Materials Frontiers

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Corporate Communications Division

Graphics Consultant: Frank A. Rodriquez

Address correspondence to:
Editor in Chief
EPRI JOURNAL
Electric Power Research Institute
P.O. Box 10412
Palo Alto, California 94303

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Cover: Alloying of metals is one example of how materials are modified to achieve desired properties. A greatly magnified photo of an advanced nickel-chromium alloy shows its exquisite microstructure. (Photo courtesy Lawrence Livermore National Laboratory)

EDITORIAL

A Broadening Perspective on Materials

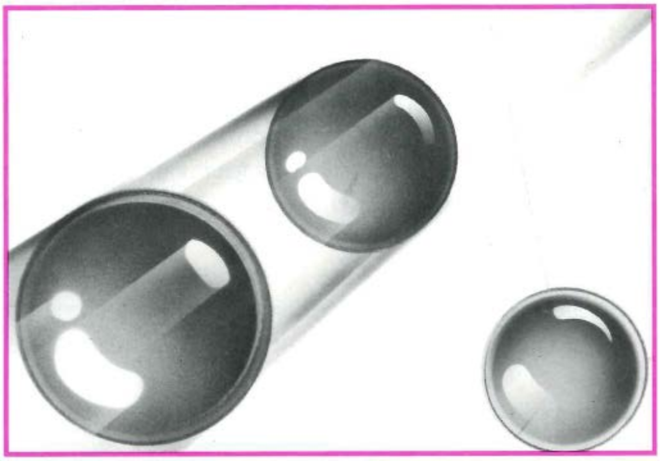
The recent surge of interest in superconductivity, spurred by an unexpected discovery of unique properties in a class of rare earth ceramic oxides, reminds us of the fundamental importance of materials across the full spectrum of technology in the production, delivery, and use of electricity. High-temperature superconductors are just one of many seminal advances in materials that have brought or promise significant improvement in the performance or cost of power generation or electric-powered technology. New formulations of steels and specialty alloys, space-age semiconductors, synthetic polymers, and other advanced materials have all played important roles and remain central to continued progress.

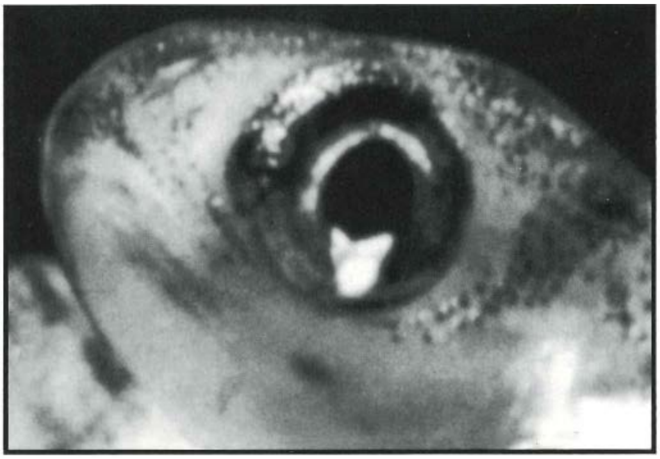
In fact, most of the technical challenges in the engineering of modern power system apparatus and industrial technology ultimately come down to basic questions involving the limits of available materials and the potential of new materials for breakthroughs. As this month's cover story outlines, materials research is at the heart of electric utility industry efforts to design advanced coal-burning power plants, nuclear reactors, megawatt-scale semiconductor electronics, advanced turbine blades, and economical solar cells, to name just a few.

Reflecting a broad social and scientific recognition of the fundamental role of materials on the cutting edge of technology, an interdisciplinary field of materials science and engineering has emerged in recent years that encompasses the diverse subfields within a framework that recognizes the need for cross-fertilization and the sharing of scientific insight. EPRI has incorporated this broadening perspective on materials in a newly established program in exploratory research. Materials topics of particular emphasis include high-purity steels, structural ceramics, and power semiconductors. Applications of improved superconductors will be assessed to determine how this exciting technology can be channeled into electricity generation, delivery, and storage.

One of the lessons of the recent breakthroughs in superconductivity is that materials advances are a dynamic force in technology development. Discovery and innovation on the materials level is an evolutionary, iterative process that can lead down many unforeseen paths, opening doors where previously there seemed an immovable limit. A continuing commitment to basic materials research is essential to a society that seeks to extend the frontiers of today's technology.

John Stringer
Technical Director, Exploratory Research





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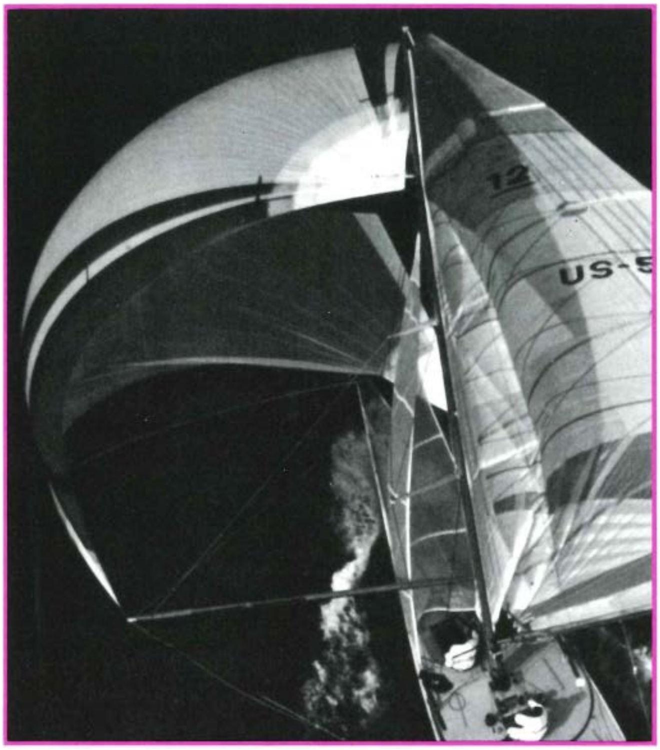
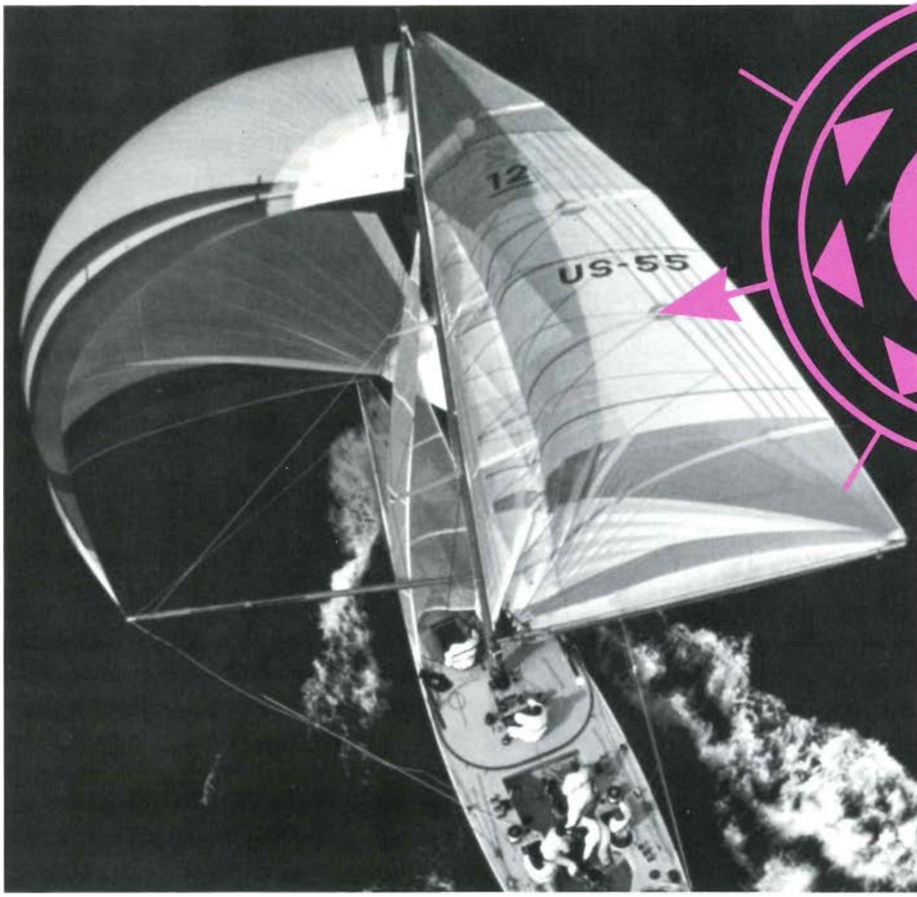


4 Materials

16 R&D Benefits


EXPLORING THE FRONTIERS OF MATERIALS



(Photo © by Daniel Forster/Duomo)

Science and engineering are expanding the four frontiers of materials research—strength, temperature, corrosion, and conductivity—to meet the demanding performance requirements of high technology.

Around 7000 years ago, Phoenician sailors are believed to have produced the first manmade glass, quite by accident, when it flowed from the coals of a riverside cook fire that was supported by blocks of soda from a cargo hold. When the greenish rivulet cooled, the stuff resembled the shiny, black chunks of obsidian that more-primitive peoples had prized for over 60,000 years and had shaped into arrowheads, cutting tools, and jewelry. It would be some 4700 years later before an artisan learned that similar glassy material could be made and worked into a useful form with the help of an iron blowpipe.

Today, amorphous or glassy materials remain one of the hot topics in the interdisciplinary field that has come to be called materials science and engineering, which includes amorphous silicon-based semiconductors and metal alloys that totally lack crystalline structure.

These days, fortunately, the time scales connecting discovery to invention to application are not nearly so protracted as in ancient history. Innovative new products made of amorphous metals are today a commercial reality, following on fundamental insights in the 1930s that were not conclusively and practically demonstrated until 1960.

In fact, most of modern civilization's edifices, tools, and consumer goods are based on materials discovered in recent decades. Quantum physics in the 1930s illuminated the potential for semiconductors, paving the theoretical road for the invention of the transistor in 1947 and the microelectronic integrated circuit in 1959. Metallic superalloys that today offer exceptional strength, as well as superior resistance to stress and chemical attack at high temperature, first began to emerge as a family of novel nickel-based alloys in the 1950s. The coherent light of a ruby-crystal laser first appeared around 1958, laying the foundation for today's fiber-optic communications and the search for improved photonic materials.

Apart from glass, ceramic materials have probably been used by man for over 10,000 years since an anonymous soul found that a pot fashioned from clay and baked in a covered fire would later hold its shape and contents even when reheated. Purdue University's Gerald Liedl pegs this dubious date as the beginning of materials technology, the first "intentional transformation of an inorganic natural material into a new material displaying novel properties."

Today, among other uses, ceramics form the insulation packaging around microelectronic components, give a sharper edge to "new stone age" scissors and knives, and provide the extra kick of acceleration in advanced automobile engine turbochargers, already available to car buyers in Japan. Auto makers on both sides of the Pacific, meanwhile, seem in an off-and-on race to develop almost totally ceramic engines that will run much hotter, possibly with no cooling, and be more fuel-efficient than today's models. Ceramics is also the category of materials from which an amazing new class of rare earth–based superconducting compounds are emerging that can conduct electricity with zero resistance loss at relatively high temperatures.

Advances in materials science and engineering are at the heart of nearly all technologies that pace economic productivity, from industrial technologies to biomedical science to electronics to weapons systems to transportation to energy conversion. They include the quest for new materials that bring unique or previously unattainable properties of interest to practical reality. But increasingly, materials research is focused on advanced methods of processing and fabricating existing materials so as to achieve characteristics by design.

"A fundamental reversal in the relationship between humans and materials is taking place. Its economic consequences are likely to be profound," note Joel Clark and Merton Flemings, both professors of materials science and engineering at the Massachusetts Institute of Technology. "Historically, humans have adapted such natural materials as stone, wood, clay, vegetable fiber, and animal tissue to economic uses. The smelting of metals and the production of glass represented a refinement of this relationship. Yet it is only recently that advances in the theoretical understanding of structural and biologic material, in experimental technique, and in processing technology have made it possible to start with a need and then develop a material to meet it, atom by atom."

Technology transfer and feedback

Although the diversity of materials in key economic sectors—metals, ceramics, semiconductors, polymers, and now composites—makes generalizations difficult, a few are worth venturing despite the exceptions to any rule.

One generalization is that discovery or development of new materials often results from intense scientific and industrial pursuit of great leaps forward in performance. This helps explain why many materials innovations have grown from weapons research, defense systems development, and the space program, where performance, not economy, is the guiding goal. Eventually, advances in materials in one realm cascade into others as industrial engineers adapt them to new markets and commercial realities.

Development of the jet engine during the Second World War provides one example. "When the first aircraft turbine was produced around 1940, it just barely ran and didn't last very long," explains John Stringer, until recently head of a materials R&D support group at EPRI and now technical director for exploratory research. "To make it into a real propulsion system it was necessary to undertake an intensive materials development program for quite some time. The development of higher-temperature materials paced the development of the aircraft turbine, which, in turn, has paced the technology of land-based turbines for power generation."

Similarly, much of the genesis of microelectronic materials can be attributed to defense requirements for more compact, miniaturized, and highly reliable command, control, and communications systems. And today, the Strategic Defense Initiative is spurring further leaps in semiconductors, superconductors, and lasers.

Another broad generalization is that there is a trend toward specialization in materials development—that is, new materials with specific properties are sought as an answer to specific application problems. For example, alloying iron with small amounts of carbon produces steel, which is harder and stronger than the base metal alone; development of improved steelmaking processes revolutionized construction in the nineteenth century. It also kicked off a string of alloying improvements that has led to an almost limitless range of choices for modern industry; nickel was added for even greater strength and shock resistance. The addition of chromium opened up a whole family of stainless steels, with greater toughness, corrosion resistance, and heat resistance. Today iron is alloyed with over a dozen elements in different proportions to produce other characteristics important for particular applications—improved hardness, stability, machinability, ductility, resiliency, and weldability, among others.

But just finding the right chemical composition is not the end-all of materials development. The question of what is now being augmented with the question of how, as researchers inquire more deeply into the potential benefits of advanced materials processing and fabrication technologies. Again, steel provides a wealth of examples. Higher purity can be achieved through such processes as secondary refining in electric ladle furnaces; because impurities and nonmetallic inclusions are greatly reduced, steels with nickel, chromium, molybdenum, and vanadium achieve exceptional strength and greater resistance to heat and corrosion. For other applications, a different approach

Materials Footnotes Through History

Humans have been making productive use of the materials around them since before the Stone Age, but materials science didn't really take off until the early nineteenth century, when it was spurred by the demands of the Industrial Revolution.

8000	Hammered copper
7000	Clay pottery
6000	Silk production
5000	Glass making
4000	Smelted copper
4000–3000	Bronze Age
3200	Linen cloth
2500	Wall plaster
2500	Papyrus
1000	Iron Age
300	Glass blowing
20	Brass alloy
105	Paper
600–900	Porcelain
1540	Foundry operation
late 1500s	Magnetization of iron demonstrated
1729	Electrical conductivity of metals demonstrated
1774	Crude steel
1789	Discovery of titanium
1789	Identification of uranium
1800	Volta's electric pile (battery)
1824	Portland cement
1839	Vulcanization of rubber
1850	Porcelain insulators
1850s	Reinforced concrete
1856	Bessemer steelmaking
1866	Microstructure of steel discovered
1866	Discovery of polymeric compounds
1868	Commercial steel alloy
1870	Celluloid
1871	Periodic table of the elements
1875	Open-hearth steelmaking
1880	Selenium photovoltaic cells

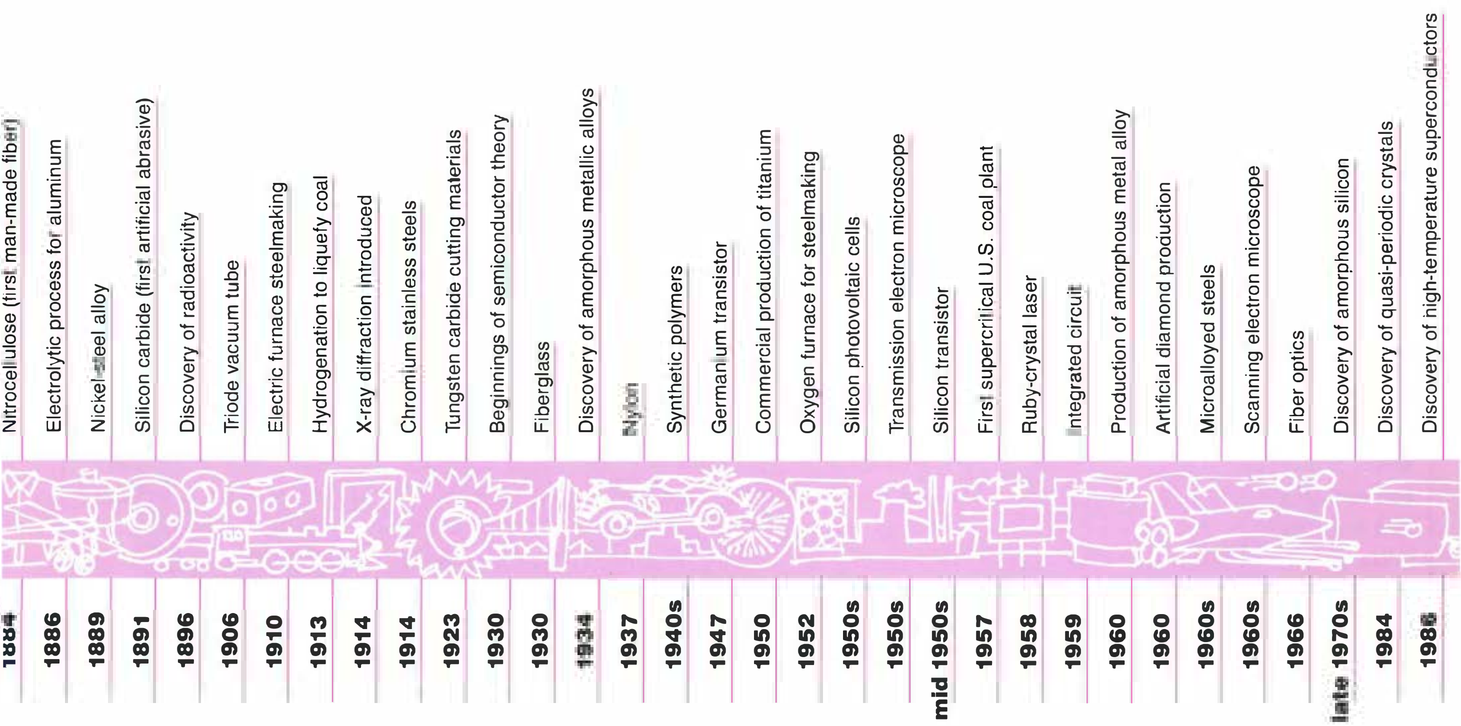
to corrosion resistance might be used: hot isostatic pressing and powder pack diffusion make it possible to achieve good corrosion resistance by applying a thin coat of a superalloy onto a conventional steel that has otherwise desirable mechanical properties.

