economies of scale should make the new machines more cost-effective than their smaller predecessors, assuming the same rapid reliability maturation. Wind turbine prices have already fallen dramatically from \$2000–\$3000/kW in 1981 to \$1000–\$1500/kW in 1984. During this same period, the quality of the turbines improved markedly. Further price declines are expected with the maturation of midrange machine technology. This potential cost-effectiveness of midrange machines makes them attractive to the utility market because the technology is approaching viability independently of special investment incentives.

Given the widespread recognition that the existing tax incentives may be altered in the near future, the wind turbine industry is taking steps to maintain its vitality in a more stringent business climate. Besides evolving midrange machine product lines that are more cost-effective than earlier lines, turbine suppliers are either becoming station developers themselves or forming tight bonds with private developers. This reduces the requisite profit margin of future stations because one party accrues the profits rather than two. In addition, the wind turbine industry recognizes that utilities may be an attractive alternative market after changes in the tax credits occur, and it is exploring ways to begin penetrating that market.

Utility market potential

EPRI has completed a study to determine the early utility market potential for wind power stations (EPRI AP-4077). The primary objective of the study was to determine if the market potential for wind power is sufficient to warrant the utility industry's pursuit of this generation option. The study results substantiate that a significant early (1990–2000) utility market potential (~20 GW) exists in the United States. The ultimate market potential may be significantly greater or less, depending on specific wind turbine design characteristics and suitable site availability.

In assessing market potential, the study used standard utility expansion planning methods to evaluate wind power relative to other generation alternatives. Wind turbine rating was normalized to ensure the results were independent of turbine rating. The turbines were assumed to be mature products, capable of high performance in moderate wind regimes. The installed cost assumptions included balance-of-station costs (the collection network, land, and so on). The best-available wind resource data were used.

Because the results of any such study are only as good as the study's assumptions, the market potential was examined parametrically to determine its sensitivity to key assumptions. The market potential was found to be particularly sensitive to the assumption of 2% real-cost escalation for energy from conventional sources. Departures from this assumption had the net effect of shifting the 1990–2000 early market window either forward or backward, depending on whether real-cost escalation was higher or lower, respectively. The study did not address market penetration, which is not tractable by modeling at this early stage.

Wind turbine price targets

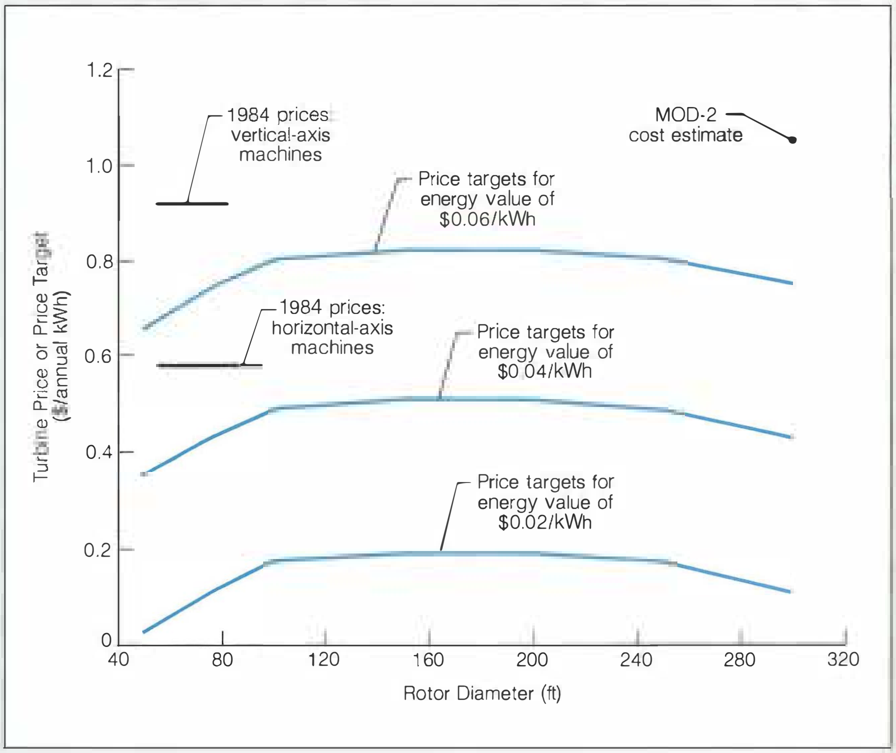
Although manufacturers' price quotes for mass-produced wind machines have been available for several years, an understanding of price targets for utility applications has been lacking. Recognizing the need for such an understanding to help turbine suppliers and prospective utility users focus on the most promising options, EPRI conducted an intensive evaluation of wind turbine price targets (AP-4284-SR). The scope of this effort included turbines from 50 kW to megawatt scale.

The approach was to design utility-grade wind power stations with different turbine sizes but comparable annual energy production. Estimates were developed for the balance-of-station costs (everything except the turbines), and turbine costs were treated as an unknown. Each wind power station was assigned a value for energy at the station bus. Using this overall energy value target and the known costs for the balance of station—together with carefully selected assumptions about wind regime, station losses, wind turbine operating characteristics, and operation and maintenance (O&M) costs—the study calculated the residual or allowable cost of the turbine (or the turbine price target) for each case. The results show what a utility can afford to pay for the turbines in a utility-grade wind power station as a function of turbine size. After this process was repeated for several energy value targets, the turbine price targets were compared with current prices.

Figure 2 shows the turbine price targets for a range of rotor diameters and for three energy values at the station bus. The price targets decrease at the lefthand end of the curves because of the combined effect of rising O&M costs and high balance-of-station costs as rotor diameters shrink. A rise in O&M costs as wind turbines increase in size and complexity causes the downturn on the righthand end of the curves. The figure also shows 1984 manufacturers' price quotations for both horizontal- and vertical-axis commercial wind turbines and the estimated cost (taken from AP-3276) of DOE's experimental MOD-2 machine, if produced on a commercial basis.

The study's primary finding is that the prices of wind turbines for bulk power applications are becoming attractive for midrange horizontal-axis machines with 80–140-ft rotors (nominally 100–600 kW). This stems from a combined effect of high price targets and downward trending prices for turbines in this class. The class is expected to dominate wind turbine commercialization over the next few years. If larger turbines are ever to become commercially viable, they are likely to evolve out of this class. Such an evolutionary growth would parallel that experienced with other technologies.

Figure 2 Wind turbine price targets for utility market penetration. The energy values are in 1984 $. The price information is expressed per unit of annual energy production at a site with winds that are representative of the Central Plains. The study used a 30-year (1984–2013) current-dollar cost analysis with 1984 as the reference year and an 8.5% inflation rate.



Wind power stations

During the past two years EPRI has engaged in field evaluations of state-of-the-art wind turbines in partnership with utilities and wind turbine developers and in coordination with related federal efforts. These evaluations involved turbines of all major sizes and configurations to achieve the following goals.

- Further understand the state of the art
- Obtain test experience to aid in the evolution of utility test methods and techniques
- Develop a technical information base
- Identify research that would promote the development and use of utility-grade wind power stations

Results of these evaluations are reported in AP-3896, AP-4054, AP-4060, and AP-4089.

The effort illuminated the development risks associated with megawatt-scale wind turbines—risks stemming from the turbines' complexity and size and from gaps in the basic understanding of the structural loads caused by the wind. Largely because of these risks, the focus of research and commercialization in the wind power community shifted to midrange machines. Further, the need for specialized equipment and other logistic problems in transporting, installing, and maintaining megawatt-scale machines led to growing skepticism that machines with rotor diameters larger than ~200 ft will ever be practical.

The small and midrange machines are now undergoing rapid reliability maturation. The significance of suitable reliability and tolerable O&M costs to utility operators was discussed in detail in the *EPRI Journal*, November 1984 (p. 44); additional related information appears in AP-3735, AP-3813, and AP-4199. Currently, the more-reliable commercial wind power stations are achieving turbine availabilities above 95%. Average annual O&M costs in 1984 were 1.7¢/kWh and are projected to reach 1¢/kWh if planned modifications and other corrective actions are successful in eliminating some problem areas. The experience base that is evolving will be valuable in preparing utility operators to run wind power stations.

The balance-of-station costs for a wind power station are a substantial portion of the total investment. Over the past 10 years, wind power research focused on turbine evolution. With the emergence of promising midrange turbines, more attention should now be given to balance-of-station technology, such as control and protective devices, which could enhance the overall cost-effectiveness of wind power stations.

Research directions

The objective of EPRI's wind power research is to promote the evolution and appropriate use of utility-grade wind power stations by directly assisting the utility industry in understanding the requirements for commercial wind power stations and by fostering mutually beneficial interaction between the utility industry and the wind turbine industry.

Technically, nothing should prevent suitably engineered wind turbines from beginning to penetrate the utility market in a relatively short time (5–10 years). The utility industry has begun to recognize wind power as a promising supplemental generation option for windy regions. The technology's relatively low risk and the financial advantages stemming from its modularity are strong selling points. However, if wind turbines are to be suitably engineered to meet utility industry needs, a significant exchange of technical information between the utility and wind turbine industries is necessary. Such interaction would also be beneficial in stimulating the utility market (which the wind turbine industry already recognizes may be its primary long-term domestic market).

To achieve this objective, EPRI is now emphasizing three high-priority areas.

- Wind power station performance and reliability assessment
- Wind power station design and operating experience assessment
- Utility–wind turbine industry interaction

The goal of the wind power station performance and reliability assessment is the development and dissemination of a central data and technical information base for commercial wind power stations. The scope includes performance (energy capture), reliability, and O&M requirements. The data are of crucial importance to the utility industry in planning and preparing to operate wind power stations; further, a demonstrated successful track record will encourage utility use of wind power. The assessment results are also vital to the wind turbine industry's product improvement efforts. The wind power community, as a whole, benefits from a systematic documentation of lessons learned in the field—what works and what does not—and of trends in the technology.

The assessment of wind power station design and operating experience will further the evolution of assessment tools for the utility industry to use during three major stages of activity: siting, planning and design, and operation. The work has started by examining the experiences of leading wind power station developers. A review of results in the literature will supplement the data. Voids in capabilities and current understanding will be filled through topical studies, methodology development, and, if appropriate, follow-up software and hardware development.

The final high-priority area is interaction between the utility industry and the wind turbine industry. To continue EPRI's efforts in this area requires certain key actions. An educational program will be assembled and updated from time to time as needed. The program will consist of presentations on the status, promise, and requirements of utility-grade wind power stations; utilities will be encouraged to begin long lead time steps, such as resource studies, as soon as possible. The educational effort will draw on current results of EPRI's wind power research to supplement the input from other sectors of the wind power community.

Additional mechanisms for enhancing the general awareness of wind power's promise and suggesting its appropriate role in national energy supply will be identified and implemented. A profile of the wind turbine industry and of existing wind power stations will be prepared periodically for use by the entire wind power community. Recent surveys of wind power stations are contained in AP-3578 and AP-3963. *Project Manager: Frank R. Goodman, Jr.*

R&D Status Report
COAL COMBUSTION SYSTEMS DIVISION

Kurt Yeager, Vice President

SPRAY-DRYING FGD

The emphasis of EPRI research on spray-drying flue gas desulfurization (FGD) systems depends on whether the application is for low-sulfur or high-sulfur coal. Commercial use of spray drying in the utility industry has been limited to low-sulfur coal applications that have required removals of less than 80–85% SO_2. Seven units are operating and several others are starting up. These systems are mainly spray-drying–fabric filter combinations that use rotary atomization. Consequently, current EPRI research in low-sulfur coal applications is directed toward developing improvements in current designs and developing comprehensive design and operational guidelines. In contrast, the spray-drying process has not yet been demonstrated as a technically and economically acceptable FGD alternative for new high-sulfur coal applications. However, concern about acid rain and the possibility that more-stringent regulations may be imposed on coal combustion emissions has spurred interest in low-cost retrofit control options, such as combining a spray dryer and an existing electrostatic precipitator (ESP). EPRI research is endeavoring to develop the spray-drying technology for use in high-sulfur coal applications.

Low-sulfur coal applications

Previous results have verified the importance of recycle—mixing waste product with lime feed slurry to improve SO_2 removal and alkali use (EPRI CS-3953). Other work, cosponsored by the Environmental Protection Agency (EPA), provided the first independent verification of the operation and emission control capabilities of a full-scale spray dryer–fabric filter combination (EPRI CS-3954). Since that early work, EPRI research in spray drying for low-sulfur coal applications has emphasized advances in the technology.

One of the major research areas has been wastewater use—specifically, using cooling-tower blowdown (CTB) as a source for system makeup and slaking water. Investigators selected CTB because it represents a relatively large-volume waste stream that must be used in power plants to maintain closed-loop operation. Some tests used CTB for all makeup to the FGD system, including lime slaking water. The remaining tests used fresh water for lime slaking and CTB for the remainder of the water entering the system.

All the tests were carried out in the spray dryer–fabric filter pilot unit at EPRI's Arapahoe Test Facility. Figure 1 shows the process flow. The unit was operated at an inlet SO_2 level of 1000 parts per million (ppm), a 280°F (116°C) inlet temperature, a 20°F (11°C) approach to adiabatic saturation at the spray dryer outlet, and a 2:1 recycle ratio (lb of recycle to lb of dry calcium hydroxide added). For these conditions 20–25% of the makeup water is used for lime slaking water. The rest of the makeup water is used to dilute batches of atomizer feed slurry and/or to control temperature. When the inlet SO_2 level is lower, lime slaking water represents an even smaller fraction of the total system makeup. Conversely, at higher inlet SO_2 levels, lime slaking water may represent half or more of the system makeup water.