Directional solidification, an innovative technique now being used to make aircraft turbine blades, produces long crystals in the metal that are oriented parallel to the stress direction for greater resistance to cracking, creep, and elongation from high centrifugal forces. Research on rapid-solidification processes has led to the manufacture of amorphous metals that lack crystal structure entirely and thus exhibit valuable magnetic properties.

These latter examples highlight the real frontier of materials research implied earlier by Clark and Flemings—complete manipulation of a material's characteristics. This means not only adding properties that are desirable but also getting around other natural properties that were long thought to be unavoidable limitations to a material's use. As mentioned, crystalline structure is one of the problems being ingeniously sidestepped in the metals area. For ceramics—porcelain, glass, tile, and a wide range of industrial refractory materials—most research is aimed at overcoming a more popularly recognized generic shortcoming, brittleness. Ceramics simply crack easily, often catastrophically and unpredictably in industrial environments.

Interest in overcoming this problem is heightened by the unique suitability of ceramics for many high-temperature applications; some forms remain stable at temperatures of 2500°F or more, where most structural metals would oxidize or melt. Research is moving toward ceramic matrix composites laminated with various types of fibers to arrest the growth of microcracks. Such ceramics as silicon carbide, silicon nitride, and oxides of zirconium are among the chief targets of interest. New chemical routes to synthesis, such as sol-gel methods, are being pursued for greater control over the microstructure of the starting material.

Brittleness is also considered one of the principal obstacles in developing



useful forms of the complex rare earth barium copper oxides that are showing tantalizing signs of superconductivity at near room temperatures. The superconducting properties of these materials are also highly sensitive to oxygen content, which can be affected by high-temperature processing. "Probably most of these difficulties can be overcome by the skills of modern materials science and engineering, but this will take a great deal of time and effort," according to John Hulm, director of corporate research at Westinghouse Electric. At the moment, however, experiments with the new compounds are outrunning the theory to explain how and why.

Polymers are perhaps the most versatile of all modern materials. Their variety of forms is impressive, including such staples of modern civilization as rubber, styrofoam, all types of plastic, glues, paints, photographic film, nylon, Kevlar, and other synthetic fibers. Expanding knowledge of the interaction between structure, properties, and processing methods is leading to polymers with unprecedented qualities.

The seemingly infinite versatility of polymers derives from the custom-tailored nature of both bulk and molecular material. These are essentially large molecules, built up from smaller molecular chains. Varying the chains and how they are linked permits the formation of a microstructure that may be amorphous or semicrystalline, uniform or inhomogeneous. Chemically distinct and separate chains can be formed to make thermoplastics, which soften when heated for easy molding and extrusion. Alternatively, the molecular bonds can be made to cross-link into extremely tight chains so the material does not deform at high temperature, a problematic characteristic of early plastics.

As research continues, new properties are being developed that promise to open up entirely new areas of application for polymers. Incorporation of double-bonded aromatic chains as fibers spun from the liquid-crystalline phase can give some polymers a tensile strength comparable to steel. Other, transparent polymers that approach optical perfection are a focus of photonic materials research for fiber-optic communications. Although polymers have traditionally been used as electrical insulators, scientists have found some forms that when doped with such impurities as arsenic pentafluoride, exhibit conductivities approaching those of metals.

Perhaps the advanced materials area of greatest importance to the economy is that of electronics, where the steady rise of functional power in information and communications systems will continue to depend directly on materials advances. Advanced semiconductors, such as gallium arsenide, are the subject of intensive research because they offer processing speeds 10 to 100 times faster than achievable with today's silicon microcircuits. Soon, high-speed logic chips may have more than 10,000 transistors imprinted on them, while memory chips storing up to 16 million bits of information are nearing reality. Yet obtaining near-perfect crystals of gallium arsenide is proving even more difficult than obtaining crystals of silicon.

Quite apart from their use today in microprocessors and memory devices, semiconductors are now also being pursued as solid-state lasers; unlike silicon, gallium arsenide can emit light with the right doping and thin-film architecture. Sophisticated optical sensors, meanwhile, are proliferating, leading to new streams and sources of data that some experts envision will eventually require optical computers to process.

Even the veteran transistor, which blazed the trail to microelectronics before it was upstaged by the integrated circuit, is the subject of advanced materials research. Scientists are now tentatively growing transistor materials in virtually one step from molten silicon and metal, opening the way to cheaper, more powerful transistors.

Utility research

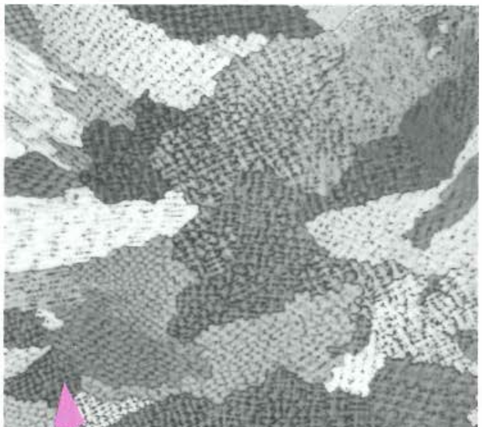
The barriers to performance that materials science and engineering seeks to break through are all central to utility operations: temperature, pressure, corrosion, fatigue strength, conductivity—even high-speed data transmission. These frontiers of materials research cut across all lines of technology used by electric utilities, and advanced materials will most likely find important niches in many areas. Some are already entering utility use, others are under active engineering development, while plenty more are still gleams in the eyes of scientists and researchers. Together, they suggest a glimpse of how the business of generating, transmitting, and using electric power may be substantially transformed in the decades ahead.

In the 1970s utilities generally retreated from supercritical operation at coal-fired steam units because of reliability problems tied to the limits of metallic materials that were then available. Advanced metals will permit a return to supercritical steam conditions and higher operating efficiencies in these plants. In one significant advance, a class of modified 9% chromium martensitic steels containing trace amounts of niobium, nitrogen, and vanadium for high-temperature strength have been qualified for use in the advanced pulverized coal plant EPRI is helping design under an international collaboration with utilities and boiler and turbine makers. They will replace conventional ferritic steels in areas ranging from superheater/reheater tubes to pipes to heavy-section castings. The steels were originally developed by Oak Ridge National Laboratory and Combustion Engineering in the

The Menace of Moisture

Corrosive deterioration is the seemingly inevitable result when moisture meets metal. The threat is particularly extreme in the high-temperature, corrosive environments characteristic of power plants, although milder conditions can also be problematic; the Statue of Liberty suffered considerable corrosion damage over the years just from exposure to the weather. The primary approach to fighting corrosion in industry has been to use corrosion-resistant alloys rich in such metals as chromium or titanium. Nonmetallic materials may takeover in many corrosion-prone applications as new composites, high-temperature plastics, and high-strength ceramics are developed. Use of protective coatings, both metal and nonmetal, can also be effective; a number of organic and inorganic coating materials have been tested for use in power plant scrubbers, including sprayed-on silicate cement, fluoroelastomers, vinyl esters, and reinforced epoxies.

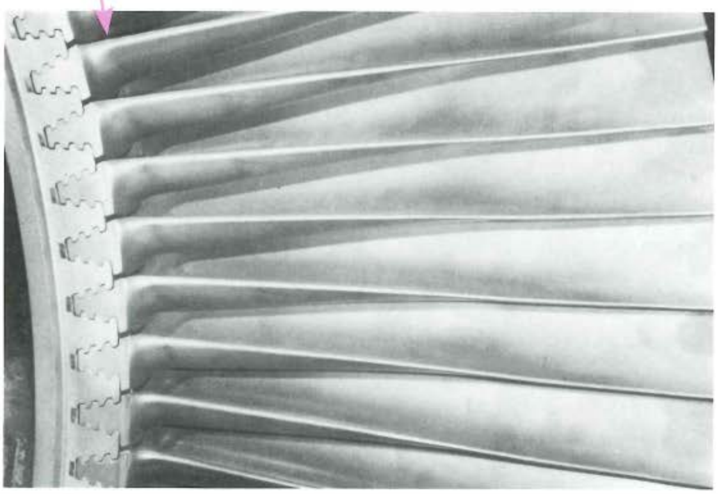
Nickel-chromium alloy microstructure



(Photo courtesy Lawrence Livermore National Laboratory)

Common corrosion (Photo by Ron May)

FRONTIER: CORROSION



Corrosion-resistant titanium steam turbine blade

(Photo courtesy AP/Wide World)

Statue of Liberty prior to restoration

mid 1970s for piping liquid sodium in breeder reactors.

Farther downstream from the boiler in the advanced coal plant, steam turbine blades are a major area of materials focus. Titanium alloys could virtually eliminate corrosion-induced fatigue in low-pressure steam turbine blades. EPRI and Westinghouse recently qualified the titanium alloy Ti-6Al-4V (containing 6% aluminum and 4% vanadium) in next-to-last-row blades for low-pressure turbines, completing a 10-year materials application effort. The Japanese and the French are developing last-row blades of titanium, which offer increased turbine power because they can be used in longer lengths than conventional 12–13% Cr stainless steels.

In another approach, blades made of directionally solidified single crystals of superalloys may put an end to grain boundary cracking from creep and thermal stress. For gas turbines operating at temperatures up to 2300°F, EPRI is funding a pioneering effort to develop single-crystal superalloy blades by adapting the Czochralski crystal growth process now used in making silicon semiconductors. Robert Jaffee, a metallurgist and senior EPRI technical adviser, is managing experimental work at Unisil, a Silicon Valley firm, to apply the Czochralski process, in which a single crystal is pulled from the melt in a crucible.

"If we can eliminate the grain boundaries in a blade machined from a single crystal, we will eliminate cracking," says Jaffee. He adds that this cross-fertilization between metallurgy and semiconductor materials production represents "the kind of opportunities we look for. Most new developments are really transfers from one technology to another." Jaffee notes that electron-beam heating, now used extensively for scrap recovery in metals production, is being eyed by silicon crystal producers in an EPRI project for improving the Czochralski process, completing a technology transfer loop from silicon to metallic single crystals and back to silicon.

Superclean steels made by secondary refining techniques could make temper embrittlement of turbine rotors or neutron embrittlement of nuclear reactor pressure vessels problems of the past. Nearly a decade of laboratory-scale work funded by EPRI has identified a superclean low-alloy specification for low-pressure turbine rotors. Embrittlement caused by manganese and silicon in conventional low-alloy steels currently limits LP turbines from operating above about 650°F. The new superclean steel is completely resistant to temper embrittlement over the range of 700–1000°F. With manganese and silicon held to 0.02–0.05%, it has also proved tough, ductile, and even stronger than steels of conventional purity. "Secondary steel refining techniques using ladle furnaces and vacuum degassing make it possible to melt steel with virtually no impurities and containing only the intended composition," explains Jaffee.

Following successful trials of 34-ton rotors made from the superclean steel, EPRI funded follow-on work at Japan Steel Works to produce the superclean steel for more-uniform yield strength. Meantime, Toshiba has made four production-size rotor forgings of the steel for use in supercritical steam plants in Japan. EPRI is actively seeking to apply the steel as a retrofit material in a U.S. utility plant in advance of the time it could show up in future units. In addition to use as turbine rotor material, superclean steels could also be applied in future chemical and nuclear reactor pressure vessels.

In contrast to advanced structural metallurgy, where much of the focus is on single-crystal metals and manipulating grain orientation, many frontiers in electrical and electronic materials are targeting amorphous (noncrystalline) forms of metals and ceramics for their unique properties. After nearly a decade of EPRI support at one of the leading technology firms in metallic glasses, Allied-Signal has produced a major materials breakthrough for power transformer cores. Ribbons of metallic glass spin off a high-speed casting wheel as molten alloy cools at a rate of a million degrees per second. A utility-scale 500-kVA power transformer with an amorphous steel alloy core is now being tested in actual utility use, as are a thousand 25-kVA distribution transformers, now commercially available. Amorphous metal technology promises to cut typical transformer core losses by 75%.

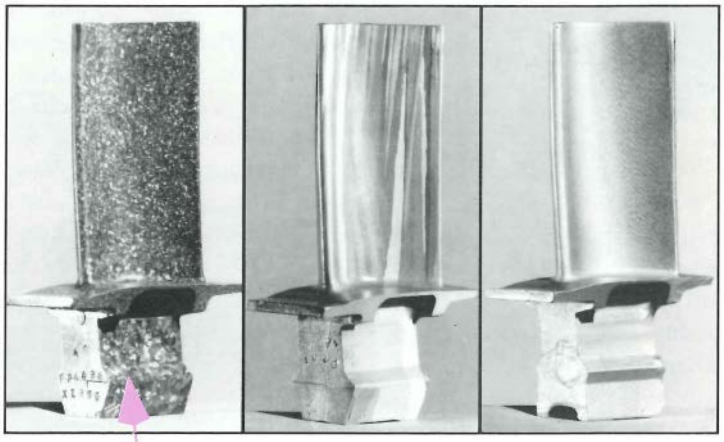
Amorphous forms of semiconductors offer a route to low-cost, moderately efficient photovoltaic cells. Rather than being grown as a crystal, thin films of silicon only a few atoms thick can be laid down on a substrate by plasma and chemical vapor deposition techniques. Amorphous silicon now forms the thin-film transistor arrays that drive liquid crystal computer displays. Meanwhile, intense materials research in hyperpure, single-crystal silicon is being pursued by EPRI for high-efficiency utility photovoltaics and for very high current power system applications, such as metal oxide thyristor–controlled solid-state switching devices and circuit breakers. In the future, such large-scale semiconductor switching devices will instantly route and control power flows and, possibly under the guidance of superconducting supercomputers and fiber-optic data communications, maintain something of a real-time spot market for electricity across large regions of the country.

Utilities are already installing fiber-optic communications links between generating plants and control centers. Some are entering the telecommunications business, stringing fiber-optic connections along their power transmission rights-of-way. Because virtually any physical phenomenon—heat, radiation, magnetism

A Herculean Challenge

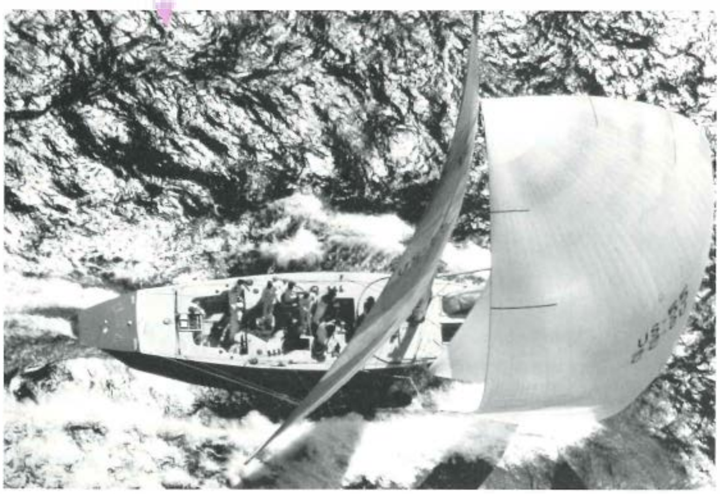
Improvements in material strength in the past century have quite literally changed the shape of modern society. Skyscrapers simply could not be built before there were steel superstructures to hang them on. Suspension bridges, a clear triumph of innovative design and material strength, have become leaner and more streamlined over the years as higher metal strength-to-weight ratios have been achieved. But improvements have not been confined to metals; high-strength polymer fibers many times stronger than steel are replacing other materials in dozens of applications, from bullet-proof vests to medical prostheses to the sails used in the America's Cup–winning yacht Stars & Stripes. Utility industry research to develop exceptionally strong superalloys for key components is focused on improved purity and new production techniques, such as directional solidification and the creation of large single metallic crystals.

Conventional turbine blade | Blade produced by directional solidification | Single-crystal blade

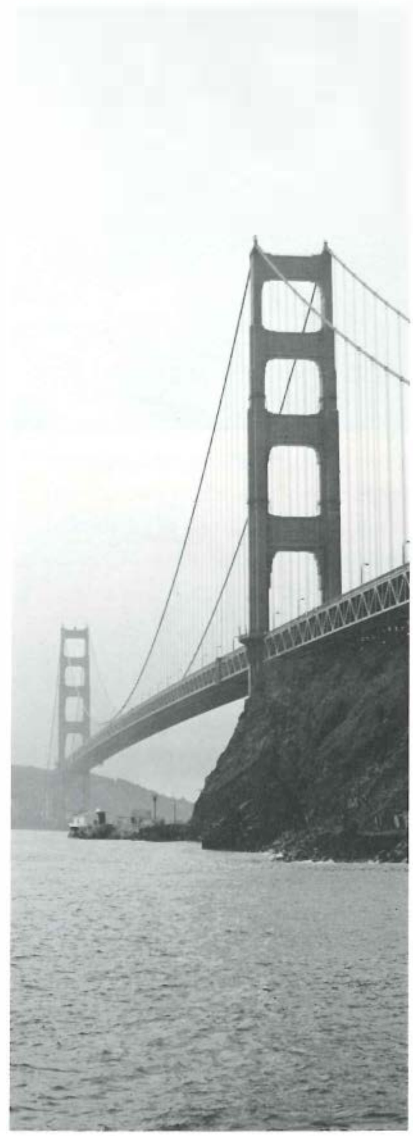


(Photos courtesy Pratt & Whitney Aircraft/United Technologies Corp.)

FRONTIER: STRENGTH



The Stars & Stripes (Photo © by Daniel Forster/Duomo)



(Photo by Ron May)

Golden Gate Bridge, opened 1937

Putting the Heat On

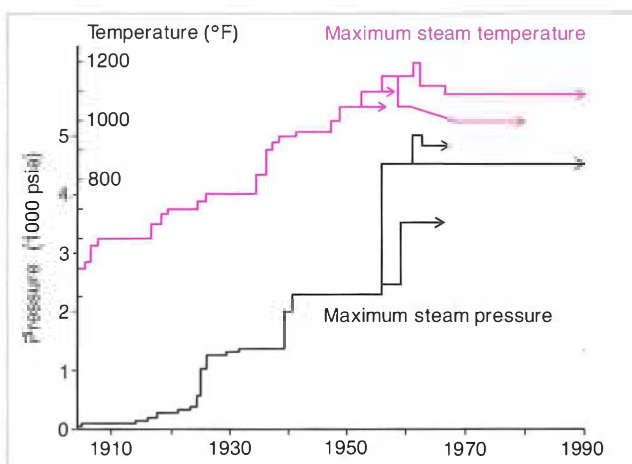
The search for higher efficiencies has meant higher temperatures for all types of power-producing devices, from truck engines to utility power plants. Boiler materials were unequal to the temperature and pressure demands of the early supercritical steam plants in the sixties, leading to severe reliability and availability problems; advanced metal alloys are now reestablishing the supercritical option for coal-fired plants of the future. Low temperatures can be a problem, too. The carbon steel used in the famed Liberty ships of World War II sometimes cracked at the welds when subjected to cold ocean waters. One of the greatest challenges in designing the space shuttle was to develop advanced ceramics and composites that could weather both extremes of temperature—the cold of space and the white heat of reentry.

Diesel-engine truck (Photo by Ron May)

NASA space shuttle *Discovery*

FRONTIER: TEMPERATURE

World War II Liberty ship (Photo courtesy The Bettman Archive)



Fossil fuel steam history

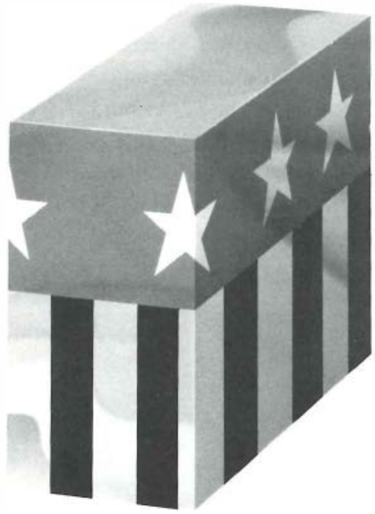
Materials on the National Agenda

An estimated 20,000 pounds of nonrenewable, nonfuel mineral resources are processed on average each year for every person in the United States. Production of primary materials directly involves some 1.5 million workers, plus another 3 million to 4.5 million whose jobs in other sectors also depend on materials. The value of shipments of advanced materials—mainly in the aircraft, aerospace, electronics, and automobile industries—has been estimated at $70 billion annually, or about 14% of total materials shipments in this country. That puts the value of the overall materials component of the American economy at about $500 billion, or over 12% of 1985's $4 trillion gross national product.

Increasing per capita consumption of materials has been one of the hallmarks of economic growth since the Industrial Revolution. But analysts note a classical demand cycle in the leveling off of consumption for most basic materials, including steel, cement, and paper.

The trends are attributed to several factors: substitution of a better material for an existing one, design improvements that use less material, saturated traditional markets, and new consumer markets involving products with a relatively low materials content. Together, they suggest a shift is under way toward high-technology products characterized by a lower materials content per dollar of value added, such as high-strength and corrosion-resistant alloys and specialty chemicals.

There are numerous signs that American industry is adapting to the changes, using advanced materials



processed and fabricated with state-of-the-art technology into products with special niche markets. In the case of steel, for example, although the total tonnage of steel produced has declined in recent years, the use of specialty alloys designed for specific purposes is in ascendancy.

Issues of materials research policy and funding have attracted increasing attention from Congress and the science policy community in recent years. Approximately $1.2 billion is earmarked for materials R&D in the federal government's proposed 1988 fiscal year budget, down slightly from the current year, according to an analysis by the Federation of Materials Societies.

"The fact that materials undergird the nation's economy and defense is reflected in the range of R&D activities. Examples include programs aimed at developing new materials and improving materials processing for advanced energy systems, the National Aerospace Plane, and the Strategic Defense Initiative; supporting university-based materials research laboratories; increasing research on production and performance characteristics of advanced ceramics, composites, and polymers; expanding the engineering science base in such technology-driven fields as mechanics, structures, and materials engineering; and understanding the effects of gravity on materials processing," the federation notes.

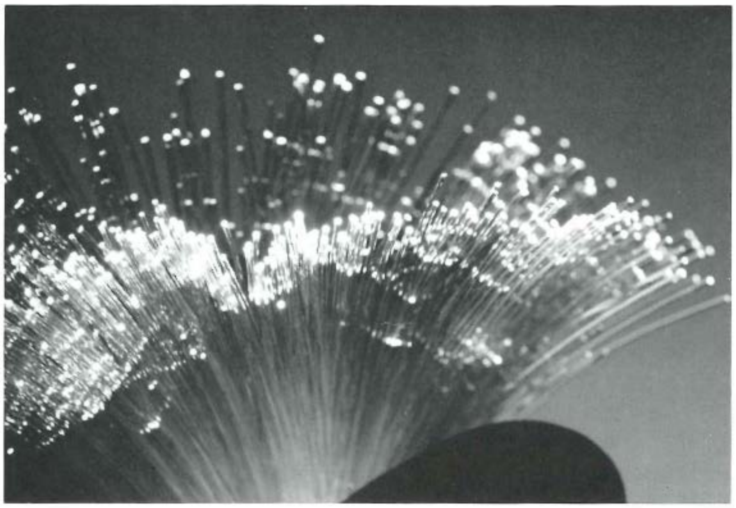
The Department of Commerce has identified a group of emerging technologies in the areas of advanced materials, electronics, biotechnology, automation, and computing that it says American industry must master by the turn of the century if it is to successfully compete with foreign manufacturers. Key materials areas include superconductors, polymer composites, optical electronics, and advanced microelectronics.

Momentum reportedly is building for expanding federal involvement in the development and commercialization of long-term, high-risk technologies through increased funding of cooperative research with industry, universities, and other private organizations. Materials R&D areas likely to be in the focus include superconductors, advanced ceramics, and submicrometer-circuit computer chips. The National Science Foundation has plans for new university-based centers in materials science, along with others in computer and information sciences, biotechnology, and social and behavioral sciences. The emergence of an active Materials Research Society is seen as further evidence that professional as well as corporate and federal attention and resources are converging for a renewed national R&D commitment to materials science and engineering. □

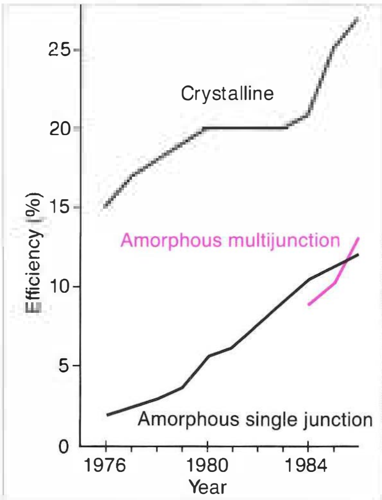
New Paths for Electrons and Light

The importance of electric power and communications in the modern world has sparked fresh interest in materials that conduct electricity and light. Of particular interest to utilities are advanced solar cells, whose high sunlight-to-electricity efficiencies have resulted in part from advances in crystalline and amorphous silicon materials. Other glassy, amorphous materials are revolutionizing communication by speeding information along transparent optical fibers at the speed of light. Meanwhile, scientists around the world are in a race to engineer and perfect a new family of superconductors made of ceramic oxides that can transmit or store electricity with no resistance losses. Even plastics, long used as electrical insulators, have shown indications of good electrical conductivity under certain conditions—a prospect that could have a tremendous impact on the technology of the future.

Fiber-optic strands (Photo © by Jon Feingersh/Uniphoto)



Silicon Photovoltaic Cell Efficiencies



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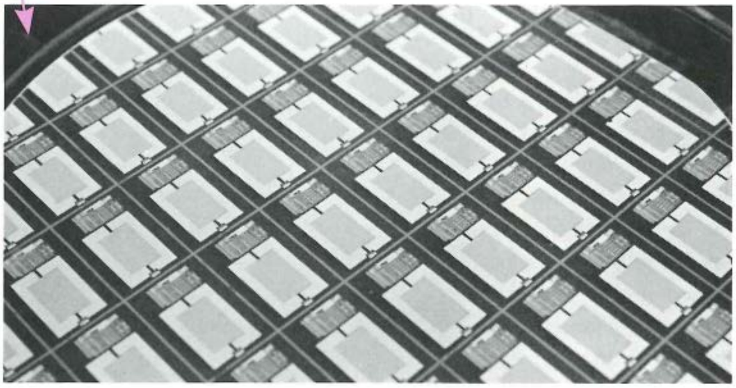
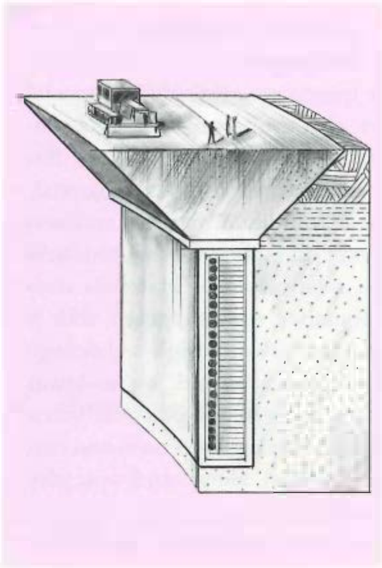


Photovoltaic concentrator cells (Photo by Ron May)



Underground superconducting energy storage coil

—can be made to alter the flow of light through an optical fiber, researchers are interested in the possibilities of placing fiber-optic sensors in such diverse places as along transmission lines, inside nuclear reactors, or in electrical gear for detecting minute changes in key conditions.

Data from such sensors might be collected and transmitted almost instantaneously—specifically, at the speed of light—and become part of a larger data/electron flow between and among utility plants, substations, and control centers. EPRI recently initiated an applications study of fiber-optic sensors and last September conducted the first conference for utilities on the possibilities for optical voltage/current measurement technology for power systems.

Successful development of the new high-temperature ceramic superconductor materials could bring profound changes in the utility industry. Power from generating plants may someday be temporarily stored in giant superconducting magnet coils. When it is needed, this electricity could be carried hundreds of miles by superconducting transmission cables with no losses to electrical resistance.

The changes promised by superconductors and advanced data transmission are so sweeping that it is easy to lose sight of the many important materials improvements being pursued in smaller components and systems. For example, ceramic-based catalytic combustors similar in concept to those on most automobiles may provide a solution to nitrogen oxide emissions in gas turbines. Porous ceramic filters for hot gas cleanup may be key elements of pressurized fluidized-bed coal plants. And other hot section parts like turbine inlet vanes may also eventually be made of reinforced ceramic matrix composite materials, permitting higher operating temperatures and efficiencies.

More-stable and longer-lasting anode, cathode, and electrolytic materials are being developed for advanced batteries and fuel cells. Efforts continue in the development of a more efficient molten carbonate–based successor to the phosphoric acid fuel cell, which is approaching full-scale utility application. Sodium-sulfur mixtures and zinc compounds still hold hope of someday becoming the basis for advanced deep-cycle, high-capacity batteries for utility load leveling.

Polymers are also receiving increased attention at EPRI. The emergence of polymer-based concretes in the 1960s led to the development by EPRI of Polysil—a superior insulator now being commercially manufactured as a substitute for ceramic porcelain. Other ceramiclike, chemically bonded polymer concretes may eventually encapsulate nuclear waste with exceedingly low rates of leaching. One of the more recent niches for polypropylene is as a film sandwiched in paper—PPP cable insulation, developed largely under EPRI auspices over the last 15 years—that will cut the cost and size of conventional underground utility lines.

Extending the boundaries

From the mundane to the exotic, from steel to silicon and beyond, materials help propel science and engineering beyond the present boundaries of understanding to improve or even revolutionize products, systems, and everyday activities. "The dominant materials of a decade ago are being supplemented or replaced by new superior combinations. Computer modeling is improving designs. A materials science and engineering revolution is under way that will be a key factor in determining the outcome of global economic competition," Philip Abelson, deputy editor of *Science* magazine, wrote recently.

MIT's Clark and Flemings sound a similar note. "In addition to meeting needs, materials science and engineering creates opportunities and provides society with new ways to address such problems as the scarcity of resources, the maintenance of economic growth, and the formation of capital. Productivity and the structure of the labor force are also profoundly affected by advances in the field. For industrial, financial, and government leaders, the definition and implementation of strategies that exploit opportunities created by materials science is a central challenge of the last quarter of the century."

Materials research is one of the foundations of modern electric power, and there is every reason to believe that as many materials advances await in the future as have been achieved in the past. The frontiers are much the same, but the new horizons promise developments we have not yet imagined. ■

Further reading

Various authors. "Frontiers in Chemistry: Materials Science." *Science*, Vol. 235, No. 4792 (27 February 1987), pp. 953; 997–1035.

T. W. Eager. "The Real Challenge in Materials Engineering." *Technology Review*, Vol. 90, No. 2 (February-March 1987), pp. 24–35.

P. J. Steinhardt. "Quasicrystals." *American Scientist*, Vol. 74, No. 6 (November-December 1986), pp. 586–597.

Various authors. "Materials for Economic Growth." *Scientific American*, Vol. 255, No. 4 (October 1986).

E. D. Larson, M. H. Ross, and R. H. Williams. "Beyond the Era of Materials." *Scientific American*, Vol. 254, No. 6 (June 1986), pp. 34–41.

R. I. Jaffee. "Materials and Electricity." *Metallurgical Transactions A*. Vol. 17A (May 1986), pp. 755–775.

Materials for Large Land-Based Gas Turbines. Final report for RP2382-1, prepared by National Research Council, March 1986. EPRI AP-4476.

Ceramics for Electric Power Generating Systems. Final report for RP2608-1, prepared by SRI International, January 1986. EPRI AP-4380.

National Academy of Engineering. *Advancing Materials Research*. Washington, D.C.: National Academy Press. 1986.

M. A. Meyers and O. T. Inal, eds. *Frontiers in Materials Technologies*. Amsterdam: Elsevier. 1985.

G. G. Libowitz and M. S. Whittingham, eds. *Materials Science in Energy Technology*. New York: Academic Press. 1979.

This article was written by Taylor Moore. Technical background information was provided by Wate Bakker, Robert Jaffee, and John Stringer, Energy Management and Utilization Division, and Karl Stahlkopf, Nuclear Power Division.

R&D and the Utility Customer

All of us use electricity— it's an embedded benefit in most of what we use, what we do, and how we do it. The difficulty is pinning down how, when, and how much we gain specifically from utility R&D.

People in the business of research and development have always had an easy conviction about their work. Advancing the frontiers of science is seen as a worthwhile pursuit. Indeed, the explosive proliferation of science and technology has pretty much paralleled the birth and growth of the United States as a nation and a society.

But can specific benefits from R&D be traced to their ultimate recipients? Can electric utility customers, for example, identify and evaluate attributes or circumstances of their lives that flow from the R&D done by their utilities or by EPRI? Even when the question is considered only qualitatively, there aren't many answers. A major difficulty is that utility customers themselves aren't often vocal on the matter, and most of the answers come from surrogates.

One such surrogate is Grant Thompson, executive director of the League of Women Voters and a member of EPRI's Advisory Council. He's also a former environmental lawyer. "R&D is absolutely to the customer's benefit," he says. "Every power pole that lasts a few years longer, every transformer that runs cooler and more efficiently—these cut the cost of electricity."

But when asked what sense individual customers have of electric power R&D, Thompson answers flatly, "None. Most of us don't think about our electrical system at all—except when there's an outage or we get the bill."