Table 1 summarizes important character-

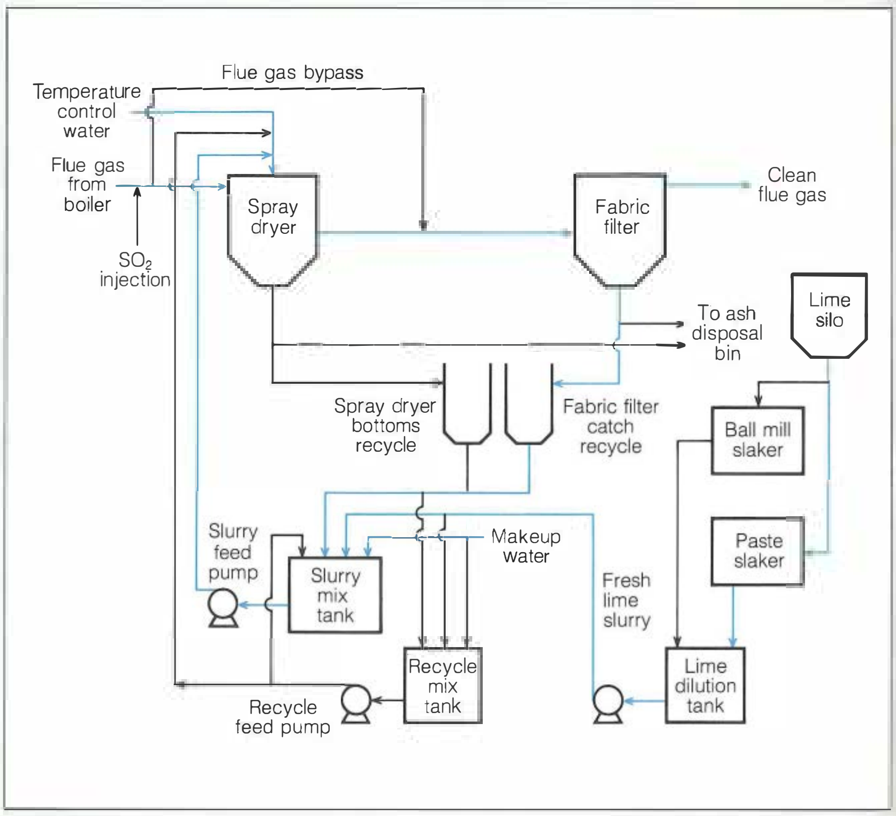


Figure 1 Simplified process flow diagram for spray dryer–fabric filter plant. The color lines show the configuration used in the majority of the tests referred to in this report.

Table 1
EFFECTS OF CTB USE ON SO_2 REMOVAL

CTB	CTB Type	CTB Composition	Effect on SO_2 Removal: Slaking and Dilution	Effect on SO_2 Removal: Dilution Only
CTB 1	Gypsum-limited	1000 ppm SO_4, 2000 ppm Cl	Increase	Increase
CTB 2	Sidestream-softened, gypsum-limited	5000 ppm SO_4, 1800 ppm Na	Decrease	Increase
CTB 3 (Craig)*	Acid-treated, gypsum-limited	2000 ppm SO_4	Decrease (decrease)	None (none)
CTB 4 (Cunningham)*	Silica-limited	700 ppm SO_4, 140 ppm SiO_2	None (none)	—

*CTB 3 and CTB 4: simulated CTB waters were compared with actual station waters (in parentheses).

istics of tested CTBs. The CTB chosen represents a wide variety of recirculating water system types, including gypsum-limited, acid-treated, sidestream-softened, and silica-limited. The test results indicate that CTB use for dilution only created no difficulties; in fact, CTB 1 and CTB 2 resulted in increased SO_2 removal. Researchers believe that the presence of chloride in CTB 1 and sodium in CTB 2 are responsible for the improvements. These compounds affect droplet drying and residual solids moisture in a way that improves mass transfer and thus SO_2 removal. The effect of chloride will be discussed later under the high-sulfur coal research results.

As expected, Table 1 shows that the results vary with the sulfate content of the CTB used in the slaking process. When sulfate levels are high, generally believed to be above 1000 ppm, the sulfate can precipitate as gypsum, coating the surface of the lime and reducing its effectiveness. In the case of CTB 1, the presence of chloride appears to have dominated, resulting in the removal of more SO_2 despite the 1000 ppm of sulfate.

CTB 3 and CTB 4 were simulations that were compared with test results using the actual blowdown. Generally, their effect on SO_2 removal was in the same direction and of the same magnitude as tests with the actual blowdown, which indicates that this type of test can show whether a particular source of CTB will have a positive or a negative effect on SO_2 removal in a spray-drying system.

Another potential use of power plant waste waters is to wet solid wastes produced by the dry FGD system. The fly ash and calcium/sulfur salts are generally wet to prevent dust and to promote cementation reactions. The water quantities vary from only a few percent to control dust to as high as 30–40% for optimal compacted strength. One question about solid-waste handling is whether the quality of the water affects the cured-waste properties; that is, does high dissolved solids content, such as in CTB, interfere with cementation reactions in the wet solids. Part of this research is being conducted in the laboratory to determine properties of solid wastes produced by the spray dryer–fabric filter system. This laboratory study compared properties of wastes wet with deionized water with those wet with CTB.

Tests determined the strength buildup and the permeability of the solids. Although only a limited number of tests were carried out, the quality of the CTB had no effect on cured-waste strength and permeability values. Future tests will measure the effect of CTB use on waste leachate quality.

High-sulfur coal application

Although no spray-drying systems are currently under construction for plants burning high-sulfur coal, their use in such applications is of interest for several reasons. Current EPRI studies (RP1610-2) indicate that in new plants such systems may be competitive with conventional wet scrubbing, using assumptions based on short-term, full-scale test data (EPRI CS-3954).

In the full-scale tests and in additional pilot plant studies, chloride was tested as an additive to improve SO_2 removal and alkali use. Results show a 25% reduction in alkali requirements at a 90% SO_2 removal rate. Although these results are promising, the gains appear to be partially offset by some potentially negative effects, one of which is high pressure drop in the fabric filter.

The effects of chloride addition on fabric filter pressure drop were discovered inadvertently. One long-term goal of EPRI spray-drying research is to determine the effects of the spray dryer on fabric filter performance. Pressure drop values are closely monitored,

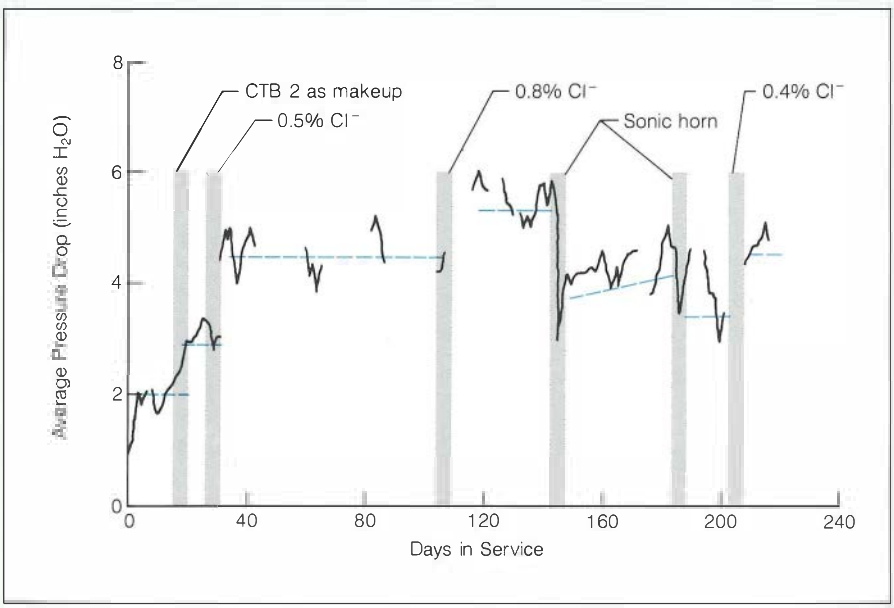


Figure 2 Average tubesheet pressure drop values for fabric filter compartment downstream of spray dryer. The fabric filter operating conditions were a 245°F (63°C) inlet flue gas temperature, a 2:1 air-to-cloth ratio, and a three-hour cleaning frequency. The shaded areas represent the spray dryer tests that corresponded to step changes in pressure drop. Increases in pressure drop followed the use of chloride additives or high-sodium CTB makeup in the spray dryer; decreases followed the use of a sonic horn to dislodge dustcakes in the fabric filter.

particularly the increase in pressure drop with time after new bags are put into service.

Recently, two compartments of the 10-MW fabric filter pilot plant at Arapahoe were rebagged at the same time. One compartment is downstream of the pilot spray dryer, and the other is a control compartment treating normal, 275°F (135°C) flue gas. The control compartment was operated at an air-to-cloth ratio of 2 $(ft^3/min)/ft^2$. For most tests, the compartment downstream of the spray dryer was operated at the same air-to-cloth ratio. On the basis of previous observations, investigators expected the compartment downstream of the spray dryer to operate at an equal or slightly lower pressure drop. However, as testing progressed, the pressure drop was significantly higher than that of the control compartment.

After data at atypical conditions (such as higher air-to-cloth ratios or longer times between compartment cleanings) were eliminated, several step changes in compartment pressure drop were observed. Figure 2 illustrates these effects; the figure shows the replotted pressure drop (data during atypical conditions having been removed). The dashed lines on the figure represent visual average pressure drops during various operating periods, and the descriptors for spray dryer tests correspond to step changes in these pressure drop averages. This figure shows that on four occasions, noted by a change in the level of the dashed line, the tubesheet pressure drop increased rapidly. In each case, the increase occurred immediately after a chloride addition or a high-sodium-content CTB test.

Although these observations about the effects of chlorides on fabric filter pressure drop are not conclusive, they do indicate a potential problem. Long-term chloride addition tests to resolve this issue are planned. *Project Manager: Richard Rhudy*

ON-LINE COAL SLURRY ANALYSIS

Approximately one-third of the steam coal burned in the United States is cleaned in processes where the coal is handled as a water-based slurry. The primary objective of these processes is to produce a cleaned coal product whose ash and sulfur concentrations do not exceed the specifications set by the utility customer. The currently poor control of these processes results in either an excessive loss of costly heating value or occasions when impurity specifications are exceeded. The best solution to this problem is automatic process control in which an on-line analyzer makes accurate measurements of the ash and sulfur content of the solids fraction of the slurry. EPRI is developing such an analyzer.

Two of the most common specifications set for steam coal are the maximum ash and sulfur concentration levels. Because the quality of run-of-mine coals fed to cleaning plants is quite variable, cleaning plants have considerable difficulty meeting ash and sulfur specifications.

The procedure to monitor product quality in cleaning plants is to analyze samples of the product coal in a laboratory, but in practice this is done only infrequently. In the absence of sufficient product quality information, the target ash and sulfur levels at the cleaning plant must be set well below product specification levels. Otherwise, exceeding the specifications from time to time is unavoidable.

Setting low targets bears a serious penalty: the lower the target ash and sulfur levels, the lower the heating value recovery to the product coal. This means that more heating value is thrown away with the refuse; more tons of coal are mined to produce a given quantity of as-delivered coal; and higher costs are paid by the utility customer.

If the cleaning plant operator could measure the product ash and sulfur levels accurately and frequently, control of the process would be much more effective. The amplitude of the swings in ash and sulfur levels could be reduced, allowing target levels to be set much closer to specification levels (Figure 3). The net effect of such control would be a significant reduction in lost heating value and a saving in the cost of producing clean coal to utility specification. This saving is estimated at about 2–3% of clean coal costs for current cleaning plants.

The need for rapid, accurate on-line analysis of ash and sulfur levels in coal at cleaning plants is evident. Because cleaning plants process coal in water slurries and the properties of coal should be measured for process control purposes as soon as possible after the coal passes through the cleaning device, the analyzer should be designed to make the measurements while the coal is still in slurry form. No acceptable commercial analyzer is available on the market for this purpose. Therefore, under RP2574-1 EPRI is currently developing Conscan (a continuous on-line slurry characterization and analysis system).

The new system

A prototype Conscan system has been designed and constructed. It is currently undergoing its initial calibration and performance testing at the Sunnyvale, California, laboratory of the development contractor, Science Applications International Corp.

Conscan consists of three principal sensor subsystems: a prompt gamma neutron activation analyzer to estimate the sulfur and iron content of the slurry; a dual energy gamma gage to determine the overall ash content and density of the slurry; and a conductivity meter to provide an estimate of the volumetric solids

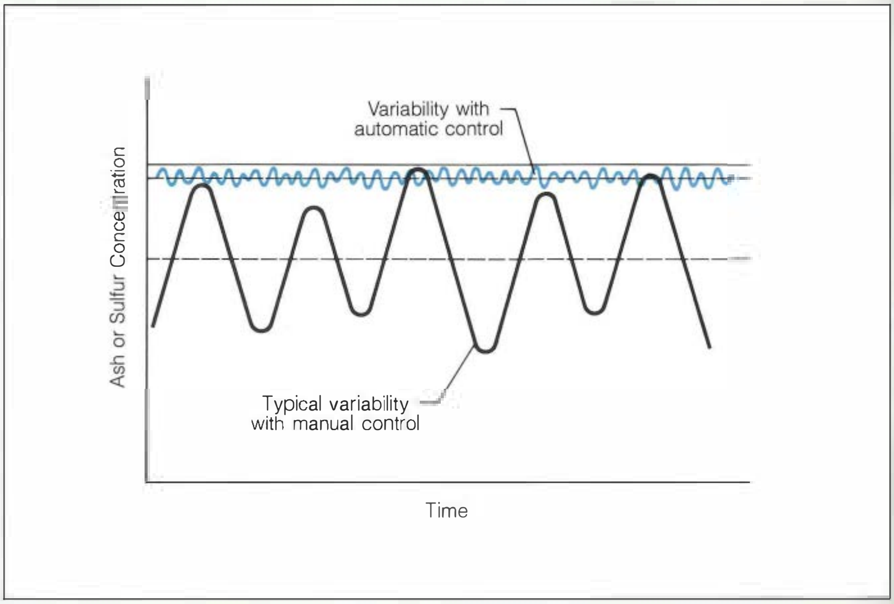
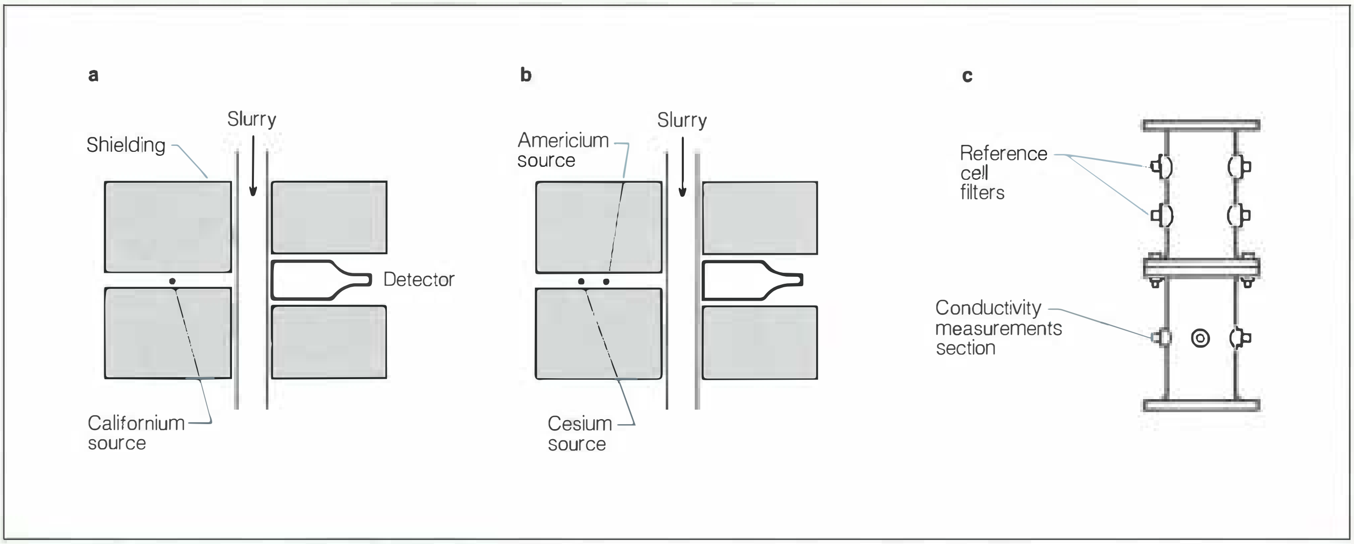


Figure 3 Variability of product coal ash and sulfur levels with manual control and with automatic control. The black dashed line indicates the target product specification in each case; the solid black line is the maximum specification. Automatic control provides many opportunities for small, precise adjustments and thus reduces product variability.

Figure 4 The major instruments of the Conscan system: (**a**) prompt gamma neutron activation analyzer; (**b**) dual energy gamma gage; (**c**) conductivity meter.



content of the slurry (Figure 4).

The output signals from all three sensors are combined to produce the desired measurements: the weight percent of solids in the slurry and the sulfur and ash content of the dry coal solids fraction. A fourth nonessential subsystem, a commercial flowmeter that measures the mass flow of the slurry, has been included to improve integration of Conscan into various cleaning plants.

The sensors are nonintrusive, which results in greatly reduced wear. All but the mass flowmeter are mounted on a 6-in pipe, which enables the sensors to interrogate a full or near-full stream in a commercial cleaning plant and avoids the need for sampling small amounts from pressurized slurry streams. The latter is important because representative slurry sampling is difficult and often unsuccessful. If sampling is unnecessary, less space is required for the instrument system, which makes the analyzer more practical to retrofit into existing plants and reduces installation cost.

The design of the prototype Conscan draws on data gathered in an earlier experimental project. This study indicated that reliable measurement of ash and solids content, with less than 1 wt% absolute error, should be possible within a 3-min analysis; and measurement of sulfur, with less than 10% relative error, should be possible on a 20-min analysis cycle.

Obtaining these ideal levels of performance for measuring the properties of coal within a slurry presents a considerable technical challenge. A major difficulty is the low concentration of coal and its constituents within the interrogated volume—coal concentrations in slurries typically handled within cleaning plants range from less than 5 wt% to up to 40 wt%. Obtaining reliable sulfur and iron concentration measurements, for example, may involve the use of a large neutron source in the prompt gamma neutron activation analyzer, as well as innovative techniques to interpret the spectrum of the induced gamma ray emissions from that analyzer.

Future plans

The current phase of work on the Conscan system, its initial calibration and performance testing, is scheduled for completion in October 1985. Conscan will then be shipped to EPRI's Coal Cleaning Test Facility (CCTF). Science Applications will train the CCTF staff in operations, maintenance, and field calibration procedures to ensure a smooth hand-over of the device.

During this acceptance phase, the mechanical operation of Conscan will be closely monitored to check its performance under near-commercial cleaning plant conditions. A coal-cleaning plant is a much more hostile environment for sophisticated analysis equipment than is a laboratory. At CCTF, Conscan will be subjected to higher levels of vibration, higher temperature and humidity fluctuations, and greater exposure to dirt and moisture.

Once accepted, Conscan will be used in multiphase testing. First, its performance while handling the wide range of U.S. steam coals tested at CCTF will be studied (CCTF handles about eight different coals annually). Second, once the accuracy and precision of Conscan has been established, it will be used to study the fundamentals of one coal-cleaning process selected from those used at CCTF; researchers will then develop a control strategy on the basis of their understanding of the process. This procedure will be repeated for a number of widely used fine-coal-cleaning processes.

Throughout this testing phase, EPRI will be seeking out companies that may be interested in manufacturing the device under license to EPRI. Ideally, such a company would assume the burden for refinement of system design, as well as for all manufacturing and marketing activities. EPRI's long-term efforts could then focus on developing and optimizing applications that use the technology in steam-coal-cleaning plants.

Although the impetus for Conscan's development has been coal-cleaning plant control, other applications may be of interest to the utility industry, including measurement of coal slurry feeds to gasifiers, of coal-water mixtures at power plants, and of coarse coal-water slurries in long-distance pipelines. *Project Manager: Robert W. Row*

R&D Status Report
ELECTRICAL SYSTEMS DIVISION

John J. Dougherty, Vice President

TRANSMISSION SUBSTATIONS

Arc products of tetrachloroethylene

Two essentially nonflammable fluid systems based on tetrachloroethylene (TCE) are available for fire-resistant transformers. One is a stabilized TCE, which was developed at Westinghouse Electric Corp. and has the trade name Wecosol, and the other is a mixture of 75% TCE and 25% mineral oil by weight, developed under EPRI contract (RP1499-2). Arc products generated by failure of transformers impregnated with these fluids have created interest in their toxicity. Such products could be produced by the effects of arcs on the combined fluid and solid insulation.

EPRI initiated the present program for an extensive investigation of the arc products of C_2Cl_4 transformer insulation systems with Springborn Laboratories and Westinghouse Electric Corp. (RP1499-4, -5). The program included the two fluids, TCE and 75% TCE/25% mineral oil, combined with solid insulations of paper (cellulose), pressboard, and epoxy coatings; also included were gaseous ambients of nitrogen, air, and products of transformer aging. Copper, aluminum, and steel electrodes were used. These electrodes represent the transformer conductors and the tank between which arcing could take place. Most of the experiments were done at Springborn Laboratories using the Westinghouse equipment and arcing cells; some of the analytic and sampling techniques developed were different from those used earlier at Westinghouse.

The major products (>10%) of arcing in the various TCE–solid insulation systems were found to be Cl_2, HCl, C_2Cl_6, and CCl_4, and the minor products (<10%) identified were $COCl_2$, CO, and CO_2. For the mineral oil–solid insulation systems, HCl and CCl_4 were found to be the major products of arcing, and $COCl_2$ (only at Westinghouse), CO, CO_2, H_2, CH_4, and Cl_2 (C_2Cl_6) were identified as minor products. (The data for total Cl_2 generation are based on the analyses for Cl_2 and C_2Cl_6 as reaction products of Cl_2 and C_2Cl_4.) It should be noted that special attention was given to the detection and analysis of $COCl_2$, and its levels were in the same range in both the Springborn and Westinghouse experiments.

The terms *toxicity* and *hazard* are used here as they are defined in the book *Dangerous Properties of Industrial Materials* by N. I. Sax (New York: Van Nostrand Reinhold, 5th ed., 1979, p. 272). "Toxicity is the ability of a chemical to produce injury once it reaches a susceptible area in or on the body. Hazard is the probability that injury will be caused by the circumstances of use." A way to interpret the data is to determine the relative hazards of the various identified arc products. Researchers made this determination in the original Westinghouse study, which showed that the hazard of exposure to $COCl_2$ is very low compared with Cl_2 and HCl for TCE insulation systems. The hazard of a given material is, of course, proportional to the concentration produced and inversely proportional to one of its toxicity indexes (e.g., time-weighted average, short-time exposure limit, or lethal concentration low).

We extrapolated the volume of arc products produced in the laboratory to determine the potential hazard of a full-scale arcing fault in a transformer. One of the most severe hypothetical conditions considered was the failure and rupture of a 3-MVA transformer in a 50-m^3 enclosed space, with the failure arc energy totaling 500–1000 kJ. Such a failure is very rare because the following conditions would have to be met: high-energy failure, arcing in the fluid, the arc energy accounting for all or nearly all the failure energy, volatilization of all arc products, and tank rupture—all of which would have to occur in an unvented area.

Although the analyses in this study were made of the arc products in the head space and in the fluid, the conclusions are based on the total amounts generated. This approach is a very conservative one, implying that all the generated toxic products would be in the ambient air where they could present a potential hazard. We must emphasize, however, that the toxic products identified here are very soluble in the transformer fluids, which mitigates their hazard.

Nevertheless, the data do indicate that high levels of Cl_2 and HCl (>1000 mg/m^3) could be generated from the TCE and TCE/mineral oil insulations under the most extreme—but highly improbable—failure conditions. Some simple measures can be taken to reduce the probability of such a catastrophic failure and its consequences. The transformer can be equipped with an incipient fault detection and alarm system, such as a rate-of-pressure-rise relay, which can be used to disconnect the transformer from the system. Ambient monitors for Cl_2 and HCl can be used for additional backup protection.

Because tetrachlorodibenzofuran (TCDF) and tetrachloro-p-dibenzodioxin (TCDD) have created so much interest, special analyses were also made of these compounds. These products were not detected in analyses done at the State of New York Department of Public Health in Albany on a fluid sample from arced TCE and cellulose, with aluminum electrodes and on a second sample with copper and steel electrodes. TCE and TCE–mineral oil–insulated transformers do not represent an arc product hazard in most instances of failure, and for those instances where they may, simple precautions are sufficient to prevent harm to personnel. High-energy catastrophic failure, with rupture in an unvented enclosure, may present problems in handling released Cl_2 and HCl, for which provisions can be made. Because of the difficulty encountered in sustaining arcs in TCE insulation systems, it may be surmised that high-energy arc failures in these systems would indeed be very rare. We should emphasize that all the arc products are volatile or soluble in the TCE. The fire-resistance advantages of these fluids and the fact that their arc products are not explosive far outweigh any measures that might be needed to minimize the toxicity hazard of these arc products. *Project Manager: Gilbert Addis*

POWER SYSTEM PLANNING AND OPERATIONS

Speech recognition and synthesis

In their work, system operators use four of their five senses: sight, touch, speech, and hearing. They rely most heavily on sight to view displays, read printouts, and review chart recorders. Touch, the next most used sense, is needed for entering data, documenting actions taken, and using the telephone. Under many power system conditions, operators' eyes and hands are busy. Speech and hearing are not fully exploited. Voice commands and recorded messages present opportunities to reduce the burden on sight and touch and to spread the sensory work more evenly.

An EPRI project, started in September 1984, was a 9-month study by Honeywell, Inc. (RP2473-1). The objective of this study was to identify useful applications of speech recognition and speech synthesis devices in modern dispatch control centers.

Honeywell was well acquainted with the state of the art of these devices and their practical application before starting this study. To focus on applications in power system operations, project personnel visited two utility dispatch control centers: Bonneville Power Administration and Florida Power Corp.

The work on RP2473-1 identified two promising applications of speech techniques: (1) data entry and data echoing and (2) equipment status changing and acknowledging. Researchers found that data entry using a speech recognition device had the most potential in dispatch control centers. When coupled with a speech synthesis device for repeating the data entered, the combination is an even stronger contender.

Speech recognition devices are also desirable for changing the status equipment, such as breakers. Speech synthesis devices to echo the stated action and acknowledge it are necessary safeguards. The final report, which will be published shortly, will contain more detailed information on the study's findings. *Project Manager: Charles J. Frank*

Display format design handbook

The advent of cathode ray tube (CRT) displays in control centers has not been a panacea. Although CRT displays can present more data to an operator faster than any other means, they sometimes make the operator's job more difficult because, for example, they become overly crowded and make poor use of color. The application of human factors design principles to display layouts is an effective method for counteracting display problems and increasing display usability. However, none of the handbooks written about displays directly addresses design for electric utility dispatch control centers.

A project, started in September 1984, is an 18-month study by Westinghouse Electric Corp. (RP2475). This project has the following objectives.

□ Identify, collect, and evaluate the available information on good CRT display design

□ Determine the types of displays required in control centers

□ Research additional displays required

□ Prepare an easy-to-use CRT display design handbook for designing systematic and cost-effective control center displays

□ Transfer project findings to the utility industry through a handbook, a video tape, two seminars to be held in the first quarter of 1986, and a final EPRI report

To date, project personnel have visited three utilities and obtained photographs of good displays currently in use. The three utilities are Baltimore Gas & Electric Co., Ohio Edison Co., and Portland General Electric Co. The photographs were added to ones taken at 13 dispatch control centers in an earlier project on human factors in control centers (RP1354). The photographs are currently being evaluated and other means of displaying the same information are being investigated. *Project Manager: Charles J. Frank*

Dynamic system security assessment

Dynamic system security assessment answers the question of what happens to the power system following a major loss of equipment. It examines the changes the system undergoes from its initial stable state to its final state after such events as loss of generation facilities, loss of transmission facilities, or sudden changes in load conditions. To assess the dynamic security of the power system, utilities have traditionally undertaken a large number of off-line studies to evaluate the effects of various events. Then they determine operating guidelines, limits for on-line operation, and corrective or preventive action plans from the study results. This type of operation may have been adequate in the past, but recent large-scale power disruptions in North America and in Europe indicate that better methods of dynamic system security assessment are needed.

In March 1985 EPRI began an 18-month study (RP2496) by Energy & Control Consultants with the following objectives.

□ Identify how to assess dynamic security in system operations

□ Identify analytic methods for establishing criteria for assessing threats to dynamic system security and determining the corrections or preventive actions

□ Prepare a research and development plan for developing a dynamic system security assessment capability for daily system operations use

Project Manager: Charles J. Frank

DISTRIBUTION

Extruded dielectric cable surveys

Because U.S. utilities experienced problems with early failure of extruded dielectric distribution cables, EPRI funded two surveys of overseas (European and Japanese) practices. Battelle, Columbus Laboratories conducted one survey on processing (extrusion, curing, materials handling), which was reviewed in recent *Journal* articles (RP2438); the University of Connecticut conducted the other survey, which covers materials and is discussed here (RP2439).

Service reliability of extruded distribution cables rated 15–35 kV in the United States has been less than satisfactory High failure rates for cables insulated with low-density, high-molecular-weight polyethylene (HMWPE) has led the industry to gradually switch to cross-linked low-density polyethylene (XLPE). Utilities are also increasingly considering ethylene copolymers (EPR or EPDM). However, because the U.S. experience has not wholly paralleled that of Europe and Japan, EPRI sponsored the survey of materials practices. The survey objective was to develop a better understanding as to how overseas producers deal with shield, insulation, and jacket reliability.

The contractor, the University of Connecticut, used questionnaires, telephone interviews, a literature survey, and personal interviews and discussions to reach the following conclusions.

□ Overseas countries plan to continue their focus on XLPE as a future insulation. Little use of EPR or EPDM is forecast.

□ European countries and Japan emphasize cleanliness of insulation; keeping out contaminants is a major concern, and this practice is reflected in the various overseas specifications.

□ Little research on materials to prevent treeing is taking place, but the Japanese appear to be experimenting more than Europeans. The greatest research effort in tree retardants seems to be in the United States.

□ Although research to date has been limited, linear low-density polyethylene (LLDPE), a relatively new material that can be considered a hybrid between low- and high-density polyethylene, is a potential insulation. A reason is that mechanical property improvements can reduce potential manufacturing costs. LLDPE is being increasingly used as a jacket material.