Ashley Brown, a member of Ohio's public utility commission, echoes Thompson's characterization. The one time electricity users are motivated to consider costs in a thoughtful, even analytic, way is at commission hearings on utility rates. But according to Brown, the individual components of electricity cost don't draw their attention. "Of all the controversies there may be about utilities, the cost of R&D isn't one of them." He adds, however, "If ratepayers were pushed, if they were reminded of R&D, I'm sure they would say it's good, because it helps bring new products to market—products for utility use as well as their own."

Brown's work as a regulator is a reminder of why the subject of ratepayer benefit arises in utility management and R&D circles. The phrase is uniquely a buzzword there because regulation is the basis of electricity pricing. Regulation is invoked where franchised monopoly service makes practical economic sense, and it substitutes for the action of competitive factors.

Few communities remain today in which electric or other utilities directly compete, up one side of the street and down the other, for customer service connections. Instead, regulatory commissions operate somewhat mechanistically, using the most objective, rational means they can find to identify, evaluate, and analyze all the factors that would bear on a competitive market.

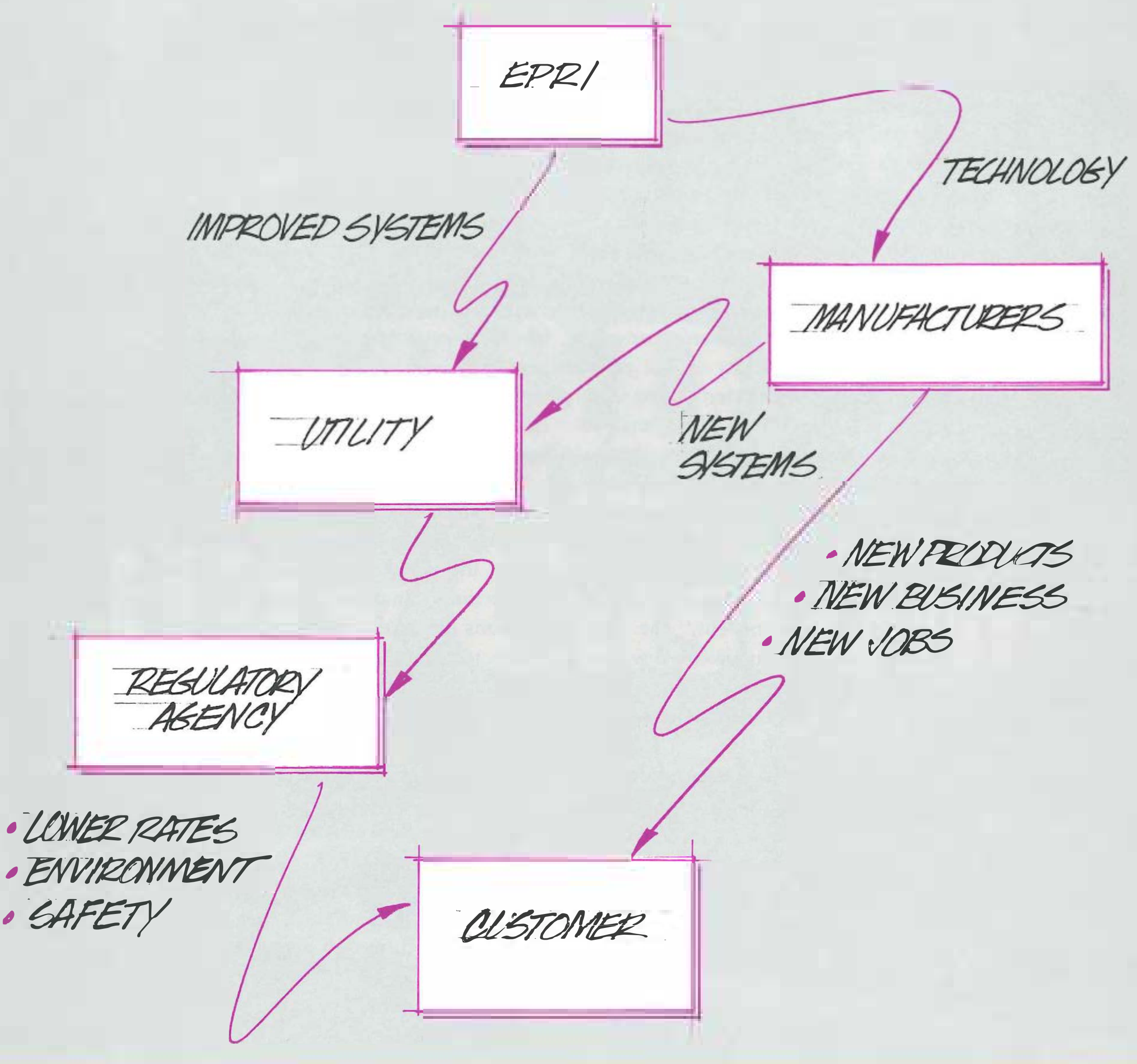
Motivation to cut costs

Bud Nelson, EPRI's Director of Regulatory Relations since 1980, was an Illinois state regulatory commissioner for nearly 11 years. During and since that time he has considered himself a student of the regulatory process. "I was a participant, of course, but at the same time always off to one side, looking."

Nelson is still looking, and in his fund

The Path of R&D Benefits

The benefits of centralized R&D flow to the customer through many pathways. Some flow through utilities in the form of technology improvements that lower the cost of producing and delivering electricity. Included in the rates, the cost of this R&D is validated by state and local regulatory bodies for the great majority of electricity consumers. Other research helps utilities reduce environmental effects and safety hazards that arise from power system operations; these improvements, also involving government regulation, are of widespread benefit to society as a whole. Somewhat less directly, benefits of EPRI R&D also flow through the economy in the form of technology that spawns new products, new jobs, and new and healthier businesses. Industry's profitable use of electricity is an engine of economic development, its electrical and electronic products easily visible and distinctive in their effects on our lives.



of experience he finds that all utility-supported R&D is beneficial to customers. For him, the conclusion is straightforward and purely logical. "Say a regulated utility applies the results of R&D and thereby cuts its expenses. Everything else being equal, the immediate benefit could go just to shareholders—but only until the next rate case." At that time, Nelson explains, the continued savings from use of the R&D act to lessen the impact of other utility costs that have crept up in the normal course of events. Rates may go up, but not as much as otherwise. Says Nelson, "Utilities can't keep windfalls, so there's customer benefit in holding costs down. That's the linchpin of the case for R&D, and the regulatory community understands it."

When inflation is a truly severe problem, Nelson observes, there's a good chance that utilities run below their approved rate of return much of the time. There isn't a windfall—only a smaller shortfall—as a result of the cost cutting made possible by R&D or anything else.

Utility operating expense isn't the only target for cost savings from R&D. Today, much more than in the past, both utilities and regulators look for opportunities to avoid capital investment. The reason is the outright higher cost of almost all equipment, plus—in the case of large power plants—interest costs that compound during very long construction intervals. There's a new appeal to any R&D that will extend existing power plant life, lend precision to the management of electricity demand, or improve the availability and reliability of power facilities. These circumvent, or at least defer, the tough, stressful choice between higher rates (from new plants) and the chance of energy shortages.

The focus on holding down costs draws a further remark from Nelson. "Publicly owned electric utilities, the municipal agencies and rural cooperatives, aren't under regulatory jurisdiction. But in a meeting of EPRI technical advisers from different kinds of utilities, you can't tell them apart in their approach to R&D matters. They're all service-oriented, they're all benefit-oriented, they're all cost-conscious."

Any doubt that customers reap the benefit of utility R&D most likely arises from uncertainty that the regulatory process ensures it or from concern that regulators themselves might be less than diligent in the matter. Indeed, EPRI's Nelson acknowledges a past time when R&D, and therefore its potential for reducing costs, probably was slighted by the electric utility and regulatory communities.

This was the explosive period of demand growth and utility expansion after World War II. Economies of scale and progressively lower fuel prices masked the "shortage" of R&D output, or even the need for it. New plants, seemingly guaranteed to produce still cheaper electricity, were added to the rate base when needed. But otherwise, utilities and their regulators believed that stability of the rate base was in everyone's best interest. "There wasn't any philosophical quarrel with science," Nelson says, "but long depreciation schedules and long plant lives were familiar and workable."

All these circumstances acted as an incentive against upgrading or replacing older plants. Their efficiency might not be the greatest, the argument went, but those plants were depreciated, paid for, and still operable, so leave them alone. "The perception was in fact wrong," Nelson admits. "It's wrong to structure things so as to work against innovation."

Nelson's conclusion emphasizes the departure in thinking that began with the environmental movement. If change was tentative at first, it was only because the new knowledge was unsettling. R&D is now seen differently by the utility world. It is a more purposeful pursuit than in the past. It is set apart from engineering departments. It is increasingly seen as an important lever for entering a new market or building a greater share of an existing market by cutting customer costs or utility costs, or both.

Value outside the rate structure

Is the benefit of R&D to customers ensured only by utility regulation? Nelson is quick to say no. "A good example is the quality of electric service. Good or bad, it doesn't directly result in a higher or lower rate. But because of R&D we have more-reliable power as time goes on—not only fewer outages but fewer fluctuations, less spiking, less danger not only to utility apparatus but to customer equipment too. Computers are the obvious example today."

Utility-sponsored R&D on the environmental impacts of power system operations is another instance of benefit that isn't measured in terms of kilowatthour cost. Indeed, much of the benefit goes beyond customers alone and is manifest across society in the form of lower health risks, reduced public expense, conserved resources of many kinds, and improved esthetics.

In fact, such widespread public benefit is probably what we most easily and quickly perceive. By its increasing presence and proliferating uses during the last 50 years or so, electricity itself has repeatedly seemed to be a technical marvel that just burst from a laboratory somewhere. Incremental improvements in how it is produced and delivered are mostly overshadowed.

Ohio Senator John Glenn, a depression child who became the first U.S. astronaut to orbit the earth, has spoken of this image of electricity in terms of his father's plumbing and heating business after electricity came to town back in the 1930s. "Pretty soon people were putting water systems in, and inside plumbing, and power to the barn to pump water. My dad suddenly was back in business again, helping to create some of that revolution of power coming out to the farm to replace muscle power. It revolutionized farming, and the Glenn household along with it."

Glenn's own later experience dramatized such technological progress. "I was the end product at one time of some of that kind of research. . . . I was on the peak of a rocket booster that had all this technological research behind it. With any piece of it missing, I wouldn't have been able to go—we wouldn't have gone into space."

Glenn's tributes illustrate how electricity and the R&D behind it are so easily seen to have wide-ranging influence on U.S. society, not just on the jobs and products of our economy but also on the values and aspirations of our culture.

Don Clodfelter manages Jackson County Rural Electric, a cooperative for electricity distribution in southern Indiana. Remarking on several examples of EPRI research applied by his utility, Clodfelter tries to put the value into dollars-and-cents terms. "Participation with EPRI really only costs about 25 cents per meter a month. And that's not really very much . . . about the equivalent of a cold six-pack a year."

The figure is startling, and it's essentially correct for an average per capita electricity use of about 1000 kWh a month, according to Lowell Endahl, manager of energy R&D for the National Rural Electric Cooperative Association (NRECA). Endahl believes people easily relate to the 25-cent figure because it's an individual measure. And they accept it, he says.

A year ago NRECA surveyed the user-members of rural cooperatives, asking among other things if they favored participating in R&D to help stabilize electricity rates. Endahl was surprised by the response: two-thirds positive, even with the qualifier that a small rate increase might be needed to begin with. "Ordinary consumers did better on the question. Directors and managers of the cooperatives were more conservative, more hesitant to spend money on research."

Speaking for customers

When electricity customers have a forum readily available and a little encourage-

The Theater of Research Benefit

Organized research has been one of the great engines of change in the twentieth century, and the benefits of R&D are now largely accepted as a matter of faith. This faith has largely been built on direct experience of change in our society—continuing emergence of new products and services and overall improvements in the standard of living. What Edison began 110 years ago continues to unfold. Beginning with illumination, electricity has delivered specialized heat, motion, sound, and information to every room. In the form of television and computers, it has in a sense delivered the entire world to our homes.

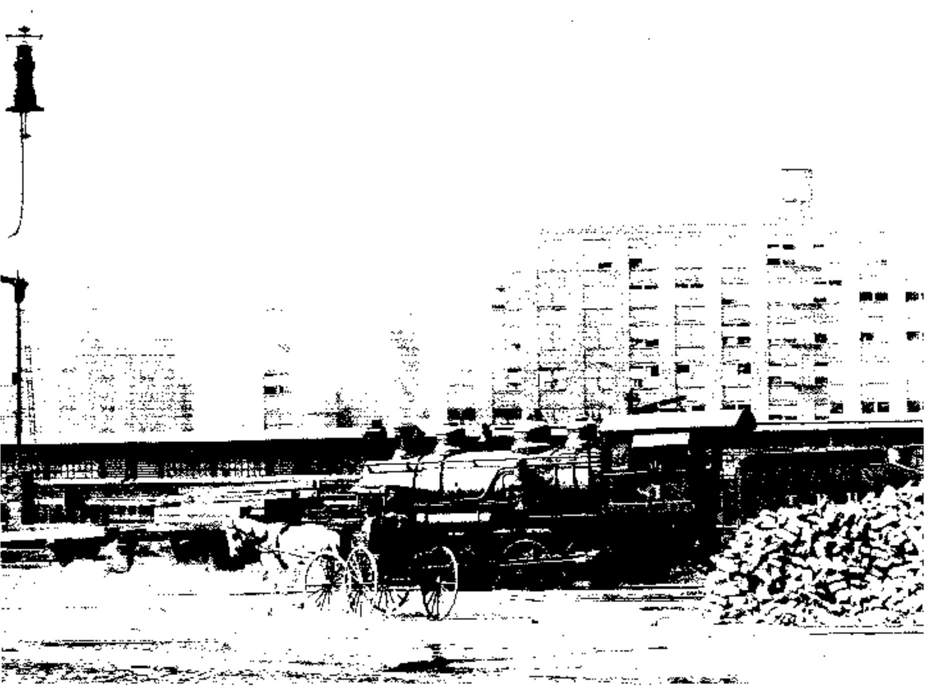


Photo courtesy The Bettmann Archive

ment to speak up, they become more sharply aware of R&D issues. Puget Sound Power & Light learned this a number of years ago, when it began sounding out opinion by means of consumer panels.

Brian Thomas, the R&D administrator for Puget Power, says, "There's intense interest, even wonder—that is, why don't we do more research?" Asked if the panels' volunteer advisers distinguish utility R&D from end-use or appliance R&D, he is equally emphatic. "Yes, very clearly. Fuel cells, for example. We got recommendations from two or three panels that we should be a leader in such research."

The Puget Power panels generally follow county lines in the utility service territory. Each panel has 12 to 40 members, invited by a local manager to serve for a year; during this term, the utility puts several issues before them, and the panel chooses which to pursue. Panels do their own legwork, or they may ask the Puget Power facilitator to round up information.

Thomas recalls being apprehensive when the panels were formed—"You know, afraid we'd be seen as self-serving. Well, some of our customers *aren't* happy about how we conduct the business at times, but they're delighted that we listen."

He cites a consumer panel that feels Puget Power should take a more active R&D role. It has recommended that the utility (1) form an R&D department that will go beyond just reviewing and adapting EPRI research results, (2) test products that can conserve electricity and report the results to customers, (3) look into the practicality of irrigation flume generators, and (4) monitor R&D progress in geothermal energy.

The attentiveness continues to catch Thomas's attention. "It's remarkable how much they really think about R&D, consider it, acknowledge it as part of our business. Their responses constantly emphasize research, innovation, creativity

—as if they want to see the things they read about in *Popular Science*."

Independent public interest and consumer organizations are another avenue to electricity customers and their view of R&D. National and local groups exercise a watchdog function on utilities, questioning many of their plans, practices, cost estimates, and rate structures.

Public Citizen, organized in 1971 by Ralph Nader, has many interests; its Critical Mass Project was begun in 1974 to focus on nuclear power questions. Joseph Kriesberg, an energy policy analyst on the project, says that energy conservation and demand-side energy management are among the main issues now engaging the group because these are where individual electricity user impacts seem most direct.

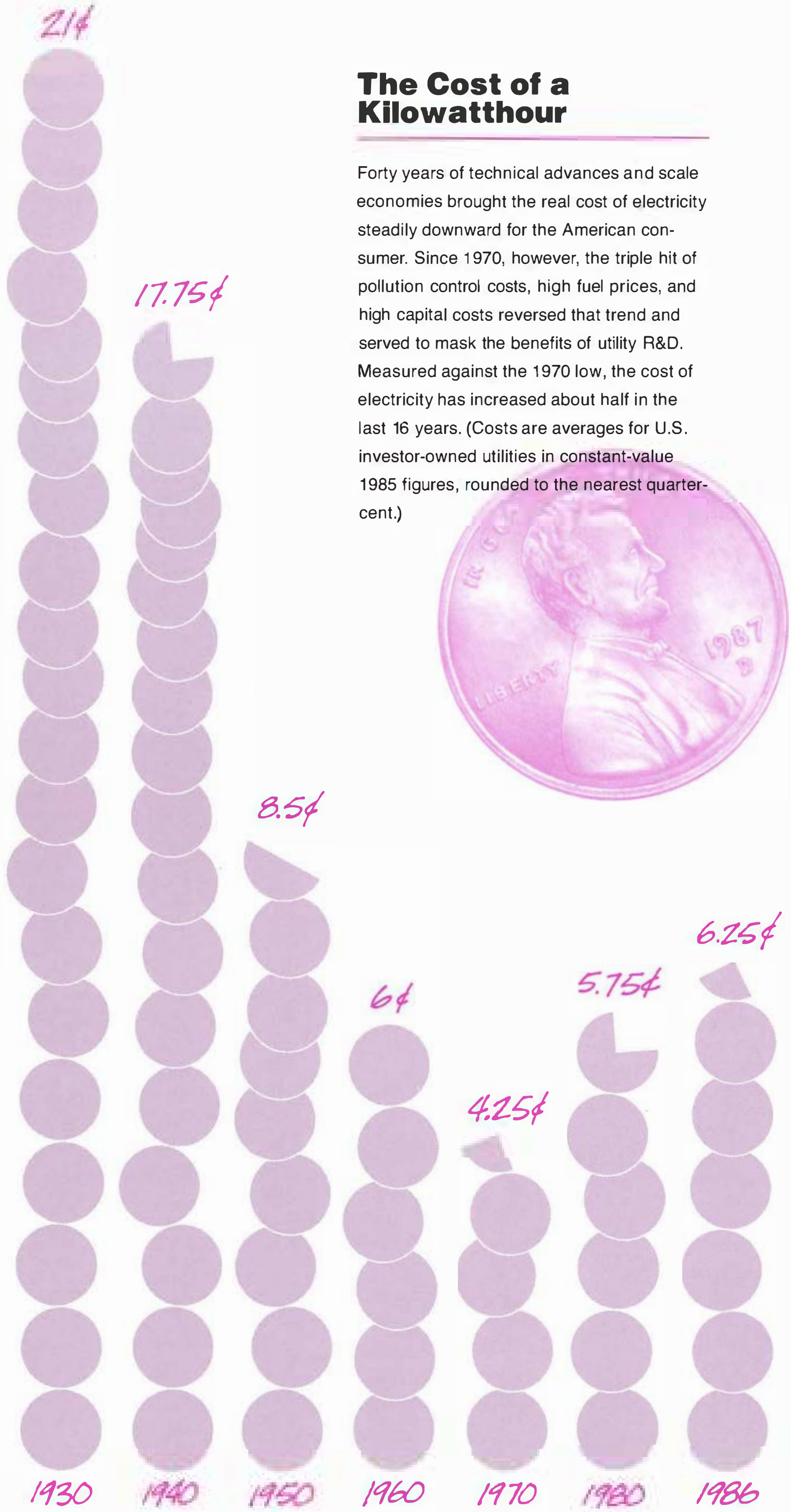
Although Kriesberg is familiar with EPRI's scope of work, he doesn't monitor the more highly technical R&D activity, such as power generation technologies and machinery efficiencies. "And from what I see here," he says, "I don't think ordinary people follow such things, either." His work tells him that some benefits of R&D can be quantified —energy conservation measures, for example—but again, the average person is unlikely to work through the numbers.

Power industry research is categorically in the public interest, Kriesberg believes, but he acknowledges that the limit has never been tested, remarking wryly, "If a utility wanted to contribute twice as much money to EPRI as it now does, then its regulators might want to take a closer look."

In California, TURN (Toward Utility Rate Normalization) is a statewide advocate on behalf of individuals and small businesses in matters of electricity, natural gas, and telephone service and rates. Sylvia Siegel, TURN's executive director and most frequent voice, emphatically affirms the cost-cutting motivation of utility R&D. "Utility research should al-

The Cost of a Kilowatthour

Forty years of technical advances and scale economies brought the real cost of electricity steadily downward for the American consumer. Since 1970, however, the triple hit of pollution control costs, high fuel prices, and high capital costs reversed that trend and served to mask the benefits of utility R&D. Measured against the 1970 low, the cost of electricity has increased about half in the last 16 years. (Costs are averages for U.S. investor-owned utilities in constant-value 1985 figures, rounded to the nearest quarter-cent.)



ways be of benefit to ratepayers, but it's not clear that's always what happens."

Siegel sharply distinguishes the responsibilities of utilities and manufacturers for their respective R&D, and she believes, for example, that electric vehicle research is not a proper avenue for utilities. "It's not in the ratepayers' interest to develop new industries, new markets for electricity. That's for utility stockholders to pay for."

Utilities see the implications of electric vehicles somewhat differently, reasoning that they will draw more kilowatthours from a given system, but largely at night when other demand declines. The capital charges on that utility system can thus be spread across more kilowatthour sales, and the result should be generally lower kilowatthour rates.

Research that foreseeably can be directly applied in utility system operations gets thumbs up from TURN. Siegel mentions the scientific enthusiasm this year over so-called hot superconductors —ceramic materials that can conduct electricity without losses, and also without expensive liquid helium refrigeration. "It's very important that superconductivity research be pushed," Siegel declares, but she is concerned that potential power industry applications are not yet evident. "Where are utilities on this?" she asks rhetorically. "I don't see them out in front."

What EPRI sees

Siegel's comment about superconductivity research suggests that the visibility of R&D, as well as its substance, has value among customers. And as Puget Sound Power & Light learned, the availability of information often elicits positive interest.

EPRI's formation in 1972 was in part a response to the pressure many utilities felt at that time, a carefully measured step into the difficult transition being urged by the environmental movement. According to Henry Darius, the Institute's general counsel, it's no mistake that EPRI's purpose was specifically formulated to be the advancement of science in the public interest.

"It's understandable," says Darius, "that the great majority of our reporting and communication is aimed at our member utility audience, because that's where most of the R&D results must be evaluated and applied. And the inherent customer benefit of R&D is clearly understood by that technical community. But it's also sensitive and wise practice," Darius argues, "to be explicit to other, more general audiences whenever we can."

Darius's point is well taken, but it's also evident that electric utilities themselves would like more precision in assessing the benefits of R&D, especially ahead of time—prospectively, in the words of Richard Block, manager of EPRI's product applications group.

Block's staff and John Neal's member service representatives together are the marketers for EPRI's several product lines of research results. Their goal is increasingly to pinpoint what should be the best-sellers well in advance of the products' availability and to do it by some means that permits ready comparison of their value. Dollars-and-cents benefit to customers may be a certainty, but it must also be unequivocably evident to the utility managers who decide to make use of EPRI's output. To Block, the win-win proposition is the combination of dollar benefit to the customer and conviction of that benefit by the utility.

EPRI's intense benefit assessment campaign with two dozen member utilities in 1985 and 1986 yielded a wide range of benefit-cost ratios, calculated by the utilities all the way from just over 1:1 to more than 12:1. But 3:1 is widely accepted as a representative figure, based mostly on utility cost savings compared with their dues paid to EPRI.

What's more important, according to Block, the 3:1 ratio is definitely recognized as a good return. He alludes also to the rough R&D cost per customer, 25 cents per meter per month, and suggests that if utilities and their customers had both figures firmly in mind, they would ask in unison, "Why am I investing so little?"

Their answer wouldn't always lead to a larger R&D piece of the funding pie, Block admits, simply because there might not always be the front money; but it would point up how much of tomorrow's progress in electricity—lower cost, higher efficiency, reduced risk, better environmental performance, and even new uses—depends on the vigor of today's R&D.

"I think utilities may not have strongly sold the role of R&D to their customers," Block suggests, "simply because its cost is in fact so small. The big numbers in a utility's rate base tend to get all the attention in a rate case."

Block takes note of market dynamics that are increasingly affecting utilities—the newly competitive atmosphere fostered by the interactions of deregulation and new technology. "New options for utilities, as well as for their customers, will eventually have tremendous effect on customer cost. And the source of most of them, the fuel that motivates them, is R&D."

The thought is consistent with an observation by Ohio Public Utilities Commissioner Ashley Brown. "There's more than one kind of R&D, in my mind. One is for the next three or four years. But the real value is in the blue-sky stuff, the basic research for the long haul. We can't let the marketplace or today's bottom line totally dictate to us.

"That's not the way to approach an intellectual enterprise," Brown insists. "It's in the nature of research that sometimes you succeed and sometimes you fail. Rigorous justification efforts are apt to be penny-wise and pound-foolish." ■

This article was written by Ralph Whitaker, aided by Bud Nelson, EPRI's director of regulatory relations; and Richard Block, manager of product applications in the Corporate Communications Division.

Strategies for Superconductivity

Representatives from government, industry, and the scientific community met in a recent workshop to discuss R&D strategies for high-temperature superconductors. The critical path is being cleared as the challenges and possibilities come into focus.

After the flurry of excitement that accompanied rapid development of high-temperature superconductors (HTSCs) earlier this year, scientists and engineers have now begun a more reflective reassessment of their capabilities and limitations. A recent workshop held in Washington, D.C., showed that considerable excitement and optimism still remain but many years of intensive research will be needed to bring the new materials into widespread use in electric utility applications.

The purpose of the Washington workshop was to bring leading HTSC researchers together with representatives of electric utilities, equipment manufacturers, and R&D funding agencies to discuss the state of the art and priorities for future research related to electric power applications. The workshop, held October 22–23, was sponsored by EPRI with the cooperation of the U.S. Department of Energy and the National Science Foundation.

The challenge of current

Superconducting materials lose virtually all their resistance to electricity below a certain critical temperature. Until recently, most superconductors were metals with critical temperatures that could only be maintained by immersing them in expensive liquid helium. The new HTSCs are ceramics with critical temperatures that are high enough so superconductivity is sustained by much cheaper liquid nitrogen.

The principal technical challenge that dominated much of the discussion at the workshop is the limited ability of currently existing HTSCs to carry substantial currents while remaining superconductive. When the current flowing through the cross-sectional area of a superconductor rises above a certain level (called its critical current density), the superconductor begins to show resistance. Bulk samples of the new ceramic HTSCs generally have critical current densities at least a thousand times too low for most utility applications. Several participants at the workshop, however, said that critical current densities could probably be raised for HTSCs.

The main reason for this optimism came from very recent research on single crystals and thin films of the new materials. In these forms, which might be useful in making computer chips and electronic instruments, HTSCs do have good critical current densities. However, high-power applications need bulk materials, and no one is yet sure how to improve their current-carrying capacity.

Part of the problem seems to be related to properties of boundary layers that form between the tiny superconducting grains contained in bulk HTSC ceramics. In some cases, impurities have been detected in these layers, which might be removed by processing the materials differently. Some researchers, for example, have reportedly reduced these impurities by changing the rate at which the bulk ceramics are cooled and by varying the chemical composition of the initial raw materials.

A more difficult aspect of this problem, however, is the fact that each grain can carry 30–60 times more current along one crystal plane than in a plane perpendicular to it. In a bulk piece of material, the planes of adjacent crystalline grains are randomly oriented. Again, some researchers at the workshop reported progress in optimizing current flow by lining up the grains through physically texturing the material.

It now appears most likely that early replication problems resulted from the effects of moisture or carbon dioxide on the sample.

Brittleness and stability

Two other technical hurdles that must be surmounted before HTSCs are ready for use in large equipment are their physical brittleness and chemical instability. These materials belong to a class of ceramics known as perovskites, which generally have poor mechanical properties and are particularly susceptible to cleavage and fracture.

In addition, there appears to be a slow reaction with moisture and carbon dioxide in the air, causing deterioration of their superconductive properties. Again some optimism was expressed at the workshop about the possibility of eventually improving the performance of HTSCs, or at least working around their limitations. Other ceramics, for example, have been fabricated into thin filaments that have 5 to 10 times the tensile strength of bulk material. Suggestions were also made about ways of incorporating HTSC cores inside metallic wires to give them mechanical support. Finding different ways of processing the materials may also improve their physical performance.

As in the case of low current densities, part of the problem appears to result from impurities trapped at grain boundaries. In some samples, cracks and faults have also been found at the edges of grains. The HTSC ceramics are created by mixing powders of the raw materials, forming the mixture into a desired shape, and then sintering it to fuse the particles. Experiments are now under way that use finer powders and slower sintering to see if the grain structure of the finished products can be improved. The chemical reactivity of HTSCs is particularly puzzling. It now seems very likely that some problems with experiments reported earlier, in which measurements of superconductivity in a particular sample could not be duplicated after a few days, resulted from the effects of moisture or carbon dioxide on the sample. The exact mechanism involved, however, remains unclear. The materials could, of course, be produced in a nonreactive atmosphere and later protected by an impermeable coating.

R&D priorities

Although experimental advances with HTSCs have so far greatly outrun theoretical explanations of how they work, a consensus emerged from the workshop that significant progress on the major technical hurdles just described will require a better understanding of the phenomena involved. There was also general agreement that high-power applications of the new materials can come only after many years of research at funding levels too high for any single company or research organization to sustain alone.

In his welcoming statement to workshop participants, John Stringer, technical director of exploratory research in EPRI's Energy Management and Utilization Division, said he hoped their discussion would help focus attention on areas of research that could become the basis of an HTSC research program related to utility needs. Later, in his concluding remarks, the workshop organizer Dave Sharma, a senior project manager in the Electrical Systems Division, said that this goal had indeed been met. The biggest problem in deciding what research to pursue is that HTSCs are much more complex than the older, metallic superconductors. Several competing theories have been proposed to explain the mechanism of superconductivity in the new materials, but none appears to cover all the observed phenomena. Also, the relationship between the crystal structure of HTSCs and their electrical, physical, and chemical characteristics is not yet understood. As a result, scientists and engineers are conducting basic materials research, while empirically trying to improve HTSC performance.

Several competing theories have been proposed to explain the mechanism of superconductivity in the new materials, but none appears to cover all the observed phenomena.

One area of research that promises to be critical for utility applications involves the ability of HTSCs to carry alternating current. In his keynote address, Mario Rabinowitz, the senior scientist in the Electrical Systems Division, said that 60-Hz ac power losses in the new materials may be substantially higher than in metallic superconductors. "The saving feature," he concluded, "is that the refrigeration power requirement for the HTSCs is on the order of 100 times less than that for the metallic superconductors, so we can tolerate higher ac losses in HTSCs within certain limits."

Ac losses in some applications may be reduced both by growing larger crystals and by orienting the crystals in bulk samples of the material.

Rabinowitz also said that ac losses in some applications may be reduced both by growing larger crystals and by orienting the crystals in bulk samples of the material. Ac losses so far have been inferred only from indirect measurements, but EPRI has now begun to sponsor efforts to measure ac losses directly.

Another area of research with particular importance for utility applications is the effect of magnetic fields on HTSCs. Initial experiments indicate that such fields reduce the current-carrying capacity of the new superconductors much more dramatically than in the older, metallic superconductors. Such reduction becomes even more pronounced at higher temperatures. In other words, even though an HTSC may be superconducting at temperatures near that of liquid nitrogen in the absence of an external magnetic field, it may require much lower temperatures when a magnetic field is applied. Again, the reasons for this behavior are not well understood and the prospects for improving performance remain uncertain.

The usefulness of HTSCs would, of course, be greatly enhanced if superconductivity could be demonstrated at temperatures well above the 77 K of liquid nitrogen. Few areas discussed at the workshop, however, proved more controversial because of conflicting evidence. With metallic superconductors, the transition to a superconducting state occurs quite sharply as the temperature is lowered below a critical point. Resistance to current flow decreases rapidly to zero, and magnetic fields are virtually excluded from the material. The latter phenomenon (known as the Meissner effect) provides the basis for the now-familiar photographs of small magnets suspended above the surface of a superconductor.

With some HTSCs, however, the transition does not occur suddenly at a distinct critical temperature, and various indications of superconductivity may not coincide. One experiment discussed at the workshop, for example, concerned a material that showed a sharp drop in resistance at 230 K, but only a slight Meissner effect at that temperature. Worse, many samples of material showing transitions at such very high temperatures are so unstable that experiments may not be reproducible after a day.

During a panel discussion on research needs, various speakers emphasized the need for more coordination of R&D at the national level and better communication among researchers engaged in work on different aspects of high-temperature superconductivity. As one researcher put it, "Technology transfer is a body-contact sport; you can't just pass papers back and forth. This meeting has been successful in that regard."

Utility applications

Even if research does lead to ways of improving HTSC performance so that these materials can carry large currents and be robust enough for everyday use, utility applications will not follow immediately. According to rough estimates discussed during the workshop, at least 10 years of further development work would be needed to incorporate the new materials into power equipment already designed for metallic superconductors, and the cost advantage of using higher temperatures would be only marginal for many applications.

The technical feasibility of superconducting transmission lines has already been demonstrated, for example, by work at Brookhaven National Laboratory that used a helium-cooled line with a metallic superconductor. The 115-meter, 138-kV superconducting cable operated more than 2700 hours over four years and was then abandoned during budget cuts. Brookhaven estimates that a one-for-one substitution of HTSCs for the metallic superconductor would produce about a 10% cost improvement, mainly because of cheaper refrigeration. Another opinion, however, was that transmission lines would be the easiest application for HTSCs, and if the system is designed, it is possible that larger savings would result.

Initial experiments indicate that magnetic fields reduce the current-carrying capacity of the new superconductors much more dramatically than in the older, metallic superconductors.

If such superconducting cables were to be buried, however, trenching and backfilling costs could represent a large fraction (25–50%) of the cost. As a result, underground transmission is generally several times more expensive than overhead transmission, and superconductivity alone will probably never bring them to parity. Several utility representatives at the workshop noted, however, that rights-of-way for new overhead lines will become increasingly difficult to obtain, and underground transmission may become the only viable alternative in some areas.

"Technology transfer is a body-contact sport; you can't just pass papers back and forth."