▫ Japanese requirements for cleanliness appear to be greater than those of either the United States or Europe.

▫ Silane-induced cross-linking (a low-temperature process) is an emerging European process.

▫ Shield materials are becoming increasingly smooth and easy to strip from the cable insulation. Newer semiconducting carbon blacks are being investigated. No apparent effort is being made in non-carbon-black systems.

▫ Jackets are always used for medium voltage cables. In the United States the use of jackets is an individual utility option.

The results of this project (RP2439) and the processing survey (RP2438) will be employed in planning future work. *Project Manager: Bruce Bernstein*

Advanced capacitors

The development of a dry-type power capacitor is a challenging task, but progress to date is encouraging and EPRI is optimistic that the development will eventually be successful (RP2205-1). Since the last status report in March 1984, hundreds of samples ranging from individual capacitor rolls to full-scale 200-kVAR units have been exhaustively tested and evaluated. Accelerated life and aging tests are the most demanding, and periodic measurements are being made of capacitance, partial discharge inception and extinction, power factor, and radio influence voltage to reveal the strengths and weaknesses of the sample designs.

EPRI has arrived at the point of adopting a basic roll design and configuration for a 7200-V, 200-kVAR capacitor, but a good deal of work with full-size models still remains before the dry capacitor for power system application can be considered a reality. Partial discharge and corona performance exert a very strong influence on the design of a dry capacitor. Without an insulating liquid to fill all the nooks and crannies, microvoids remain to limit the permissible operating voltage stress.

To supplement the ongoing work of optimizing the roll design using current technology, EPRI initiated another project for basic research into methods of suppressing partial discharge (RP2205-2). A breakthrough in this area would permit operation at a higher voltage stress, which would have a major impact on cost. The design currently adopted is expected to cost more than its liquid-filled equivalent, but only a modest increase in permissible voltage stress would drop the cost below that of a liquid unit. With such a potential payoff and research results that are already encouraging, EPRI will continue to concentrate on this effort.

Work is now in progress to optimize the 200-kVAR design in preparation for the production of five 600-kVAR, 7200-V racks for field trial. This dry capacitor unit will have the standard mounting dimension and will be approximately equivalent in overall size, weight, and losses to current liquid capacitors. In addition, the dry capacitor will meet all applicable industry standards. In the near future EPRI will be looking for five utilities to install and monitor the performance of the new, advanced state-of-the-art capacitors. *Project Manager: Herbert J. Songster*

PLANT ELECTRICAL SYSTEMS AND EQUIPMENT

Power-angle instrument for large synchronous machines

A conventional method of measuring the power angle of large synchronous machines is to direct a stroboscope at a chalk mark on an exposed shaft and measure with a protractor mounted on a stationary part of the machine adjacent to the exposed shaft. This method is crude and, on some machines, nearly impossible to implement. The project discussed here comes up with an alternative to the chalk mark method (RP2308-5). The objectives of this project are to design, develop, and build an instrument to measure the relative internal power angle of a synchronous generator.

The power-angle instrument relates armature voltage zero crossings (used as a reference) to a signal derived from rotor position. A voltage proportional to the angular difference between these signals is developed and appropriately conditioned to drive a digital readout, FM tape, and/or chart recorder. The instrument has been designed and built. Schematics, parts lists, and drawings are provided in the final report (EL-3667). The components are available from electronics parts houses, and construction and calibration are easy.

The instrument has been thoroughly tested, both in the laboratory and in the field, with excellent results. The device is suitable for both transient and steady-state measurements and has both digital and analog outputs of power angle. It is suitable for both measurement and feedback control applications.

A manual procedure is required to calibrate the power-angle zero reference each time the instrument is disconnected or turned off or the generator field is deenergized. However, if the unit is to be installed as a permanent monitoring or control device, it will be necessary to make the instrument self-calibrating. This work is currently in progress under RP2591-1. *Project Manager: D. K. Sharma*

Turn insulation capability of large ac motors

Almost all large motors have form-wound multiturn stator coils. The insulation between the turns and strands is not highly stressed under normal operating conditions. However, transient conditions, such as switching surges, can cause severe voltage stress on the turn insulation because the stress is not uniformly distributed across the turns. The introduction of vacuum switchgear on motor drives in power plant auxiliary applications is of particular concern because this type of switchgear can generate very steep-fronted surges.

Relatively little published information is available on the actual surge environment, as well as the turn insulation capability, of motors used in power plant drives or elsewhere in the utility system. EPRI has initiated a testing and analysis project to fill this gap (RP2307).

One objective of this project is to determine the actual surge environment in power plants and establish a measure of modern motor turn insulation capability to withstand the magnitude of voltage surges characteristically generated during the process of current interruption by fast-acting circuit breakers and, in particular, by vacuum switchgear. An additional objective is to make information available to utilities on how to specify turn insulation and protect motors. The information gathered in this project will provide the necessary data to the industry for the development of appropriate standards.

As a subcontractor to Ontario Hydro, the principal contractor, Rensselaer Polytechnic Institute, has been entrusted with the task of investigating the effect of abnormal switching operations that may occur in unusual, but not improbable, circumstances. Attention focuses particularly on the behavior of vacuum circuit breakers that may create overvoltages by interactions with the motor and the source. Ontario Hydro's work concentrates mostly on what might be termed normal switching operations.

Monitoring of switching surges has been completed so far on 14 motors at three U.S. and Canadian utilities. More surge monitoring tests are planned. Destructive and nondestructive surge tests have been completed on 10 motor stators and more are planned. Analytic studies to support the project objectives are proceeding on schedule. *Project Manager: D. K. Sharma*

UNDERGROUND TRANSMISSION

Extruded cable breakdown study

A mass of ac, impulse, and switching surge breakdown data on random extruded transmission cable samples appears to be of little interest or value to cable designers and users. Consequently, recent work on heavy-wall, extruded dielectrics was oriented in a different direction. The project will include a study of the relationship between full-reel ac test severity, considering both voltage level and voltage application time, and either the improvement in or the loss of service life, as measured by short-time breakdown tests (RP7879).

The question of the adequacy of the present full-reel ac test has been debated for years, one side questioning its ability to even find severe mechanical damage and the other suggesting that it in itself generates incipient damage in the cable. Similar incipient damage concerns have been expressed about impulse testing.

The general approach to answering some of these questions is statistically simple, starting with testing to fill a 3 × 3 voltage/time exposure matrix (Figure 1). The experimental procedure uses one quite long sample, 2000 ft or so, cut into nine pieces of equal length, which will be later subdivided into shorter, but adequate lengths for breakdown testing. Each of the nine pieces will be tested per the exposure matrix. Failures will be cut out as they occur, and tests will continue on any remaining (but shorter) lengths as long as possible. Ac breakdown testing will be done on multiple short samples from each matrix block test, following its voltage/time exposure. Blocks 1 and 2 will also include impulse testing.

The conclusions to be drawn will, of course, depend on the experience in the base exposure testing and also in the subsequent ac and impulse breakdown testing. A proper analysis of the data using Weibull procedures will be done. This testing should suggest a procedure to determine the optimum full-reel ac test for any extrusion system. This testing is expected to take a year or so. *Project Manager: John Shimshock*

Figure 1 This matrix defines voltage/time exposure tests that will be conducted to evaluate the adequacy of full-reel ac testing of heavy-wall, extruded dielectric cables. The numbers in the blocks indicate the test sequence. Each test voltage is a multiple of E_o, the rated line-to-ground voltage.

Test Voltage	Test Time: 5 min	50 min	500 min
2.5 E_o	1	6	3
3.5 E_o	7	5	9
4.9 E_o	4	8	2

PPP laminate for low-loss, 138–550-kV pipe-type cable

The development program on paper-polypropylene-paper (PPP) laminate, initiated over 12 years ago under EPRI–DOE–Phelps Dodge Cable & Wire Co. cofunding, has resulted in the successful completion of the two-year Waltz Mill life testing of a low-loss, 765-kV high-pressure oil-filled (HPOF) pipe-type, PPP-insulated prototype cable. The cable system sample has shown very favorable stability at conductor temperatures up to 105°C and applied 137% line-to-neutral voltages. Dielectric losses and power factors after the completion of the tests are less than one-third those of paper.

The application of PPP to commercial cable rated at voltages of 138–550 kV has been spearheaded by EPRI during the last five years, and research has shown PPP to be economically and technically viable. Prototype 345-kV cables with approximately one-half the insulation thickness of paper and one-third to one-fourth the dielectric losses have been successfully tested up to the basic insulation level. In addition, economic studies using some 280 scenarios have shown PPP to be more economical than paper at all voltage ratings, even with PPP costing $7.50/lb compared with paper at $0.85/lb. Development of a domestic PPP source has repeatedly produced quality laminate at projected costs of $2.50/lb. Compatible PPP joints approximately one-half the length and one-fourth the diameter have been developed and tested; they reduce the volume of hand-applied insulating tape to less than one-third that of paper joints.

Because of their reduced insulation thicknesses and diameter, reduced-wall, low-loss PPP cables increase power capacity three to four times when they replace old high-loss paper cables in existing pipe/manhole structures. These benefits can be attained by raising the system voltage by two levels.

Studies have also indicated particularly beneficial advantages and economics when PPP cables are forced-cooled. Substantial decreases in oil flow, pressure drop, and cooling plant requirements are possible because of the reduced dielectric losses and appreciably smaller diameters available in PPP reduced-wall pipe-type cables.

Forced-cooled PPP cables would be especially attractive, even at the same voltage rating, as retrofit of old paper systems in existing pipe structures, using existing oil circulation and cooling plants. Instead of increasing MVA capacity with forced-cooled paper cables the usual 40%, increasing the throughput capacity by some 150 to 200% with lower-loss PPP cables is economically and technically feasible and uses existing cooling plants much more efficiently.

A full-reel commercial production length of 345-kV PPP is being manufactured for two-year life testing at Waltz Mill and for extensive supplementary laboratory testing. *Project Manager: Stephen Kozak*

R&D Status Report
ENERGY ANALYSIS AND ENVIRONMENT DIVISION

René Malès, Vice President

BIOLOGIC EFFECTS OF PLUME FLY ASH

Coal-fired power plants emit combustion byproducts into the atmosphere. Some emissions, such as sulfur dioxide, have been the subject of considerable interest and research. Others, such as fine inhalable particles and particle-associated chemicals, are less thoroughly understood. Any material may affect human health if the concentration and toxicity are sufficient. At present, data on emitted particles and associated chemicals are too fragmentary to determine whether a health problem exists and, if so, how serious it may be. EPRI has developed a research project that will provide the first coordinated data on the biologic, chemical, and physical properties of plume particles and associated chemicals (RP2482). The data will help utilities evaluate control strategies and meet environmental protection requirements. Work is under way, and the first results are expected early in 1987.

Investigation of the biologic effects of plume fly ash began with development of a detailed research plan (*EPRI Journal*, December 1983, pp. 58–59, and an EPRI special report on RP1598 to be published shortly). The planned research has the following objectives.

- To assess the biologic activity of fine particles that are emitted from coal-fired power plants and to which people may be exposed
- To assess the feasibility and necessity of whole-animal fine-particle studies that would be relevant to human health (*feasibility* to be assessed by developing techniques to collect large samples of ash that represent plume and ambient conditions and by describing the biologic, chemical, and physical differences between samples collected from a coal-fired power plant's stack and samples from locations in the plume; *necessity* to be assessed by conducting preliminary toxicity evaluations)
- To assess the potential for health effects of plume fly ash by conducting whole-animal studies (if feasible and necessary)

The project is divided into eight phases. Phase 1, project planning, began in 1980 and has been completed. Phase 2, the evaluation of storage techniques, is under way (discussed below). Phase 3 will be an intensive examination of the emissions from one rural plant. Funding has been approved, but this phase will be implemented only after phase 2 results have been used to perfect its design. Phase 4 will evaluate techniques and equipment (laboratory combustors, for example) likely to be needed later in the project. Funding has been approved, and this phase will be implemented as needed. Depending on the results of phases 1–4, further work (phases 5–8) may be appropriate. Such work would use optimal techniques to study plume fly ash from many power plants and conduct a long-term animal study on the plume fly ash judged most representative of the industry.

Evaluation of storage techniques

Phase 2 is the first experimental phase of the project. The driving force behind it is data from prior studies suggesting that chemical and physical changes may occur while samples are stored in the laboratory. If such changes are prevalent, the value of analyses of stored samples may be questionable. The importance of determining whether there are changes during sample storage is further highlighted by the recognition that storage, in one form or another, is an unavoidable procedural step. Phase 2 examines the means of preserving plume fly ash characteristics between the time that samples are collected and the time they undergo testing. It also seeks to minimize and standardize any inevitable storage-related changes so they will not significantly affect subsequent phases of the project. During refinement of phase 2 design, it became clear that a storage study on plume fly ash could not be conducted until certain matters of technology were resolved.

The problems and issues are how to collect enough particles, how to ensure that they are relevant to public health, how to perform relevant testing on minimal quantities of particles, and how to design an experiment to assess the importance of storage time and temperature. The design of phase 2 was adapted to address these issues through a series of preliminary studies. A full-scale storage study will follow if justified by the preliminary results. The work in part A is subdivided into collection and storage, biologic testing, chemical and physical testing, information handling, and technical coordination.

The collection and storage component focuses on obtaining far larger quantities of plume (as opposed to in-stack) fly ash than have ever been obtained previously.

Collecting even milligram quantities is far more difficult that obtaining truckloads of precipitator or baghouse ash. The job requires work in several areas.

- Developing and constructing special large-volume samplers that are selective for inhalable particles
- Developing a means of situating these samplers in the plume with a helicopter
- Designing reliable temperature-controlled shipping containers
- Developing protocols that will permit coordinated collection and handling of samples and ancillary data on plant operating conditions, air quality, and meteorology

Once these requirements have been met, samples will be collected in and near a power plant. Ideally, eight helicopter flights of two hours each should be able to collect over 2½ grams of plume fly ash within three days. In reality, the eight flights may require more than three days, and the total quantity collected may be much less than 2½ grams. Limitations may be imposed by such factors as weather, power plant operating conditions, and equipment dependability. Given these uncertainties, contingency plans have been developed to permit optimal use of any sample quantity. Freshly collected samples will be shipped to a central repository in the temperature-controlled containers. At preset intervals they will be distributed for testing. The collection and storage is being handled by Battelle, Columbus Laboratories, with subcontracts to Texas A&M University (for design and construction of the particle-sampling devices) and

NEA, Inc. (for preliminary dilution-device studies).

Power plants in Delaware, Michigan, Minnesota, Nevada, Tennessee, and Utah were evaluated as potential host sites for phase 2 of the project. Tennessee Valley Authority's Cumberland steam plant, situated in northwestern Tennessee, was selected eventually as the host because of its many attractive features.

- Rural, isolated from other pollution sources
- Two identical units (1300 MW each) that use a single control technology (electrostatic precipitators) representative of the industry
- A good record of being on-line at a reasonable load factor
- Wet ash handling (thus minimal fugitive emissions from the ash pile)
- Stacks over 900 ft high (thus minimal contamination of the plume by the ground-level air parcel)
- Site of other air quality studies that may help in finalizing the project design

Evaluation procedures

Initially, to minimize the amount of sample required, the biologic testing component is using nonplume samples to identify the most relevant sample preparation method. Once the procedures are optimized, repository samples will be analyzed by an inexpensive battery of tests. These procedures will be used throughout the project to indicate differences among samples and will set the stage for studies on the potential for health effects. The selected tests (identified in the phase 1 planning as tests that are widely accepted and useful for evaluating small samples) are the Ames test, which detects base-pair and frameshift mutations in the basic genetic material (DNA); the unscheduled DNA synthesis assay, which detects general damage to DNA, measured as a function of the amount of excision repair; and the pulmonary alveolar macrophage assay, which detects physiologic changes in the principal type of cell that protects the lung from inhaled particles.

If enough sample ash is available, the mouse lymphoma cell mutagenesis assay also will be performed; this procedure permits quantification of forward mutations in a specific part of the DNA. This work is being performed by the Toxicology Laboratory at SRI International, with one subcontract to Oak Ridge National Laboratory for study of a key extraction method.

Initially, the chemical and physical testing component also is using nonplume samples to evaluate an array of techniques recommended during the phase 1 planning study. A battery of up to six techniques will be selected for further use throughout the project to indicate differences among samples, as well as to identify the characteristics most likely either to change during storage or to be responsible for any biologic activity. (Wherever possible, coordinated batteries of biologic, chemical, and physical tests are being performed on samples.)

This battery of chemical and physical tests includes computerized scanning electron microscopy, which conducts particle-by-particle evaluations for morphology and for elements with atomic numbers as low as 6 (carbon); polarized light microscopy, which analyzes particle morphology and classifies particles on the basis of differences in refractive index; X-ray photoelectron spectroscopy, which shows the elemental composition, valence state, and chemical class of the surface of a blanket of particles; a bulk trace-element analysis technique (e.g., instrumental neutron-activation analysis, proton-induced gamma emission spectroscopy, proton-induced X-ray emission spectroscopy, or spark-source mass spectrometry); and a technique for analyzing organic compounds (e.g., sublimation, mass spectrometry, gas chromatography–mass spectrometry, or mass spectrometry–mass spectrometry). If the quantity of the ash sample is sufficient, high-performance liquid chromatography also will be performed to analyze for the more unstable polycyclic aromatic compounds. Battelle is handling the above work, but portions are subcontracted to IIT Research Institute, Energy Technology Consultants, Elemental Analysis Corp., and the University of Illinois.

The information-handling component of these preliminary studies establishes a system for management of the data generated during collection, storage, and testing of ash samples. The system will permit data intercomparisons and thus will be a vital resource in ensuring data quality and in evaluating project results. Ultimately, a user's guide will be prepared for the data base. Both the user's guide and the data base will be available to utilities and other interested parties. To work with the entire data base will require access to a mainframe computer with substantial disk storage, but significant parts will be suitable for use on an IBM–PC. Martin Marietta Environmental Systems is responsible for this work.

The technical coordination component assists the EPRI project manager in ensuring the smooth conduct of this complex, multidisciplinary project. Its focus is on coordinating contractors to ensure timely collection of data for optimal evaluation of project results, performing quality assurance and data review for each project component, tracking project progress and recommending changes to ensure that objectives are met, and preparing documents that synthesize results and present conclusions. Other activities will include preparing a master file of relevant literature, coordinating technical meetings among contractors, and conveying the results and conclusions to the scientific community, the government, and the utilities. The technical coordination described above is being performed by SRI's Bio-organic Chemistry Laboratory, which is operationally distinct from the group performing the biologic studies.

EPRI has formed a scientific advisory committee, which comprises representatives of industry, universities, and government. The committee is experienced in particle collection, general toxicology and industrial hygiene, in vitro biologic testing, general analytical chemistry, particle-surface chemistry, and statistics and experimental design. It has already played a vital role in guiding the development of the project and will evaluate data throughout the study.

Preliminary studies for the evaluation of storage techniques began in July 1985 and will be completed in the second half of 1987.

Collection of plume fly ash from the host power plant is scheduled for late in the spring of 1986. Major project deliverables will appear about one year later. Major deliverables will include EPRI reports; access to the contents of the data base management system; regional workshops that will present project results to the industry and other interested parties; a meeting in metropolitan Washington, D.C., that will focus on conveying detailed technical results to the scientific community and the government; and a videotape that will highlight project methods, results, and implications. By autumn 1986 there will be an interim version of the videotape, which will explain project background and methods. *Project Manager: Blakeman S. Smith*

SHORT-RUN FORECASTING OF ELECTRICITY SALES

For most utilities, the importance of accurate sales forecasts for the one or two years immediately ahead can hardly be exaggerated. These forecasts, usually expressed as monthly energy (kWh) and billing demand (kW) by rate class, are essential in the establishment of rate levels and are useful in budget preparation, maintenance scheduling, fuel purchasing, and many other aspects of planning and operation.

A variety of factors affect sales in this timeframe, and it is useful to consider them in three categories. First, certain factors influence the long-term trend in sales, including an increase in the number of customers, a greater saturation of appliances, and changes in values (e.g., adoption of a conservation ethic). In turn, these factors may be influenced by other trends, such as growth in customer income and changes in price. The long-term trend in sales is not fixed but changes over time in response to changes in other factors.

Second, sales may vary because of seasonal fluctuations, in particular the recurring patterns of variation due primarily to monthly weather cycles. Non-weather-related seasonal variations in economic activity may also occur, and they also influence sales.

Third, there is a random factor that affects sales: the short-run variation in sales that cannot be accounted for by standard, measurable variables and is either completely unpredictable or at least unpredictable beyond a few months in the future. Short-run variation may be caused by temporary changes in attitudes toward conservation, temporary changes in lifestyle, and other unique events.

Forecasting models for electricity sales must take into account each of these sources of variation. The performance of the standard approaches to forecasting has not always been satisfactory, and a potential explanation is the failure to account for some of the above factors. A number of advances reported in the econometric and statistical literature in the past few years appear to have promise for sales forecasting in the timeframe of 12–24 months.

About three years ago EPRI began a research project designed to determine whether these new techniques would be useful for developing short-term electricity sales forecasting models (RP2279). When applied to the data used in the study, the methods consistently produced more-accurate forecasting models than did traditional techniques.

In the second phase the project developed a microcomputer-based software package, FORECAST MASTER. Just released for commercial use, it is designed to facilitate the construction of short-term forecasting models by means of selected techniques and to teach these techniques to experienced forecasters who may be unfamiliar with them.

Modeling approaches

Short-term forecasting models can be considered either econometric or time-series based, and they may be either adaptive or non-adaptive.

Econometric forecasting methods gained extraordinarily in popularity during the 1970s, primarily because of their superior ability to explain the long-term variation, or trend, in sales. These models explain changes in sales in terms of changes in such economic variables as electricity prices and income; their great success during the past decade resulted from their ability to explain the slowdown in the growth rate of sales in response to the rise in electricity prices.

In contrast, time-series-based models seek to predict sales by projecting past patterns of change into the future. Typically, short-run and seasonal fluctuations are the ones most effectively modeled by this approach because these patterns are recurring and thus predictable. Even very simple time-series models can often provide forecasts for the period immediately ahead that are superior to those generated by elaborate econometric models.

Thus a broad but nevertheless useful distinction is that econometric methods are better suited to modeling longer-term trends and time-series methods are superior for capturing short-term variation. Models synthesizing the two general approaches potentially promise improved short- and long-run forecasts.

Most of the models considered in this comparison are adaptive in some sense. That is, the models change in response to the accuracy of their predictions. They seek in various ways to break down the variation in sales into the interrelationships of trend, seasonal variation, and short-run variation, and to model the underlying relationships in an adaptive way.

The purpose of the project was not to identify a single best technique. In fact, the analyses showed that different approaches forecast best in various circumstances. The purpose was to determine whether these new methods are sufficiently superior to commonly used techniques to make it worthwhile to pursue them further. In addition, researchers hoped that the analyses would indicate which approaches were the most promising. Both goals were fulfilled.

Estimation techniques

The analysis conducted in the first phase of the project consisted of constructing a number of forecasting models that use different estimation techniques. The simplest—and most traditional—were econometric models estimated by the ordinary-least-squares method and time-series models using the Box-Jenkins technique. More-adaptive econometric methods were employed as well, including serial-correlation models, time-varying-parameter models, and adaptive-variance models. These models are all structured like simple, ordinary econometric models except that the estimation technique allows the intercept, coefficients, or error terms to change over time.

At the same time, a group of time-series models were estimated, including various experimental smoothers, Parzen's ARARMA, ridge vector autoregression, and the most general method, state space.

In addition to these primary models, a great many others were examined. In some cases, as many as 25 separate versions of a particular model were tried with various sample periods, dynamics, variable definitions, estimation methods, and detrending. In some cases, methods were combined.

Analysis method

The analysis was based on forecasting models developed with monthly data on residential sales per customer by state. Each model was estimated over a relatively long data set, consisting of observations from 1962 through 1977. For each model, a forecast was generated for each month of the subsequent three-year period (January 1978—December 1980) and were then compared with actual sales to determine accuracy.

This general approach was applied to data from 10 diverse and representative states. Results are reported as average forecast error for a particular model across the 10 states. The best models did not behave well in all states. No single best approach was found, but such an outcome was not expected. The models described below as performing the best, however, were rarely (if ever) in the mid-to-low end of the range. Conversely, the poorest performers rarely, if ever, did better than the average.

Results

Table 1 presents the heart of the results of the experiment, listing only the unconditional root-mean-square forecast errors (in kWh per customer) for several horizons averaged across states.

In addition to comparing methods, the table also reveals the difficulty of forecasting over long horizons. Some models that are superior at very short horizons perform rather poorly over long horizons. The accuracy of the NAIVE (or static econometric) model is dramatically lower than that of any of the alternatives considered in this study; clearly, these other methods promise to improve on at least this very simple econometric approach.

As the table indicates, the multivariate state space–transfer function (SS–TF) model performed best for short time horizons. As the test timeframe lengthened, higher-order models, which include more explanatory variables, were more accurate. The best, most consistent models were autoregressive (AUTO–B and AUTO–D) and time-varying-parameter (TVP–B) models. In short, either a well-specified structural econometric model or an adaptive trend estimate is necessary for superior forecasting of a period longer than a year.

A variety of approaches to seasonality were used in this analysis. Several models differentiated the data seasonally, others used seasonal dummy variables, many used monthly weather variables, some interacted these with

Table 1
UNCONDITIONAL RMS ERRORS BY FORECAST HORIZON
(arithmetic averages over states—kWh/customer per month)

Method	1 Month	12 Months	24 Months	12-Month Avg.
OLS–A (simple econometric model estimated with ordinary least squares)	36.3	68.1	89.6	29.8
AUTO–B (econometric model estimated with serial correlation corrections and containing both monthly and seasonal adaptation)	39.7	46.7	48.6	13.2
AUTO–D (econometric model estimated with serial correlation corrections and containing both monthly and seasonal adaptation)	36.1	44.3	47.0	14.9
TVP–B (model containing adaptation in the parameters)	35.3	43.2	47.1	13.2
SS–TF (multivariate state-space model)	34.2	52.2	63.7	18.7
WINTERS (exponential-smoothing model)	47.9	56.9	63.6	30.7
ARARMA (autoregressive moving-average model and filtering of long-term trend)	44.1	58.3	65.0	26.8
R–VAR (ridge vector autoregressive model)	44.7	60.7	57.9	26.5
BAYESIAN (seasonal, multistate model estimated by using Kalman filter and Bayesian probability assessments)	50.1	62.8	76.9	31.2
SS–UNI (univariate state-space model)	50.6	60.0	64.7	27.5
NAIVE (static econometric model)	88.3	166.3	241.4	78.1

time trends, and some used stationary autoregressions to explain seasonality. Simple solutions were not very effective. All the best models used weather data with short lags; without such data, high-order overparameterized time-series models were required. Even though weather was replaced by historical monthly averages in the forecast period, it helped the long-term unconditional forecasts.

The best models for a 12–24-month period are those that do well at modeling both the trend and the seasonal behavior. The best such models from Table 1 are TVP–B and AUTO–D; AUTO–B is nearly as good. The others are substantially less accurate. Neither of the two most-accurate models has seasonal dummy variables or important economic components.

What do these results show? First, the adaptive models, particularly those with structural variables, perform significantly better than the traditional methods. From the last column of Table 1, it is clear that the two autoregressive approaches and the time-varying-parameter approach are about twice as accurate as either the ordinary-least-squares (OLS) econometric model or the Box-Jenkins (SS–UNI) approach and about six times more accurate than the NAIVE model. The SS–TF model also does well in this measure.

Second, by their nature some of the approaches, such as SS–TF, did particularly well at very-short-term (1–6 months) forecasting. To obtain superior forecasts for a year or longer, the forecaster will need either a well-specified structural econometric model (such as AUTO) or one with adaptive parameters (such as TVP). It must model both long-term components and seasonality.

New software

In an attempt to make these improved, adaptive estimation techniques available to utility forecasters, EPRI developed FORECAST MASTER. The software was designed for use on IBM–PC microcomputers and makes extensive use of screen graphics, help messages, interactive editing, and so on.

In general, the software assumes that the user is an experienced forecaster who is not necessarily familiar with the particular techniques incorporated in the package.

FORECAST MASTER provides six procedures for fitting a statistical model to a historical time series of one or more dependent (endogenous) and one or more independent (exogenous) variables. The resulting model is then used to compute forecasts of the dependent variable(s) into the future.

All the programs follow the same easy-to-understand format. A full range of standardized diagnostic statistics and graphic output is presented as each trial model is fitted to the historical data. The programs require very few keyboard entries; they run virtually automatically, except when the user wants to deviate from the default procedures. These procedures are presented to the user in full-screen display, to be changed as desired. Because an on-line help facility is always available, the user rarely has to consult the manual after the first time through.

Brief descriptions of the six programs follow. The software was programmed for EPRI in the C language by Scientific Systems, Inc., of Cambridge, Massachusetts.