Another widely discussed application was superconducting magnetic energy storage (SMES). One small unit designed by Los Alamos National Laboratory has already been placed at Bonneville Power Administration for damping of line disturbances. Previous studies indicated that a storage ring constructed with metallic superconductors might be cost-competitive today if it had an energy capacity of 5000 MWh and could deliver peak power of 1000 MW. Estimates made at the workshop indicated that a one-for-one substitution of HTSCs for the metallic superconductors would lower the overall cost by about 8%, assuming the new materials had the same cost and could give comparable performance.

In addition to cost, there was a lively discussion of environmental issues and utility trends that could affect the viability of SMES. The proposed 5000-MWh storage unit would have a diameter of 1000 meters and emit high magnetic fields, which might mean that such a facility could face severe siting problems and close regulatory scrutiny. But one utility representative noted that the industry trend toward smaller generating units and life extension in older plants will put a premium on load leveling and storage, such as that provided by SMES.

The use of HTSCs also might not substantially change the prospects for superconducting generators, which have already been built on a small scale with metallic superconductors. Designs for building a larger, engineering test model were abandoned in this country for reasons other than technical. The Japanese, however, have reportedly launched a major project to build a small, utility-scale superconducting generator utilizing metallic superconductors by the turn of the century. Some workshop participants suggested that this approach would put the Japanese in a better position to substitute HTSCs for superconducting metals in such a generator when they become available with suitable characteristics. Some concern was expressed over the application of HTSCs in generators and motors because they have moving parts that subject materials to high mechanical stresses, as well as to large magnetic fields. One participant noted that despite their generator project, the Japanese appear to be concentrating more of their research efforts on the use of HTSCs in thin films.

The Japanese appear to be concentrating more of their research efforts on the use of high-temperature superconductors in thin films.

A coordinated approach

Perhaps the most important area of general agreement at the workshop was the need for a coordinated approach to research on HTSCs. Such an approach is required not only because of the limited resources of individual funding organizations but also because of the diversity of research needs. Thus development work could proceed on generators with metallic superconductors at the same time as fundamental materials research on HTSCs. Meanwhile, experiments on thin films might bring early application of HTSCs in electronics equipment. One utility participant suggested that an important EPRI contribution might be to help adapt early low-power superconducting equipment for power system use—for instance, in measuring fluid flow or dc currents.

"R&D is a risky business that requires judgment and faith," Narain Hingorani, vice president of the Electrical Systems Division, told participants at the end of the workshop. "EPRI is already coordinating its research efforts with the National Science Foundation, the National Bureau of Standards, and the Department of Energy. There's no need to rush into large demonstrations, but we do need a focus for research and continuous conceptual thinking. I have become more of an optimist as a result of this meeting, for I see no fundamental problem with the high-temperature superconductors that we can't solve eventually." ■

This story was written by John Douglas, science writer, following his coverage of the conference on October 22 and 23.

Safe Passage for Migrant Fish

When hydro projects get in the way of fish migration routes, utilities must take a hand to provide safe passage. But the task is trickier than it appears and regulatory concerns are increasing the stakes.

In the dark, quiet cabin of a boat anchored on Lake Michigan, a team of biologists huddles around a computer monitor, watching as a jagged line of light on the screen changes suddenly from white to blue. Something deep below the surface of the lake is traveling by night again, heading straight for the hydroelectric plant. "Yellow perch," says one of the biologists. "And it looks like they're avoiding the strobe lights."

This is one of EPRI's cofunded experiments at the Ludington Pumped Storage Plant; the purpose is to test the effectiveness of strobe lights for repelling various species of fish. After suspending an underwater array of the flashing lights on a cable attached to their boat in the plant's forebay, the biologists use hydroacoustic equipment and a computerized imaging system to track the behavioral response of yellow perch and other species. They hope to develop a generically applicable solution that will keep fish from entering the turbine intakes at Ludington, just one of hundreds of hydro sites throughout the United States where fish protection is a growing concern.

A changing regulatory picture

Electric utilities in all parts of the country are facing tough new regulatory requirements to minimize fish mortality at dams and other hydro stations. These new requirements reflect the changing public attitudes about environmental protection, an improved understanding of how pumped storage stations and dams affect fish, and the increased threat to fish populations posed by construction of dams in series along waterways in different regions.

The new requirements have made fish protection into a nationwide industry concern. In the Pacific Northwest, where hydro producers have already spent hundreds of millions of dollars on fish ladders and other measures to protect and restore the region's huge anadromous fishery (sea-run salmon and trout), regulators are now insisting on reduced or even zero mortality related to turbine passage. In the central and eastern United States, new regulations are intended to protect many resident and migrant species, while the Atlantic salmon and other species are the focus of intensive restoration programs. As a result, many utilities in these regions are evaluating and implementing fish protection measures for the first time.

For utilities in all regions, meeting these requirements is both a technical challenge and a crucial condition of the federal licensing process. To successfully license or relicense a hydro station with the Federal Energy Regulatory Commission (FERC), utilities must establish their success in complying with fish protection requirements and other environmental regulations. With licenses due to expire at some 260 U.S. hydroelectric sites between 1987 and 1999, many utilities are feeling added pressure to meet these requirements.

These relatively short time frames add to the difficulty of choosing from among many different fish protection technologies, none of which has proved 100% effective and none of which has yet received regulatory agency approval for general use. The area of greatest uncertainty is the technology for downstream migrant fish protection: various barrier and diversion systems designed to keep fish out of hydraulic turbines and provide them with safe passage past dams.

As they search for ways to protect downstream migrant fish, utilities are now investigating systems that use behavioral barriers, such as lights and sound, to either repel fish from turbine intakes or attract them to a bypass channel past the dam. "If behavioral barrier technologies prove effective in repelling or attracting fish, they could be incorporated in cost-effective, generically applicable solutions for downstream migrant fish protection," says Charles Sullivan, hydro program manager in EPRI's Advanced Power Systems Division. "At the same time, generic solutions could give utilities a more solid technical basis from which to actively propose fish protection devices to the regulators, both for relicensing older plants and for planning new ones."

A complex of problems

The most vexing fish protection problems for utilities are located on the upstream side of dams, where juvenile, downstream-migrant fish—often less than six inches in length—tend to follow strong currents into turbine intakes during their migratory journey to the sea. "The impact of dams on adult fish battling their way *upstream* was understood and sometimes taken into consideration when many hydro projects were being built," explains Sullivan. "Juvenile mortality due to *downstream* passage through the turbine has come under pressure more recently and has brought with it a new series of regulatory and technical problems for many utilities."

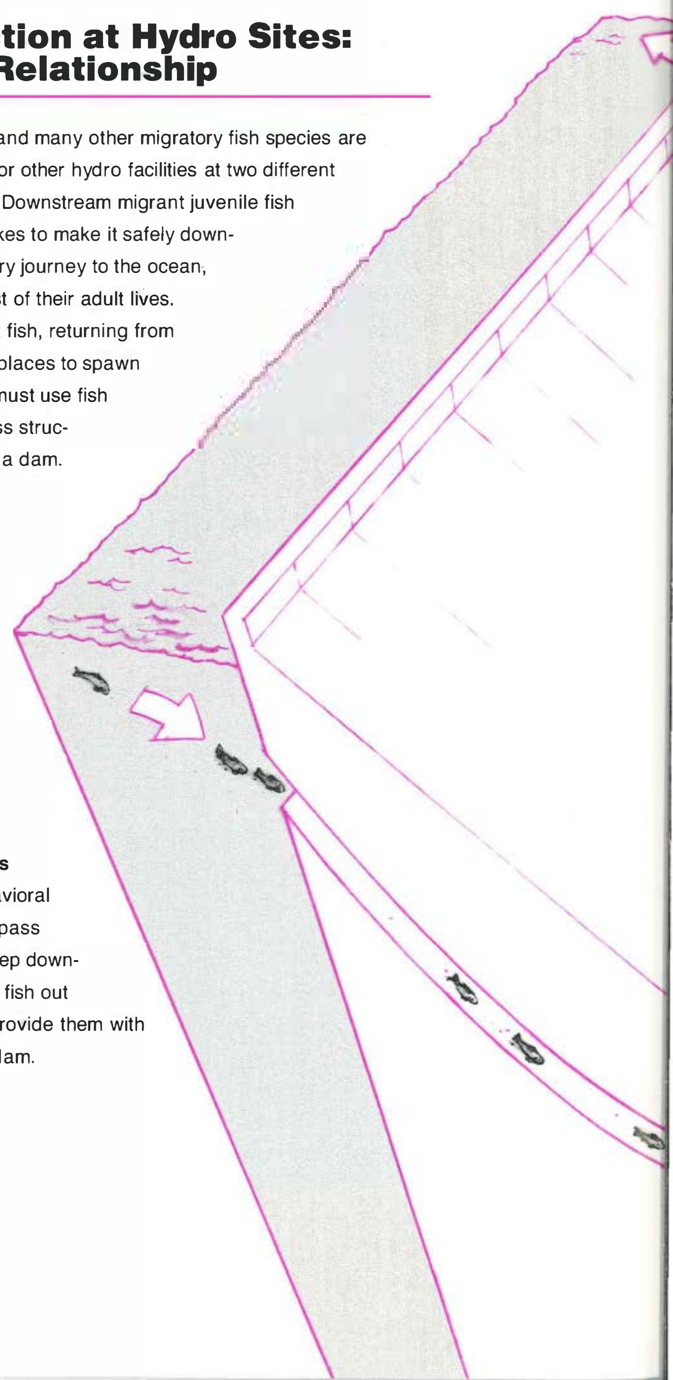
Today, after years of government and utility R&D into the turbine passage problem, most utilities have given up hope of minimizing fish mortality by modifying the turbines themselves. "We still don't know exactly how or exactly where fish are injured or killed in the turbines, and there is no evidence to suggest that greater knowldge would lead to a solution," says Sullivan. "Rather than spending tens of millions in an attempt to develop lower-mortality turbine designs, we believe that the more sensible course of action is to develop better diversion technologies to effectively keep fish out of the turbines in the first place."

To date, the most widely applied systems for downstream migrant fish protection use diversion systems, such as screens, which are installed at turbine intakes in an attempt to divert fish. The diversions are usually combined with bypass routes to provide fish with safe passage around the dam.

The principal hardware component in a diversion system, for example, might be a traveling screen extending down into the turbine intake. To keep its small openings from clogging with debris, the screen is mounted on a chain drive and rotated vertically in a design somewhat

Fish Protection at Hydro Sites: A Lifetime Relationship

Sea-run salmon, trout, and many other migratory fish species are apt to encounter dams or other hydro facilities at two different times in their life cycle. Downstream migrant juvenile fish must avoid turbine intakes to make it safely downstream on their migratory journey to the ocean, where they will live most of their adult lives. Upstream migrant adult fish, returning from the ocean to their birth places to spawn and start a new cycle, must use fish ladders or similar bypass structures to make it around a dam.



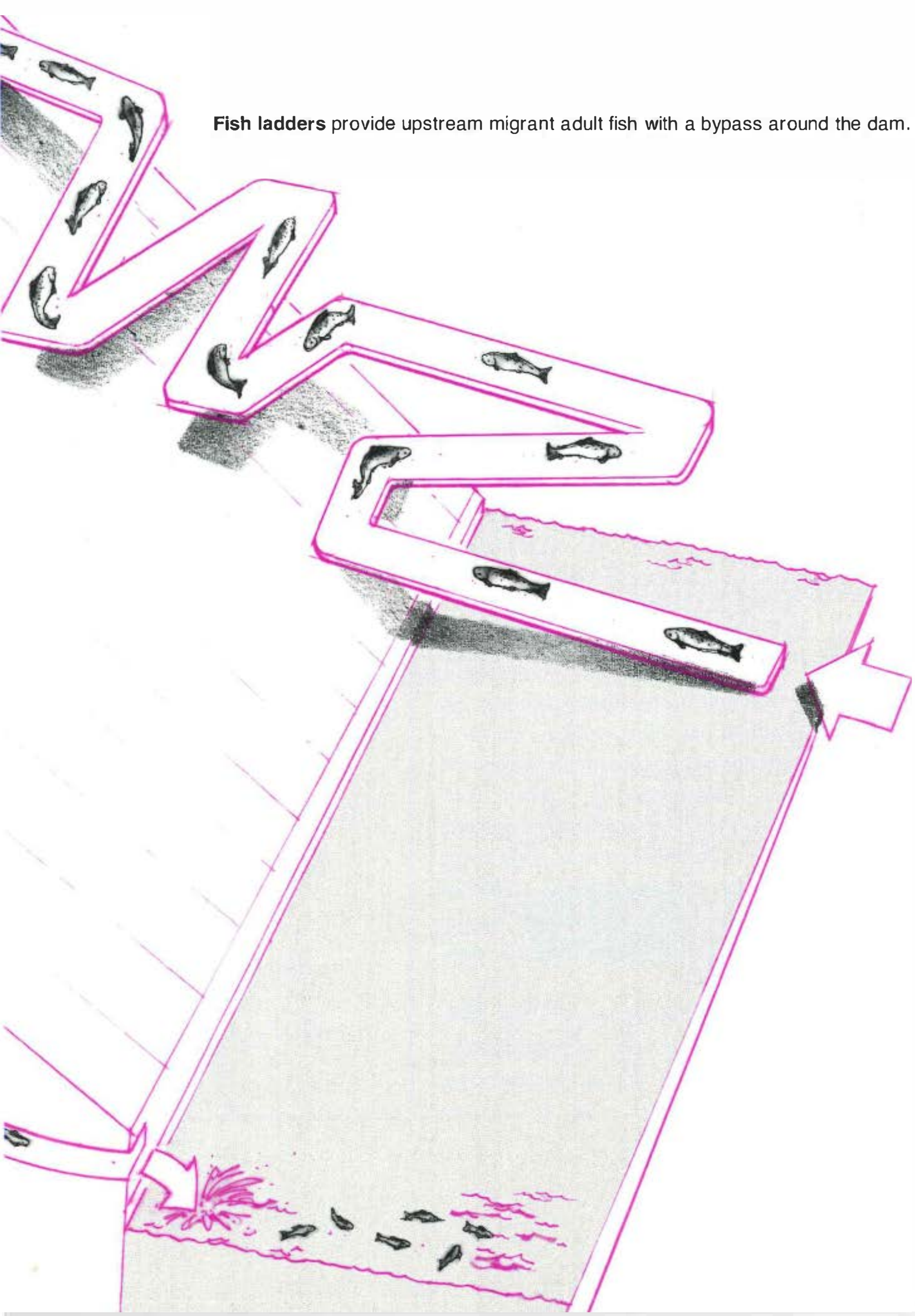
Diversion technologies including screens, behavioral barriers, and special bypass conduits are used to keep downstream migrant juvenile fish out of turbine intakes and provide them with safe passage past the dam.

like a treadmill or conveyor belt. As fish are attracted by the current toward the intake, many will encounter the moving screen and move upward into a gatewell, where they find a safe bypass around the dam.

This is just one of dozens of screen designs available to utilities. Other systems use drum-shaped screens, angled screens, or stationary louvers. Bypass routes also vary at different hydro sites, with fish sometimes diverted into trash sluiceways or simply spilled over the dam. To provide fish with a safe spill over high dams, some utilities mount an inclined water slide or over-shoot structure on the dam.

In choosing among diversion systems, utilities must consider and balance many different factors, including the existing structures and flow rate at a given site, the size of the fish being protected, and the maintainability and overall effectiveness of the equipment. If the mesh of a particular screen is too large, for example, juvenile fish can slip through or become caught in the openings. On the other hand, smaller openings can clog more quickly and require frequent maintenance; smaller openings can also reduce flow through the turbine, affecting the station's generating capacity. Use of moving rather than stationary screens can reduce clogging, but the drive mechanisms on moving screens can also cause maintenance problems.

With such a wide range of equipment designs and operational factors to consider, utilities have been hard-pressed to make optimal decisions. "Utilities have to balance cost against their analyses of which systems will best minimize fish mortality and satisfy the regulators," says Ned Taft, a senior environmental scientist at Stone & Webster Engineers who has studied fish protection problems at hydroelectric sites for more than 15 years. "Even the largest and most costly screens, however, have produced varying results, and that leaves utilities still searching for generic solutions."



Fish ladders provide upstream migrant adult fish with a bypass around the dam.

Seeking behavioral solutions

To improve this situation, EPRI in 1986 commissioned an assessment survey to identify the available technologies for downstream migrant fish protection, assess their effectiveness and applicability to different sites and species, and point out directions for future R&D. Prepared by Stone & Webster, the survey assessed the commonly used physical barrier and diversion technologies, as well as behavioral barrier technologies for attracting or repelling fish, such as lights, sounds, electric charges, hanging chains, and curtains of air bubbles. The experts who wrote the study concluded that no single existing system is biologically effective, operationally reliable, economically feasible, and acceptable to regulatory agencies. However, several of the behavioral technologies showed promise as possible generic solutions, especially if combined with bypass technologies in hybrid systems.

Acting on this conclusion, EPRI initiated a program in 1987 with four individual utilities (Northeast Utilities, Consumers Power, Pacific Power & Light, and Grant County PUD) in field-testing combinations of behavioral and diversion systems at representative hydro sites around the country. The behavioral technologies chosen for this work include mercury lights, which have shown promise for attracting some species of fish, and strobe lights and sound-generating devices, which have both shown potential for scaring fish away.

In making use of light and sound, researchers are using age-old methods to solve modern problems. "Fishermen in different cultures have used light to influence the behavior of fish for thousands of years," says Ronald Klattenberg, a biologist at Northeast Utilities who is currently involved with EPRI in field-testing mercury lights, strobe lights, and an underwater sound-generating hammer at his utility's Hadley Falls–Holyoke hydro station. "As for the possible effectiveness of sound, most fishermen will tell you that loud noises can frighten fish away."