- State-space forecasting—uses the state space method and may be used for either univariate or multivariate forecasting with up to five variables.
- Box-Jenkins forecasting—uses the Box-Jenkins method to build an autoregressive moving-average (p,q) model for forecasting univariate time series.
- Exponential smoothing—allows the user to prepare univariate forecasts by using any of four exponential smoothing techniques: adaptive exponential smoothing, simple exponential smoothing, Holt two-parameter exponential smoothing, and Winters three-parameter exponential smoothing.
- Ridge vector autoregression—implements Litterman's Bayesian approach to vector autoregression. It is a multivariate forecasting method for use with up to five variables.
- Curve fitting—fits a univariate time series to one of eight different predefined curves and estimates the parameters that minimize the sum of the squared errors over the fit set.
- Autoregression—adapted from the original AUTOPRO program developed by Quantitative Economic Research, Inc., at the University of California at San Diego. The program includes three forms of estimation for econometric time series: ordinary least squares, serial correlation correction (an extension of the Cochran-Orcutt method), and adaptive variance correction (Engle's ARCH method).

There is no magic solution to the forecasting problem faced by utilities: electricity sales 12 months in the future will be strongly influenced by the mildness or severity of the weather at that time and by other unpredictable events. The methods analyzed in RP2279 will help to sort out the effects of weather and other variables on sales.

Currently, FORECAST MASTER is being evaluated in a series of other applications, including the forecasting of peak demand, commercial and industrial sales, and system-level sales. This work will probably culminate in the publication of a guidebook on the use of adaptive estimation techniques for utility forecasting problems. *Project Manager: Shishir K. Mukherjee*

R&D Status Report
ENERGY MANAGEMENT AND UTILIZATION DIVISION

Fritz Kalhammer, Vice President

PLASMA-FIRED CUPOLA DEVELOPMENT

Plasmas produced by exposing a gas to a high-intensity electric arc can achieve temperatures in excess of 10,000°F (5500°C), far higher than the 2800°F (1500°C) practical limit for fossil fuel combustion. This high-temperature capability—along with other characteristics, such as rapid heat transfer and excellent controllability—suggests that plasmas may be an efficient and economical tool for effecting physical and chemical change in industrial materials processing.

Since October 1983 an EPRI-supported project has been investigating the application of plasma technology to the melting of iron (RP2219). This effort to develop, assess, and demonstrate a plasma-fired cupola for foundry use has brought this technology to the verge of commercial application.

Plasmas can dramatically benefit metals processing in many ways. For example, the use of plasmas can reduce requirements for costly metallurgical coke, thereby increasing capacity and lowering unit production costs; permit use of less-expensive feedstocks, such as loose machining chips; and eliminate such intermediate operations as briquetting. Moreover, plasma heat, which is independent of combustion and can be introduced with a wide variety of gases, affords greater control over processing conditions and, hence, over product quality. Reduced dependence on fossil fuels also may result in significant environmental benefits.

The EPRI project is cofunded by Westinghouse Electric Corp. and assisted by Modern Equipment Co. and General Motors–Central Foundry Division (GM–CFD). By applying the above advantages of plasma to existing cupola technology, this research promises to markedly enhance the productivity of U.S. foundries.

Foundry cupola technology

The cupola is a vertical-shaft furnace that has long been the predominant technology for the melting of iron in foundries. The conventional cupola consists of a cylindrical steel shell, often refractory-lined, equipped with a windbox and tuyeres to deliver combustion air to the shaft. Feed materials (primarily metal scrap, metallurgical coke, and limestone) enter through a charge door at an upper level, and slag and molten metal leave through a tap hole and spout at the bottom. The metal scrap is typically a combination of iron and steel in various forms—from relatively large castings to shredded sheet metal to the borings and turnings produced in machining operations. The predominant product is gray iron; malleable and nodular iron are produced in lesser quantities.

A key feature of conventional cupola technology is that the process energy is derived entirely from the combustion of fossil fuels, primarily metallurgical coke. This not only limits operator control of gas chemistry in the cupola but also imposes significant system costs for handling large volumes of combustion gases. High gas velocities (wind rates) in the cupola caused by such large volumes make it impossible to introduce small, loose metal scrap through the charge door. In conventional cupolas, such scrap must be briquetted prior to melting; this prevents the borings (or chips) and turnings from being severely oxidized and/or physically carried out the top of the cupola before they reach the melt zone. Although briquetting costs vary widely, $15/t or more is common.

Some limited laboratory testing by Westinghouse indicated that the application of plasma torches to cupola operation could provide a solution to these problems. The ability of the plasma torch to provide precisely controlled heat independently of combustion would both lower coke requirements and drastically reduce wind rates, with several derivative benefits.

- The ability to process large quantities of unbriquetted borings and turnings in place of conventional scrap, at a saving of $50/t or more
- Reduced gas-handling and environmental control costs
- Improved product quality made possible by the partial decoupling of energy input and melt chemistry
- Increased production rates as a result of much higher metal-to-coke ratios

As a bonus, the plasma torch would also provide the cupola with an ultrahigh-temperature capability not achievable in coke-fired cupolas because of the limitation on combustion temperatures and the operating limits of heat recuperation equipment. Plasma can produce hot blast temperatures of 3000°F (1650°C) or higher; these temperatures are conducive to the reduction of ordinary sand (SiO_2) to silicon, a necessary additive for producing on-spec iron. Conventional cupolas use expensive ferrosilicon, which costs as much as $1000/t.

Cupola test unit

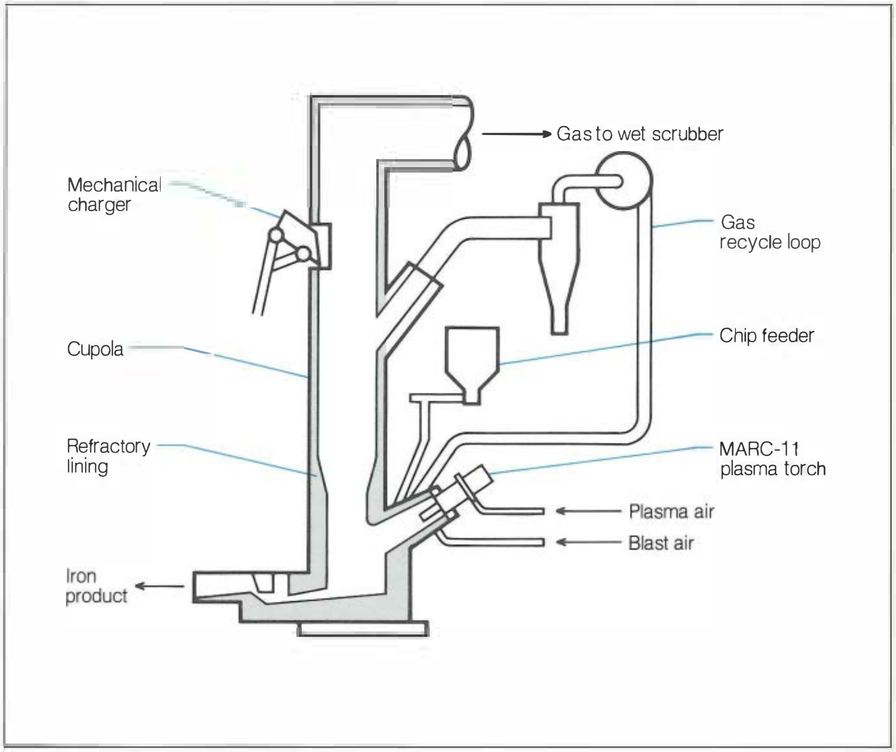
To realize the promise of plasma technology in foundry applications, EPRI initiated a 23-month, $1.7 million project to design, fabricate, install, and test a 2.5-t/h pilot-scale plasma-fired cupola and provided $1 million. Westinghouse, which provided major cofunding, is the host for the test at its 20-MW Waltz Mill Plasma Test Facility in Madison, Pennsylvania. Modern Equipment, a leading supplier of cupola technology, designed and fabricated the test unit, and is providing expertise in the areas of cupola operation and evaluation. GM–CFD, the world's largest foundry organization, has supplied technical assistance and a variety of raw materials for the test phase.

For greater correlation of test results with actual foundry operations, the test cupola was constructed on a small yet commercially significant scale, corresponding in size to an industrial No. 3 cupola. As shown in Figure 1, the pilot unit is a water-cooled, refractory-lined design with a shell diameter of 42 in (107 cm) and an inside-refractory diameter of 30 in (76 cm). Additional refractory (and hence a smaller inside diameter) is present in the melt zone. Liquid iron and slag are continuously tapped and separated in a conventional front-spout dam-and-skimmer arrangement. Combustion stack gases go through particulate removal and water-scrubbing equipment; a stack gas burner ensures complete conversion of all combustibles.

The main cupola charge—scrap, coke, alloys, and slag formers—is loaded through the open charge door at the top of the cupola by an end-dump, skip-type mechanical charger. The charge materials, prebatched in 55-gal drums in an adjacent material storage shed, are transported and transferred onto the skip hoist by fork truck. In a significant departure from conventional cupola configurations, charge materials can also be introduced at the tuyere level in front of the plasma torch. A feeder system, consisting of a vibrating storage bin connected to a calibrated screw conveyor, is capable of continuously feeding variable and controlled quantities of borings and turnings. These materials enter the cupola by gravity flow, assisted by a small flow of gas from the recycle loop. The chip feed system, which is supplied by a bucket and overhead crane, can also be used for introducing other granular materials, such as coke breeze and sand.

The key component of the plasma-fired cupola system—the torch—replaces the conventional cupola tuyere. Large industrial cupolas would use multiple torches symmetrically arranged around the cupola shell, but the test unit requires only one Westinghouse MARC-11 torch (Figure 2). This is a water-cooled, nontransferred arc dc torch with copper electrodes and a nominal rating of 1.5–2.0 MW (e). The torch is powered and controlled by one of four 5-MW (e) thyristor-controlled power supplies available at the Waltz Mill facility. During actual operation, a relatively small quantity of plasma air (typically 100 ft^3/min; 0.047m^3/s) flows through the torch; however, additional blast air can be supplied and mixed with the plasma torch air flow in a special mixing chamber between the torch and the interior of the cupola. (Special refractory and water-cooling designs were developed for this connection.) For added flexibility, nitrogen can also be fed through the torch and/or into the special mixing chamber.

Figure 1 The plasma-fired cupola pilot plant allows charging of feed materials both at the top of the cupola and at the tuyere level in front of the torch.



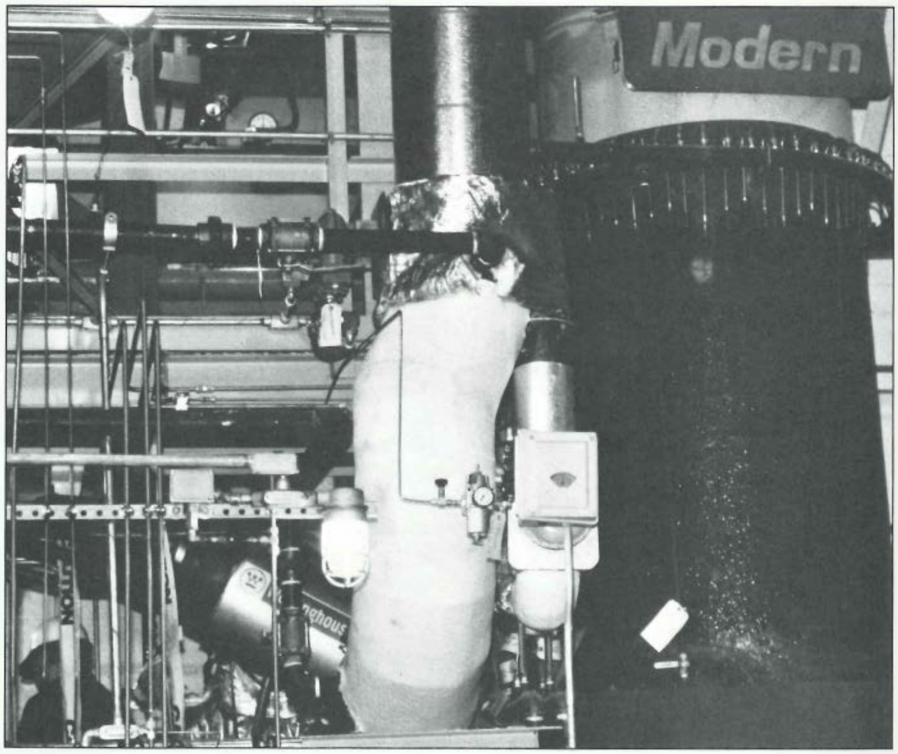


Figure 2 Plasma-fired cupola test unit. Heat is supplied to the process by a Westinghouse MARC-11 plasma torch, visible to the left of the cupola.

Also unique is the test unit's gas recycle loop, which withdraws variable amounts of cupola top gas just below the charge door, removes the larger particulate matter, and reintroduces the gas to the melting process at the torch-cupola junction. Operation of this loop, which is optional for specific melts, provides an alternative source of thermal diluent gas to mix with the small but extremely high-temperature flow from the plasma torch. Unlike the diluent air used in so-called hot-blast cupola operation, the recycle gas consists almost entirely of carbon monoxide and nitrogen; this provides a nonoxidizing atmosphere that dramatically reduces the consumption of coke and precludes excessive metal loss due to oxidation when processing charge materials having high ratios of surface area to volume. Use of the recycle loop also reduces the top gas flow rate to the air pollution control devices to a small fraction of its typical value.

Another feature of the test cupola system worth noting is its extensive instrumentation, which includes a gas analysis system, a Hewlett-Packard data acquisition system, and a Numa-Logic programmable controller. The controller is needed to accommodate the numerous control parameter interlocks and emergency shutdown procedures that ensure safe operation.

Project results

After a 12-month phase of process design (supported by limited bench-scale tests), detailed engineering, equipment procurement, and field construction, the test cupola was commissioned on schedule in November 1984. As of the middle of August 1985, the test unit had logged 14 successful operating test heats, all but one consisting of a 10–12-h operation during which a 4–5-h test melt period was obtained. (The remaining time was required for startup and shutdown procedures.) These tests were supplemented by one extended operation over a two-day period to demonstrate longer-term operation and provide a better indication of equipment and refractory performance.

Much additional analysis remains to be done to translate the mass of test data into industrially significant conclusions. However, it is already apparent that the plasma-fired cupola significantly outdistances coke-fired cupolas in its ability to process loose borings and turnings. Following the initial addition of chips to the primary charge (in heat No. 3) and at the torch (in heat No. 5), tests rapidly confirmed that low wind rates in the plasma-fired cupola greatly enhanced the system's chip-handling characteristics. Progressively greater quantities of unbriquetted chips were processed in successive test heats, culminating with the demonstration (in heat No. 11 and, on an extended basis, in heat No. 13) of the unit's ability to handle 75% of the total metallic charge in the form of borings and turnings at the charge door.

Although chips have also been injected successfully at the torch-tuyere level, results with this option thus far have been mixed. As initially conceived, melting large quantities of chips with the cupola's recycle loop in operation would prevent oxidation of the fine metal and thereby ensure good metal yield. To be successful, however, such operation requires clean chips (chips free of the oil and grease used in machining operations). Prior testing by others on the use of recycle operation in conventional cupolas has shown that such hydrocarbons, if present on the feed material, tend to dissociate or crack at the high process temperatures, producing free hydrogen that could build up in the recycle loop and create an explosion risk.

In an effort to avoid this, the initial tests used chips that were nominally (though incompletely) cleaned prior to being fed to the cupola; however, hydrogen buildup was still experienced. This does not necessarily mean that melting commercially available loose chips is incompatible with recycle operation when the chips are fed through the charge door. In larger cupolas, the distance between the charge door and the recycle take-off could allow sufficient contact time for the hot stack gases to drive the hydrocarbons off the chips before they reach temperature levels that would promote hydrogen generation. Confirmation of this would require additional testing. However, given the results achieved in heats 11 and 13 (both involving up to 75% chips without recycle), there may be no incentive for using recycle operation to enhance chip melting. Yield loss in those heats was only a few percent, representing primarily the amount of oil and dirt on the chips. Conventional cupolas processing chips in briquetted form can experience losses of 10–15% due to oxidation.

In addition to the successful chip-melting operations, considerable progress has been made in confirming that sand can be used to enhance silicon pickup. Limited testing to date, with the cupola in both the recycle and the nonrecycle modes, has confirmed that the high temperatures achievable with the plasma torch enable the cupola to reduce sand (98% SiO_2) to silicon. Additional testing is required to quantify this phenomenon and to determine the extent to which it is enhanced by recycle operation and/or by the manner in which the sand is introduced into the cupola.

The tests also verified several other anticipated benefits of plasma technology.

- Operation at metal-to-coke ratios as high as 70:1 (conventional cupolas typically operate at around 10:1)
- Productivity improvements of up to 50% due to the high-temperature hot-blast capabilities of the plasma torch
- Consistent and rapid control of melt temperature by varying the torch power level (response time of 3–4 min)

An overall assessment of the economic value of the above benefits in actual foundry operations is now being done by applying the results of the test program to case study analyses of existing production cupolas covering a broad range of foundry types and environments. Additional testing is also being planned to explore the use of alternative reductants, like coal, in place of metallurgical coke. Initial success in using anthracite (heat No. 14) suggests that significant incremental savings in this area are likely. *Project Manager: Alan Karp*

R&D Status Report
NUCLEAR POWER DIVISION

John J. Taylor, Vice President

SEISMIC HAZARD, EASTERN UNITED STATES

Concern about the seismic design of nuclear plants in the eastern United States was heightened in November 1982 by a clarification of a previous licensing position by the United States Geological Survey, which acts as principal adviser to the Nuclear Regulatory Commission (NRC) on seismic hazard issues. The clarification involved the technical basis within the current regulation for considering large historical earthquakes in assessing seismic hazard. In response to this change, NRC developed a plan to assess probabilistic seismic hazard at all 75 nuclear generating plants east of the Rocky Mountains. To develop an independent methodology for use by industry, EPRI initiated a seismic hazard project in August 1983, with joint funding by EPRI (RP2356) and the newly formed Seismicity Owners Group (SOG). The strategic objective of the EPRI study is to achieve a stable basis for probabilistic seismic hazard evaluations for the eastern United States by building on pioneering NRC-sponsored research. EPRI will also be working with NRC to gain acceptance of probabilistic seismic hazard procedures for future application.

The term *seismic hazard* is generally taken to mean a quantitative description of expected ground shaking from future earthquakes. Proper assessment of this important design parameter is difficult and time-consuming and has become a major impediment to the timely, cost-effective licensing of nuclear power plants. Extended disagreements over acceptable levels of seismic hazard caused abandonment of at least seven nuclear generating projects at advanced stages of site development and licensing. In each case, the years of delay in resolving these disagreements created tremendous financial burdens that made it uneconomical to continue.

Why do earthquakes have such a severe effect on licensing? The explanation is found in both their potential for damage and our limited understanding of their causes. An earthquake is one of the most severe natural hazards and is very difficult to predict. In the United States the limitations on predictability are greatest east of the Rocky Mountains, where the relationship between earthquake occurrence and geologic features of the Earth's crust has not been generally established.

Earthquakes—West and East

In the western United States, most large earthquakes have occurred on major faults in the Earth's crust. Typically, these faults are characterized by geologic evidence of movement (often abundant) and the associated occurrence of frequent, small earthquakes. Large earthquakes also have been recorded east of the Rocky Mountains. Unlike those in the West, however, none has been associated with large-scale faults identified at the Earth's surface; in fact, only the very large earthquakes that occurred in southeast Missouri in 1811–1812 have been clearly associated with faults in the subsurface.

This lack of surface faulting associated with large, eastern earthquakes is only one manifestation of the fundamental difference between seismic activity in the East and West. For example, earthquakes occur almost a hundred times more frequently in the West than in the East. However, the damage potential of an earthquake is significantly greater in the East because of low attenuation of seismic energy. This reduced attenuation in the East tends to nearly offset the lower frequency of occurrence. Thus, at the level of demonstrated safety required for nuclear plants, designing for earthquake hazard is a dominant concern on both sides of the Rockies.

Current regulations (10 CFR, Part 100, Appendix A) require that nuclear plant structures, equipment, and associated facilities important to safety be designed to withstand the maximum expected earthquake ground-shaking at a site. No consideration is given to occurrence frequency. This requirement has a major effect on the cost of siting, constructing, licensing, and operating the plants. It is estimated that seismic costs are now 6% of the total for plants in the eastern United States; for West Coast plants, the costs range up to 15% or more. Recurrent concerns about the safety of operating plants, however, can be of even greater impact. New hypotheses about geologic causes of earthquakes in the East appearing in the scientific literature often require costly reassessment of operating units.

Current regulations lack robustness to accommodate the uncertainties resulting from limited scientific understanding of earthquake processes. Yet the time scale required for regulatory decisions is significantly shorter than the time scale for developing the desired practical knowledge base. Decisions based on developing theory and limited information almost always include built-in margins to accommodate perceived uncertainty, with attendant costs. This situation has recently stimulated efforts to develop methods to quantify the probability of exceeding seismic design ground motions for nuclear plants east of the Rocky Mountains.

Probabilistic seismic hazard research for nuclear plant licensing was initiated by NRC in 1977 as part of the Systematic Evaluation Program (SEP); the methodology development was conducted by the Lawrence Livermore National Laboratory (LLNL). This initial method has been applied to determine the seismic hazard appropriate for assessing the seismic adequacy of eleven of the country's oldest plants, and additional NRC–LLNL research is currently being carried out to develop a second-generation probabilistic seismic hazard characterization methodology. SOG and EPRI are pursuing a similar goal in their joint program, launched in 1983. It is expected that these efforts will lead to a generic trackable methodology that will allow utilities to confidently assess seismic hazard in a timely and noncontroversial manner.

Probabilistic calculation methodology

Three basic inputs are required to perform seismic hazard calculations.

- The geometry of earthquake sources

- A model of earthquake occurrence (distribution of earthquake magnitude and occurrence in time and space) for each source

- An attenuation function for estimation of ground motion as a function of earthquake magnitude and distance

Given our knowledge about earthquake causes, these inputs are supplied by scientific interpretations based on experience.

The EPRI project captures and quantifies uncertainty in interpretations through a modeling structure (Figure 1). To reduce unquantified scientific bias, interpretations are made by six multidisciplinary earth science teams, each including a geologist, a geophysicist, and a seismologist. To reduce uncertainty caused by uneven data and information, a national geologic, geophysical, and seismologic data base has been compiled specifically for this study and made available to each of the six teams. Each team's interpretations are captured in a two-tiered logic structure that permits scientific uncertainty and data uncertainty to be expressed independently. The teams' interpretations and the assessed probabilities form the basic input for seismic computations.

To generate the input, the earth science teams first specify earthquake source geometries and parameters of the earthquake occurrence model for each source. They then assess the probability that each source is the true origin of earthquakes and consider dependencies among sources. Seismic energy attenuation functions appropriate for the region of the site are also specified in this step.

The second step identifies the earthquake source zones that contribute to the site's seismic hazard. Earthquake source zones in the vicinity of a site dominate its seismic hazard. Because seismic energy attenuates with distance from the source, source zones beyond a certain distance will not contribute to the hazard. Source zones that do contribute to a site's seismic hazard depend on applicable seismic energy attenuation functions (which vary regionally) and on the source's maximum earthquake.

The third step calculates the probabilistic seismic hazard at a specified site for each contributing earthquake source. To capture the uncertainty in interpretations, all variations in source parameters established in step 1 are incorporated at this stage. Source-by-source hazard computations are made separately for each earth science team.

Dependencies among sources are established in step 4 by considering interdependencies among earthquake generating structures in the Earth's crust. For example, if two structures in the crust cannot be active in the same stress field, this fact becomes a part of the source analysis. The flexibility of this ap-

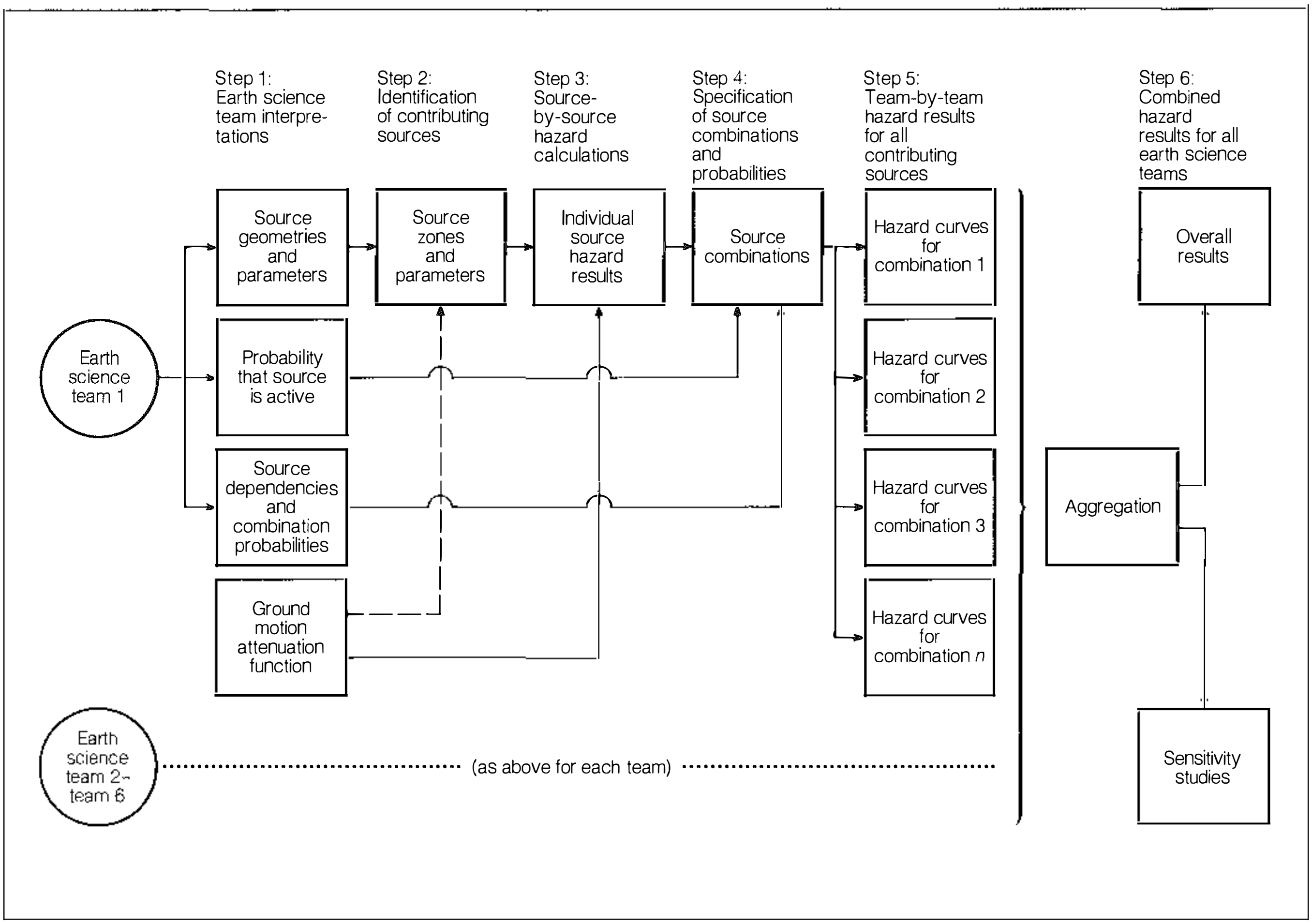


Figure 1 EPRI's probabilistic calculation methodology for assessing the seismic hazard at a particular site is based on scientific interpretations (by six earth science teams) of the parameters outlined in step 1. Step 2 identifies the contributing earthquake source zones, and the probabilistic hazard for each source is calculated in step 3. Dependencies among sources are established in step 4. In step 5 the hazard is computed for each source combination and all source variables; this yields a series of hazard curves for each source combination. The team-by-team results are aggregated in step 6 to obtain the combined seismic hazard for the site.

proach allows the earth science teams to make source zone interpretations in any degree of complexity. Thus their interpretation uncertainty is expressed as alternatives with associated probabilities of a source being the true local origin of earthquake activity.

Probabilistic seismic hazard at a site from all contributing sources is obtained in step 5 by aggregating the source-by-source hazard results. Aggregation is based on the earth science team's assessed probability that each source is active. Dependencies among sources are also expressed as probability statements. For each team's interpretations, the seismic hazard at a site is the weighted sum (weighted by assessed source probability) of the source-by-source marginal hazard for all contributing sources in the combination. For each source combination, hazard results are obtained for all possible combinations of source parameters (recurrence model parameters and maximum magnitude) and seismic wave attenuation functions. This approach allows evaluation of the dispersion in hazard results caused by an earth science team's determinations.

In the final step, the team-by-team combined hazard results are aggregated to obtain the estimated site hazard and its uncertainty. Aggregation at this step is accomplished by weighting each team's combined hazard results either by assigning the teams equal weights or by team self-weighting. Final seismic hazard results for a site are presented as fractile curves (Figure 2). These curves represent the range of uncertainty in seismic hazard as a function of the range of alternative interpretations of all six earth science teams. The variables include earthquake source interpretation, source combinations, source occurrence model parameters, source maximum magnitude, and regional seismic wave attenuation functions. Similar results can also be presented team by team to show uncertainty in hazard estimates for each team individually.