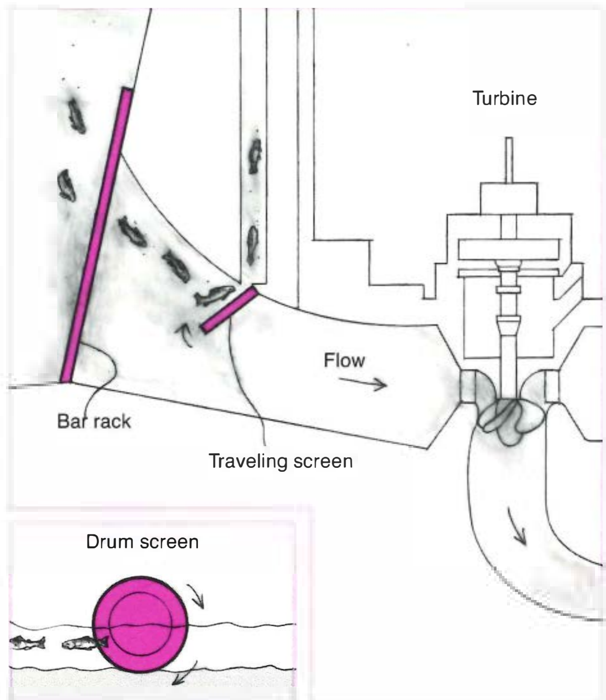
Behavioral barriers such as sound and lights could also provide a spinoff application on the downstream side of dams, where many utilities have problems attracting adult fish into upstream bypass ladders. The ladders are long, inclined channels often built in a series of steps or weirs that fish can negotiate a bit at a time; some are even equipped with mechanical elevators to help fish over the dam. Strong currents below a dam, however, can attract fish away from the ladder or mask the entrance. If mercury lights prove effective for attracting fish to bypass channels at the tops of dams, they may also provide a method for luring upstream migrants into ladders.

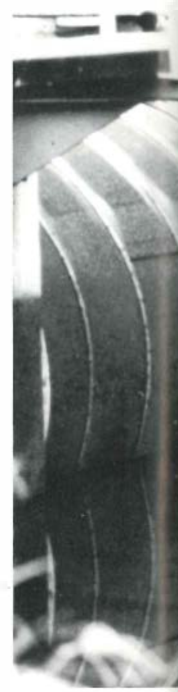
The regulatory challenge

While waiting for new solutions from the R&D community, utilities must negotiate a complicated regulatory process that includes FERC, the U.S. Fish and Wildlife Service, the individual state fish

Barriers and Fish Diversion

Screens are important components in most systems used to divert downstream migrant fish from turbine intakes and direct them to bypass routes around dams. Traveling screens of the same type used at cooling-water intakes to thermal power plants are designed like treadmills—rotated to prevent clogging and to move fish in an upward direction. Cylindrical drum screens, rotated to prevent clogging, are often positioned at the entrance to diversion canals leading to turbines or irrigation systems. Bar racks, which often serve as trash barriers, could act as deterrents to fish passage.



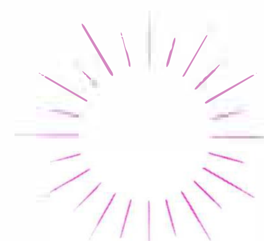


The Lure of the Bright Lights

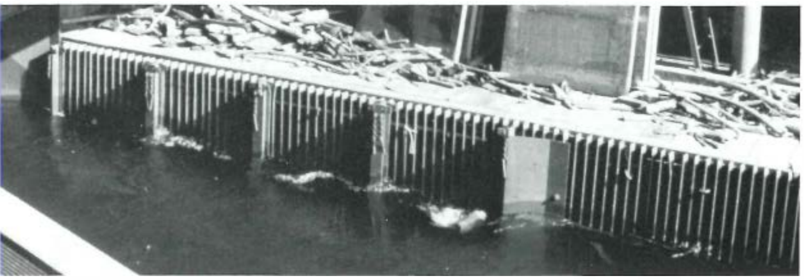
Behavioral barriers show promise for diverting fish from turbine intakes or attracting them to bypass channels around dams. Researchers are currently field-testing three such technologies at representative hydroelectric sites to determine their individual effectiveness, as well as their effectiveness when combined with such traditional fish protection hardware as screens.

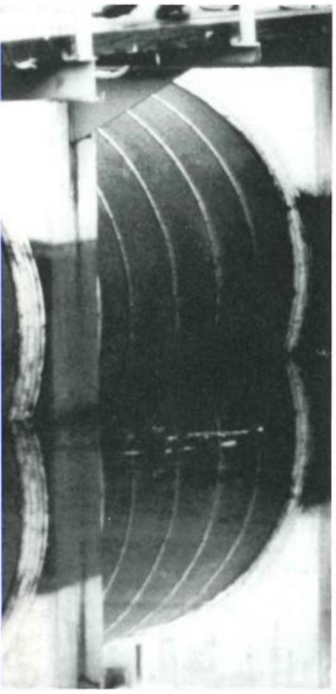
Similar behavioral systems are being tested for application on cooling-water intakes at fossil fuel and nuclear power plants.

Mercury lights, a modern application of an ancient fishing technique, are positioned underwater at the entrance to bypass channels or fish ladders to lure fish in a safe direction.



Bar rack

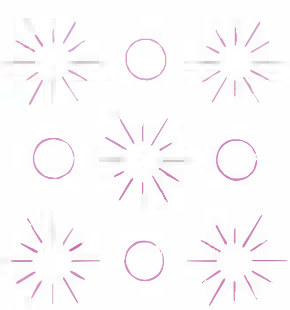




Drum screen

Traveling screen

Strobe lights, also used underwater, flash on and off repeatedly to divert fish from turbine intakes or other equipment that may endanger them.



Sound-generating devices make loud noises that may help frighten fish away from turbine intakes.

and wildlife agencies, and—in cases where commercially harvested fish are involved—the National Marine Fishery Service. In addition, Native American tribal groups involved in fishing as part of their livelihood and culture are often included in the regulatory process.

To license or relicense a hydro station, a utility must gain approval from all these groups before reporting to FERC, which is the final judge of the utility's stewardship of fish and the overall natural resource. Also, FERC may reopen the licensing process at any time if fish and wildlife agencies report the utility's fish protection efforts are inadequate.

According to EPRI's 1986 assessment of downstream migrant fish protection technology, the key to successfully negotiating new licenses is active participation with regulators from early in the licensing process to identify and correct any fish mortality problems. FERC allows existing licensees to file for a new license within a two-year window, three to five years before the initial license expires. EPRI's assessment emphasizes that close utility cooperation with the agencies should begin at least five years before expiration. By starting early, the utility and agencies have time to review the fish mortality situation at a site and to agree on field studies that might be necessary to gather more data. This leaves enough time before relicensing for all parties to agree on the pros and cons of the various technology alternatives available.

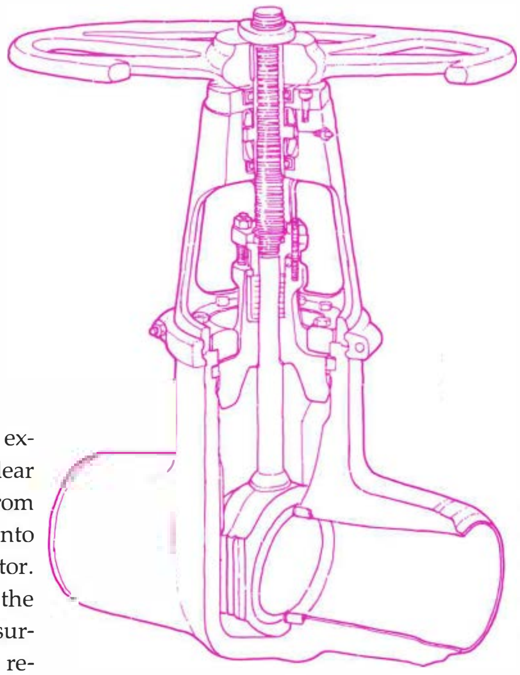
"It's our goal to assist utilities with relicensing by developing better fish protection technology," says Sullivan. "But we can also help utilities by repeating the message that fish protection is one aspect of hydroelectric generation where times are rapidly changing. Utilities must aggressively act—not just react—to arrive at solutions acceptable to the regulators." ■

This article was written by Jon Cohen, science writer. Technical information was provided by Charles Sullivan, Advanced Power Systems Division.


1987 COMPETITION WINNER
25th YEAR
IR 100
Cited by Research & Development magazine for developing one of the 100 most significant technical products of the year

Cobalt alloys have been the mainstay for wear resistance in industry. But the material is costly, scarce, and can become radioactive in nuclear plant applications. New iron-based NOREM alloys will allow utilities—and perhaps industry in general—to kick the cobalt habit.

Just Say No to Cobalt



About 30% of the radiation exposure received by nuclear plant personnel comes from cobalt released by valves into the primary cooling water of a reactor. Cobalt is the major constituent of the hard-facing alloys deposited on the surface of these valves to improve their resistance to wear and corrosion. A new type of hard-facing alloy developed with EPRI funding may virtually eliminate this source of radiation, while most likely costing half as much as cobalt-based alloys.

Now available for licensing under the trade name NOREM, the new material may also find a ready market in many other industries where hard-facing alloys are used. Potential applications include wear-resistant bucket teeth and ore crushers for mining, drill bits and tool joints for petroleum exploration, agricultural equipment, shovels, and automotive valves.

In recognition of NOREM's importance, both for nuclear utilities and for companies outside the electric power industry, EPRI recently received a prestigious IR-100 award from *Research & Development* magazine. These awards are presented annually to organizations judged to have developed the 100 most significant technical products of the year.

"The search for cobalt-free hard-facing alloys has been going on for some years because cobalt became so expensive in the late 1970s and the United States does not have major deposits of it," says Howard Ocken, project manager in the Nuclear Power Division and a co-inventor of NOREM. "One of the reasons we were successful is that EPRI has dedicated long-term funding to the alloy development work as part of a larger, ongoing effort to reduce radiation exposure."

Challenge and potential

When cobalt is worn or corroded from the surface of valves and other equipment and carried to the reactor core by its cooling water, the naturally occurring cobalt-59 isotope is transmuted by irradiation to radioactive cobalt-60. By the early 1980s, cobalt-60 had been identified as the principal isotope contributing to radiation fields on components that require inspection, repair, or replacement—such as the steam generator in pressurized water reactors (PWRs) and the recirculation system piping in boiling water reactors (BWRs). To lower radiation fields, EPRI initiated a series of studies to identify cobalt sources in different types of reactors and assess various options for reducing cobalt deposition on primary-circuit components.

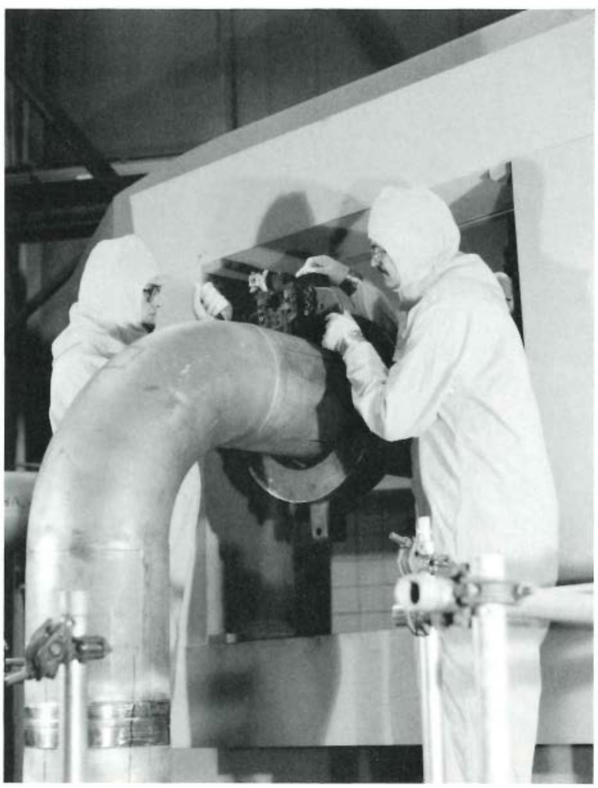
In 1982, EPRI published a General Electric study of cobalt sources in BWRs and studies by Westinghouse Electric and Combustion Engineering of sources in PWRs. Among the leading sources identified in these studies were physical wear of the control-blade pins and rollers of BWRs and corrosion of steam generator tubing in PWRs—as well as wear of hard-faced valve surfaces in both types of reactors.

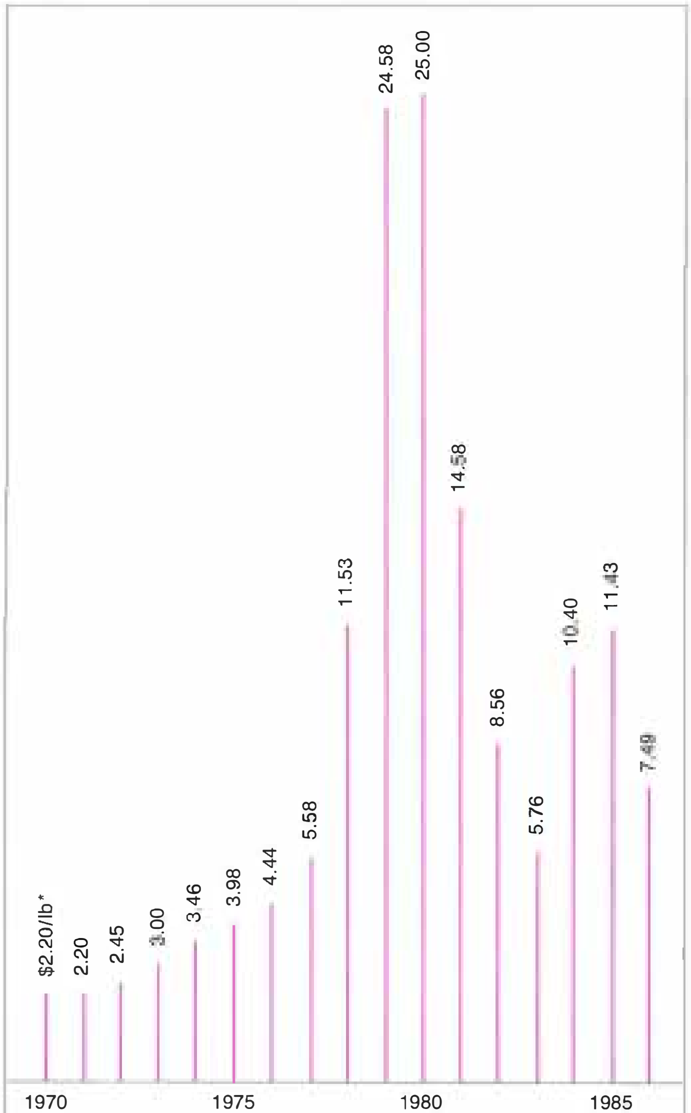
In response to these findings, EPRI has worked with nuclear suppliers and utilities on a number of approaches to reducing cobalt contamination. Some of these, such as changing the chemistry of coolant water, are now being used in operating plants. Raising the pH of water in PWRs, for example, helps prevent deposition of cobalt on reactor core surfaces, while adding zinc to BWR water inhibits corrosion and cobalt deposition on recirculation piping. Decontamination processes have also been developed for older plants. Such processes will permit cobalt-bearing corrosion products to be removed from component surfaces. Electropolishing of the cleaned surfaces, in some cases followed by oxidation in moist air, can then prevent recontamination.

A more-basic approach involves eliminating cobalt altogether. Initial efforts focused on reducing in-core cobalt. EPRI worked with General Electric to develop and demonstrate cobalt-free alloys for use in the pins and rollers of BWR control blades. This work was successful, and all replacement blades now use these alloys. Also, cobalt-contaminated nickel plating used in some PWR fuel assemblies (to

The Cost of Cobalt

The use of cobalt alloys in reactor coolant systems can be a costly proposition. Considered a strategic element and mostly purchased from sources abroad, cobalt has shown extreme price instability over the last two decades. But the more important impact for utilities is what cobalt does to plant maintenance costs. Particles of the material worn from component surfaces become radioactive as they circulate through the reactor core and are then deposited on many surfaces within the system. The resulting radiation fields limit the amount of time each utility worker can safely spend on a job. Labor efficiencies thus decline as more workers must become involved to complete each task.





*Weighted average annual price of electrolytic cobalt, from U.S. Bureau of Mines.

braze Inconel fuel spacer grids) was eliminated. This single cobalt source is believed to have been responsible for unexpectedly high radiation fields in several PWRs in the early 1980s.

Replacing cobalt in hard-facing alloys presented a longer-term challenge. Studies showed that cobalt alloys in relatively low-wear flow-control valves could be replaced with stainless steel. This option was not deemed suitable for high-wear valves because EPRI-sponsored tests published in 1984 clearly showed that none of the existing cobalt-free hard-facing materials was sufficiently resistant to wear at high stresses. These results led to the decision to develop new cobalt-free alloys.

At about the same time, a procedure was also developed for ranking different types of valves according to their potential for contributing to radiation. A detailed study of PWR valves, using this procedure, revealed that those with the highest potential for cobalt release are globe-type flow control valves located downstream from the demineralizers.