Underpinnings of the approach

The EPRI project has made significant scientific advances in probabilistic seismic hazard methodology. Because the causes of earthquakes in the eastern United States are not well known, the distribution of earthquake sources is necessarily interpretive and based on experience. Interpretations for the EPRI study specifically included all competing hypotheses for earthquake causes in the East that appear in the scientific literature. In this sense, the interpretations capture the current state of scientific knowledge. To express completely the total uncertainty, earthquake source interpretations are made independently by the six earth science teams. Discipline bias is avoided by requiring at least one experienced geologist, geophysicist, and seismologist to serve on each team. Regional bias is avoided by requiring each team to generate interpretations for the entire eastern United States.

A formal structure was developed that permitted each team to assess a probability that a seismic source is the true origin of local earthquake activity. The structure further permitted each team to express uncertainty in its interpretations so that the effects of limitations in scientific knowledge about earthquake causes and characteristics can be differentiated from the effects of data limitations. The method also allows specification of dependencies among sources in terms of probabilities.

All interpretations are based on a comprehensive geologic, geophysical, and seismologic data base compiled specifically for this program. The data have been subjected to a number of analyses and enhancements. For example, the standard historical earthquake catalog was carefully evaluated to eliminate errors and extraneous entries (such as explosions), and a uniform measure of size was established that includes an estimate of error. The geophysical data were also processed to emphasize the distribution of material properties of the Earth's crust at depths below 10 km, where larger earthquakes are expected to be generated. The comprehensiveness of the data base, together with the extensive analyses performed on it, provides a consistent basis for interpretations. This aspect of the program enhances scientific confidence in the interpretations. It also provides a visible and traceable basis for review and evaluation of the program results.

To model the statistical occurrence of future earthquakes within a source, new techniques have been developed and applied that advance the state of the art in the use of historical earthquake catalogs. First, magnitudes of earthquakes in the catalog were estimated by using a statistical procedure that included an error estimate.

Second, procedures were developed to correct the catalog for incompleteness. Reporting varies with time, and the variation is a function of earthquake size, location, distribution of recording networks, and standard reporting practices. A method developed to account for these effects allows the use of a large data source heretofore generally unused in earthquake hazard evaluations.

Third, the probability distributions are fitted to the historical earthquake catalog for each seismic source with a statistical procedure that accounts for error in magnitude estimates. The occurrence distribution parameters are allowed to vary in space within a source according to the spatial distribution of historical earthquakes. This flexibility offers a great advantage in representing variations in earthquake occurrence over large source zones. It can be used, for example, if historical activity is believed to be indicative of the local relative rates of occurrence of future events. It can also be used to specify spatially uniform activity within a source region.

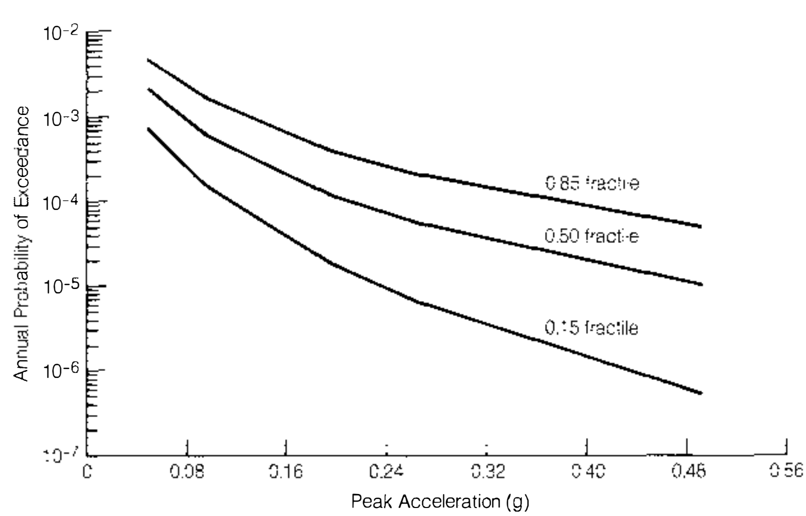


Figure 2 Results of the seismic hazard analysis can be presented as fractile curves that represent the annual probability of exceeding a given peak acceleration value at a selected site. The 0.50 fractile is the median estimate, and the 0.15 and 0.85 fractiles approximate a standard deviation on the median.

Testing and review

The EPRI methodology has been used to evaluate seismic hazard at nine nuclear plant sites. The test computations are based on regional-scale earthquake source interpretations provided by the six earth science teams. The test results do not include site-specific interpretations. Therefore they are considered appropriate mainly for self-consistency testing and for comparative evaluations of the methodology.

SOG will pursue the following during the remainder of 1985.

- Peer review of the methodology by a group of eminent scientists
- Comparative evaluation of the calculations made by NRC–LLNL and by SOG–EPRI at the nine test sites in order to delineate sources of differences
- Preparation of a generic seismic hazard methodology report for submittal to NRC

It is anticipated that NRC will review the generic seismic hazard methodology report during 1986 and prepare a Safety Evaluation Report. Thus by January 1987 utilities could have an NRC-accepted methodology for assessing the seismic hazard at sites in the eastern United States. In the longer term, EPRI plans to work with NRC to accomplish revisions of Appendix A to 10 CFR 100. The availability of a technically sound method for determining the seismic design basis should markedly reduce one source of licensing delay. *Project Manager: Carl Stepp*

FLAWED-PIPE INTEGRITY ANALYSIS

EPRI has evaluated flawed austenitic stainless steel pipe for continued service and worked to incorporate research results into the ASME Boiler and Pressure Vessel Code. Earlier changes to the code included procedures for evaluating flaw depths exceeding 10% of the pipe wall thickness, which was then the maximum acceptable depth. These revisions showed that crack depths of up to 75% of the wall thickness were allowable under certain conditions. More-recent code changes reduced the range of applicable piping materials, particularly flux weldments and cast piping susceptible to toughness degradation from thermal aging. The work is applicable to all light water reactors and fossil fuel plants.

EPRI work on cracked austenitic stainless steel pipe accelerated in the late 1970s when increasing incidence of intergranular stress corrosion cracking (IGSCC) in boiling water reactors brought additional funding from the BWR Owners Group for IGSCC research. One EPRI assignment was to determine the margin of safety remaining in a flawed pipe and the time a flaw took to grow to the allowable size limit. Growth rate data would give plant owners time to plan an orderly shutdown and would minimize pipe repair outage time.

Three questions needed answers: (1) What is the critical flaw size (i.e., the size at which pipe failure will occur)? (2) How much time is available before the crack reaches this size? (3) Will an undetected crack result in a detectable stable leak or an unstable pipe break (leak before break)? The answers to these questions lie largely in the area of fracture mechanics, the discipline that considers the failure of flawed material at loads below the limit load of the flawed cross section, but they also required crack growth rate tests in simulated reactor water, determination of crack-opening area, prediction of flow rates through tight (and not-so-tight) cracks, and calibration of leak detection instrumentation.

This status report discusses critical crack size. Earlier *EPRI Journal*s (May 1981, pp. 45–56; May 1983, pp. 58–60) reviewed the other issues. Details appear in EPRI final reports.

Critical crack size

Research showed that flawed austenitic stainless steel wrought and cast pipe failed by plastic collapse. Failure occurs when the net pipe cross section (the section reduced by the cracked area) forms a plastic hinge. Crack geometry then may be related to loads and material properties by simple tension and bending equilibrium equations from which tables of allowable flaw size can be constructed by using appropriate factors of safety on load. Researchers devised tables for axial and circumferential flaws, and the results were incorporated in Section XI of the ASME Boiler and Pressure Vessel Code in the 1983 Winter Addenda as tables IWB-3641-1 through IWB-3641-4. The tables are appropriate for pipe, pipe fittings, and associated weld materials made of wrought stainless steel, Ni-Cr-Fe alloy, or cast stainless steel with ferrite levels of less than 20%.

Earlier, at NRC's meeting on light water reactor safety in November 1981, researchers presented fracture toughness data from a cast stainless steel flux weldment that showed significantly lower toughness than the base pipe material. This did not appear to be relevant to the development of flaw evaluation procedures discussed above because the weld material's ferrite content made it immune to IGSCC.

However, anticipating potential problems, in early 1982 EPRI started a test program at Westinghouse Electric Corp.'s research laboratories to determine the fracture toughness of tungsten-inert-gas (TIG), submerged arc (SA), and shielded metal arc (SMA) weldments. The results of these and other tests showed that TIG weldments exhibited toughness about equal to that of the base piping material but that the SMA and SA flux weldments were generally less tough (Figure 3). These data became significant in late 1983 when cracks were found in repair welds and in other welds where stress corrosion cracks had grown from the base material into the weldment.

To determine whether cracked weldments could reach the limit load that was the basis of the Section XI flaw evaluation procedures, EPRI used elastic plastic fracture analysis procedures developed in other EPRI programs to compute the load-carrying ability of the flux weldments. The calculations showed that weldments were not likely to reach limit load and that failure might occur by unstable ductile tearing at loads of about 80% of limit.

Working with the code groups and NRC, EPRI revised procedures for evaluating flux welds (Figure 4). Researchers used elastic-plastic fracture mechanics to compute the ratio of the load that produced unstable crack growth to limit load. Then they used the reciprocal of this ratio to increase the code table load ratio for the base material (determined from plant stress reports) by an amount that

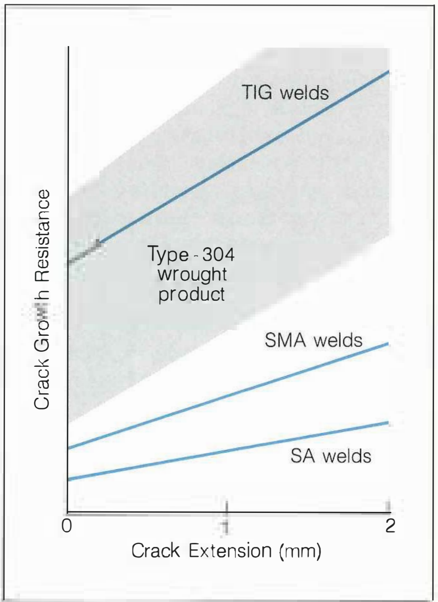
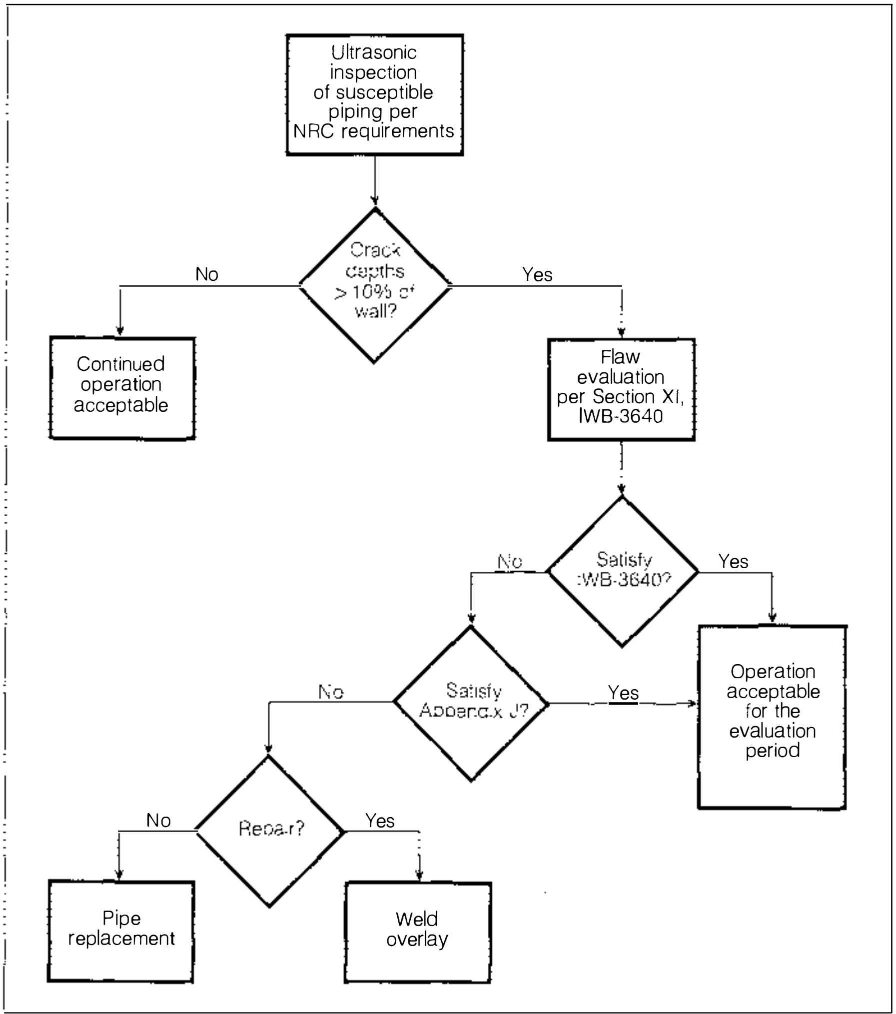


Figure 3 Relative weldment toughness at 550°F (288°C). The crack growth resistance increases with the crack extension that results from increased load. The SMA and SA flux welds have less resistance than do the base metal (shaded band) and the TIG welds.

Figure 4 Flaw evaluation procedure. A flaw exceeding 10% of the pipe wall thickness may be accepted for continued service if it satisfies conditions specified in Section XI, IWB-3640, of the ASME Boiler and Pressure Vessel Code. A flaw failing to meet these criteria may still be acceptable if it satisfies the criteria of Appendix J to Section XI.



represents the flux weld's reduced load-carrying capacity relative to limit load. This procedure increases the operating load determined from the stress report and reduces the allowable flaw size.

Researchers simplified this methodology into two new flaw size tables for evaluating flux weldments, IWB-3641-5 for normal and upset conditions and IWB-3641-6 for emergency and faulted conditions. These two tables were added to the code in April 1985. Appendix C of Section XI, which was prepared in connection with EPRI's original work, describes the procedure and use of the tables.

Because of the lower ductility of the weldments, the code group required use of thermal expansion stress in flux weldment evaluation, limited allowable flaw depth to 60% of the pipe wall, and redefined the weld volume to address flaw sizing uncertainties. Aged cast stainless steel may be evaluated as wrought product if the plant owner can demonstrate the failure mechanism is plastic collapse.

EPRI is currently working on Appendix J to Section XI, which will allow plant-specific evaluation of flaws found unacceptable by the conservative procedures discussed above. Code action on this appendix is planned for this year. The project team is also preparing tables for ferritic piping analogous to those discussed above for austenitic steels. This work proved to be more difficult because of the wide spectrum of toughness properties exhibited by the carbon steel pipe used by the nuclear industry. EPRI has been studying carbon steel for the past year (RP2457-1, -2). A summary report has been prepared for RP1757-51 that contains code copy for consideration by the appropriate code committees in late 1985. *Program Managers: Douglas Norris and Robin Jones*

New Technical Reports

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

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

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Contractor: Kerr-McGee Corp.
EPRI Project Manager: C. Kulik

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EPRI Project Manager: C. Kulik

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