During this phase of the research, a cost-benefit assessment of replacing the hard-facing surfaces on certain valves with low-cobalt substitutes revealed just how much utilities might save if suitable alloys were available. In one older plant, a single valve was found that had apparently lost 14 grams of cobalt from its plug in nine years of operation—thus accounting for roughly 2% of the total cobalt input to the coolant system. Over the life of the plant, the radiation exposure resulting from cobalt released from this one valve would be about 250 man-rem.

Replacing the valve with a cobalt-free substitute would cost approximately $23,000, or about $90 per man-rem. The value of a man-rem of exposure avoided, however, has been variously estimated at between $1000 and $5000. Thus a utility could anticipate a benefit-to-cost ratio of at least 10 to 1 by replacing such a valve, if the appropriate substitute hard-facing materials were available.

The search for new alloys

Hard-facing alloys are used to impart a variety of desirable characteristics to the surface of equipment parts fabricated from much-less-expensive base metal. These characteristics include increased hardness, toughness, and tensile strength, along with higher resistance to corrosion, erosion, and galling. Of these, the most difficult property to duplicate without the use of cobalt is resistance to galling—the type of wear that occurs when two unlubricated metals are rubbed together at high stresses. The contacting surfaces may even exchange material, causing seizure.

In the valves of nuclear power plants, stress levels on a hard-faced surface may rise as high as 30,000 psi, so galling is a particular concern. And possible safety implications make the chance of seizure in such valves especially problematic. For these reasons, reactor manufacturers have traditionally surfaced their valves with a family of highly galling-resistant hard-facing alloys called Stellites. These alloys contain about 60% cobalt and are thus quite expensive.

To avoid the radiation levels associated with use of cobalt-bearing hard-facing alloys, a number of foreign nuclear plants have turned to valves hard-faced with nickel-based alloys. Some of these alloys were tested during the early phase of EPRI's work on hard-facing materials; the procedure involved rubbing alloy samples together under high stress and measuring the resulting weight loss from adhesive wear. Most of the nickel alloys had weight losses several times higher than those recorded for the Stellites. If such particles of nickel are circulated through a reactor core in its cooling water, they can also contribute to radiation exposure of personnel, although not so severely as particles of cobalt. In view of these findings, EPRI's efforts shifted to creation of a new family of alloys, which would be based on neither cobalt nor nickel.

In 1984, the AMAX Materials Research Center of Ann Arbor, Michigan, began experimenting with austenitic iron-based alloys for hard-facing. Austenitic materials are characterized by a particular crystal structure. They have been used as the basis for complex alloy systems—in particular, a class of stainless steels designed to provide superior corrosion resistance. This corrosion resistance results from addition of elements such as chromium, nickel, and manganese. Carbides dispersed in the matrix of austenitic stainless steels increase their hardness.

Only a few austenitic stainless steels, however, are strongly resistant to galling. One of these is Nitronic 60, a mixture of iron, chromium, nickel, manganese, and silicon—with a very small amount of nitrogen. By adding carbon to this mix to produce a carbide network, researchers hoped to produce a microstructure resembling that of the Stellites. Proportions of other constituents were then fine-tuned to produce the right combination of physical properties in the resulting alloy. Nickel, for example, helps stabilize the austenite structure. With too little nickel, the alloy would be brittle; with too much, galling resistance would suffer. The initial alloy design effort, therefore, concentrated on adding carbon and then determining the minimal level of nickel needed to prevent brittleness.

The first samples of the new family of austenitic iron alloys were melted in an induction furnace and cast in molds. A very demanding test of galling resistance was then performed by rotating an alloy pin against a plate of the same material under different applied stresses. In this test, the amount of galling is determined by measuring the microscopic surface damage on the specimens using a fine stylus; such measurements are far more accurate than trying to determine the

Rub-off Value

Although developed mainly to reduce the presence of radioactive cobalt in nuclear power cooling systems, NOREM is most likely to have applications in other markets as well. Oil-drilling bits and the blades on earthmoving equipment, for example, are normally hardfaced to prevent excessive wear. The iron-based NOREM alloy should be attractive for such uses on the basis of cost alone.

amount of galling from visual observations only, which had previously been the accepted procedure. A variety of other tests were also performed, including experiments to determine the weldability of the new alloys, because hard-facing surfaces are usually welded onto the base metal.

Results of these early tests were both exciting and frustrating. Alloys were found that indeed had galling resistance equivalent to that of the Stellites. Surface damage as measured in the galling tests was only about 1 micrometer for both the Stellites and the new alloys, compared with more than 20 micrometers for the nickel-based alloys. Microscopic examination revealed, however, that the metal's carbide deposits were interconnected. As a result, welded overlays created with rods of alloy as the welding medium cracked through the carbide layers. Clearly, a way had to be found to improve the distribution of carbides in the new material.

Efforts to create carbide deposits with a finer structure—so as not to form a continuous network through which cracks could propagate—involved changes in both the composition and the method of welding. Carbide-forming metals, such as niobium and titanium, were added to form discrete rather than interconnected carbides. The metal substrate was heated before welding, and a different welding method, called the plasma transfer arc (PTA) process, was used. Instead of welding with alloy rods, this process injects the hard-facing alloy as a powder into an electric arc in the vicinity of the surface to be welded.

These efforts were largely successful. By 1986 the AMAX team led by Edward Whelan, working closely with EPRI's Howard Ocken, had succeeded in producing the NOREM family of carbide-strengthened iron-based alloys. The galling resistance of these alloys was found to be as good as that of the Stellites, and their PTA weldability was acceptable. The NOREM alloys generally required higher preheating temperatures of the substrate, but this is considered only a minor disadvantage.

In other ongoing laboratory work, EPRI is sponsoring corrosion tests on the new alloys in high-temperature water that simulates reactor chemistries. The early results of these tests, being performed by Westinghouse Electric, suggest general corrosion rates about equal to those of the Stellites.

Demonstration work

Having developed and tested the NOREM alloys in a laboratory setting, EPRI is now moving to demonstrate their effectiveness in nuclear plant service. The first step in this effort is to test NOREM and two other galling-resistant cobalt-free hard-facing alloys on valves at a loop facility of Atomic Energy of Canada, Ltd. (AECL). In this experimental facility, valves can be cycled repeatedly under temperature, pressure, water chemistry, and flow conditions similar to those in an operating reactor.

Gate valves, which are used only for on-off operation and are unable to throttle flow, have been chosen for testing the hard-facing alloys. Gate valves are closed by a sliding disk that moves into place at right angles to the flow path. This sliding action subjects the hard-facing to galling wear.

The test valves will first be exposed to simulated PWR coolant chemistry conditions, then refurbished and exposed to simulated BWR conditions. The duty cycle for each exposure will simulate the demands placed on the valves over a full reactor lifetime. During these tests, the hard-facing surfaces will be examined periodically by nondestructive techniques. Once the full duty cycles are complete for each set of exposures, the valves will be disassembled and their hard-facing alloys destructively examined.

Earlier, the AECL facility was used to qualify nickel-based hard-facing alloys for nuclear service. These alloys are now used extensively in Canada's pressurized heavy water Candu reactors. During the current loop tests, a direct comparison will be made between the performance of NOREM and the other cobalt-free alloys, using a cobalt-based Stellite as a reference alloy.

To prepare the NOREM alloys for commercialization, work is continuing on ways to produce them as weldable powders and rods, using standard industrial practices. Although the PTA welding method has been demonstrated satisfactorily, feeding powders into an arc above a base metal surface is gravity-dependent, and the valve must be oriented properly beneath the arc for effective deposition. This method is thus suitable for original application of hard-facing to valves in a factory. Field use will require alloys to be available in rod or wire form as well—a fabrication problem not yet resolved.

"Development of NOREM will enable utilities to move more aggressively in replacing cobalt hard-facings on nuclear valves," says Howard Ocken. "Now we've provided a new family of cobalt-free alloys that can be used as hard-facing on even those valves that suffer the most wear. Our laboratory work has shown that NOREM can match the performance of cobalt-based alloys in a number of key areas.

"We expect to be able to produce NOREM hard-facing, using standard practices, at lower cost than that of alternatives. With a ready market in the utility industry and a host of potential applications outside, we are confident of licensing these materials for commercial production in the near future." ■

This article was written by John Douglas, science writer. Technical background information was provided by Howard Ocken, Nuclear Power Division.

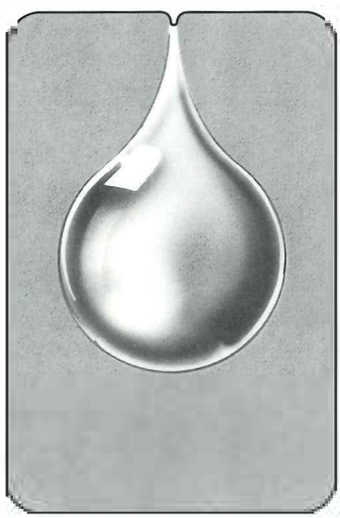
TECH TRANSFER NEWS

Water Chemistry Guidelines Revised

The development and implementation of nuclear power plant water chemistry guidelines by EPRI and associated owners groups is a success story that included some revisions in 1987. During the past year, EPRI published revisions of *BWR Normal Water Chemistry Guidelines* (NP-4946) and *PWR Primary Water Chemistry Guidelines* (NP-4762) and began work on revising *PWR Secondary Water Chemistry Guidelines* (NP-5056). In addition, the Institute published two new documents to guide those utilities using the hydrogen water chemistry (HWC) option for BWRs (NP-5283-SR-A, NP-4947-SR-LD).

The ongoing development of the guidelines and their acceptance as virtual standards by the U.S. utility industry is a story of utilities working together with EPRI to share information, arrive at generic solutions, and remedy corrosion problems that were having a negative impact on plant availability. In the early 1980s, research established that impurities in cooling water could accelerate two major corrosion problems facing the industry: corrosion in PWR steam generators and intergranular stress corrosion cracking (IGSCC) in BWR recirculation piping. The challenge facing EPRI, the Steam Generator Owners Group, and the BWR Owners Group was to arrive at consensus water chemistry guidelines that would help utilities across the industry to arrest and prevent these problems.

To develop the PWR secondary, BWR, and HWC guidelines, the owners groups used a cooperative committee system that has also been used by EPRI to develop the PWR Primary Guidelines and other guidance documents. In this process, a guidelines committee of industry leaders creates a working group of utility specialists, vendor representatives, and expert consultants to discuss the state of the art in the technology and draft the guidelines. This task entails consultation with the Institute of Nuclear Power Operations (INPO), a source of expert technical advice. In a last step, the draft guidelines are reviewed by a technical committee of nuclear plant personnel, who check them for accuracy and applicability at plant sites.



One aim of this process is to create generic guidelines that can be useful and cost-effective at diverse power plants with different water sources and corrosion problems. "Rather than impose a rigid series of specifications on plant operators and managers, the guidelines establish recommended water quality limits and suggest methods for controlling the water chemistry within the proposed limits," explains Chris Wood, EPRI program manager for nuclear power plant coolant technology. "This provides a framework in which different plants can meet their water chemistry goals in an effective and cost-effective manner."

The evidence to date suggests that the guidelines are serving their purpose. With the guidelines in use at nearly all U.S. nuclear power plants, water purity in BWR and PWR coolant systems has been improved across the industry. In response, the NRC has given its approval to water chemistry management programs based on the guidelines. "This is an example of the industry demonstrating to the regulators that it can effectively address its own problems," says Gerry Neils, a Northern States Power executive who chairs the BWR Owners Group Committee for IGSCC Research. "The success of the guidelines shows what can be accomplished when utilities work together to share their experiences and concerns."

Although the current versions of the guidelines have proved effective, recent revisions reflect new R&D discoveries and technology improvements. ■ *EPRI Contacts: for BWR and HWC guidelines, Robin Jones (415) 855-2790; for guidelines on PWR primary water chemistry, Chris Wood (415) 855-2379; for guidelines on PWR secondary water chemistry, Chuck Welty (415) 855-2783*

Targeted Chlorination Tested at Brayton Point

Investigators at New England Power's Brayton Point station are demonstrating a new technique to arrest biofouling in power plant condensers. Known as targeted chlorination, the technique allows utilities to control biofouling, while also limiting the discharge of chlorine to receiving waters to negligible or nondetectable amounts.

EPRI developed one targeted chlorination design as an alternative to bulk chlorination of the plant cooling water, a traditional strategy that has become less effective as a result of new environmental restrictions on the amounts of chlorine that can be used or discharged. EPA guidelines now limit the effluent total residual chlorine to 0.2 mg/L for only two hours a day per plant.

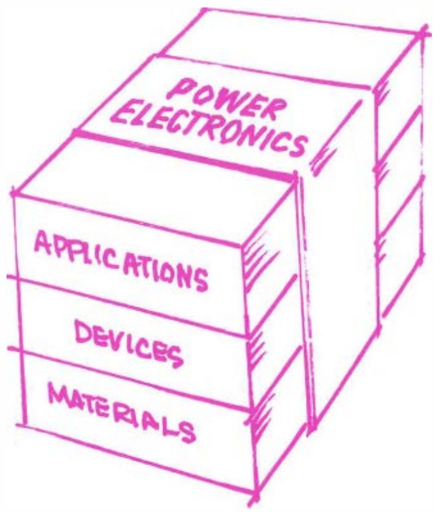
Full-scale demonstration of the new system began on the 250-MW Unit 2 at Brayton Point in June 1987. For the demonstration, an array of fixed nozzles was installed on the condenser waterbox and aimed toward the condenser tubesheet. The nozzles work sequentially, applying high dosages of chlorine (1–2 mg/L) to fractional areas of the tubesheet for short periods (5–15 minutes) until the entire tubesheet is chlorinated. Chlorine delivered by this method reacts with the unchlorinated bulk water to the point where it cannot be detected at the plant discharge.

The 12-month demonstration includes testing to compare the new system with bulk chlorination still in use in a parallel condenser. By the end of testing in June 1988, investigators hope to assess the effectiveness of several different chlorine addition schedules. Preliminary tests at Brayton Point indicate that targeted chlorination does not cause corrosion problems in the AL-6X stainless steel condenser tubes or Muntz metal tubesheet. Investigators hope to confirm these findings by collecting corrosion data over a 12-month period.

EPRI has published several reports on this topic, including a description of five designs for targeted chlorination within a condenser waterbox (CS-4279) and an assessment of commercial applications (CS-5180). EPRI members are invited to visit Brayton Point station to see the targeted chlorination system in operation. ■ *Contacts: William Freddo, New England Power; Winston Chow, EPRI (415) 855-2868*

Applications and Effects of Power Electronics

Significant technology advances have produced many new applications of power electronic technology in the utility industry. A new report, *Materials and Devices for Power Electronic Applications* (AP/EM/EL-5470), provides a concise summary of the roles and prospective effects of power electronics on future utility system planning and operation.



The report ranges over the major classes of nonmilitary power electronics, concluding that developments in applications, power semiconductor devices, and semiconductor materials are apt to have a revolutionary effect on the generation, transmission, and use of electric power. Current and possible future applications range from multimegawatt switching equipment in utility networks to fractional kilowatt controls for home appliances.

The report contends, however, that more interaction between the application, device, and materials sectors of the United States power electronic community is needed to ensure a leading role for the United States in the development and commercialization of the technology. The report also points to a need for more and better coordinated basic research. The report sets priorities in specific areas of device and materials technology that need more research and recommends that EPRI's power electronics program be intensified and coordinated to complement and support the larger national effort in power electronics. ■ *EPRI Contact: Frank Goodman (415) 855-2872*

State-of-the-Art Guidance on Electrostatic Precipitators

Improvements in electrostatic precipitator technology are helping utilities meet increasingly stringent regulations on particulate emissions from coal-fired power plants. For comprehensive information on the new technology, and for detailed guidelines to precipitator design, operations, maintenance, and troubleshooting, utilities can turn to a new report, *Electrostatic Precipitator Guidelines* (EPRI CS-5198, Vols. 1–3).

Designed for practical use by utility engineers, plant operators, and maintenance personnel, the report is divided into three companion manuals. Volume 1, *Design Specifications*, includes guidelines for the specification and procurement of virtually every component of a precipitator. Volume 2, *Operations and Maintenance*, provides step-by-step procedures for precipitator startup, operation, and shutdown, and for routine and periodic maintenance; it is designed for use in conjunction with vendor-supplied manuals. Volume 3, *Troubleshooting*, offers detailed information to help engineers and plant operators determine the root causes of unsatisfactory precipitator performance.

Although the manuals are written primarily for users having some knowledge of precipitator design and operation, they provide enough background material and precipitator theory to be useful as training aids. The manuals also feature a loose-leaf format to allow updating. ■ *EPRI Contact: Ralph Altman (615) 899-0072*

Coal Quality

On-line Coal Analysis

by Dave O'Connor, Coal Combustion Systems Division

ABSTRACT *On-line coal analysis technology promises to open new frontiers to utilities. Until recently, emphasis in this technology has been on demonstrating the feasibility of obtaining coal quality information in real time under power station and coal mining conditions. EPRI has led this effort by sponsoring a comprehensive continuous on-line analysis of coal (CONAC) demonstration at the Tennessee Valley Authority's (TVA's) Paradise steam plant, an evaluation of a real-time coal sulfur analyzer at Detroit Edison's Monroe plant, and comprehensive evaluations of microwave attenuation moisture measurement techniques. With the successful completion of these projects, the focus at EPRI and throughout the industry has shifted to the effective and economic application of this never-before-available information to utility and coal mining/cleaning operations.*

The coal consumption rate at a typical utility power station can be as much as 5000 t/d. Present sampling and analysis practices prescribe that the contents of the 5000 tons be determined by analysis of only 1 gram. Although sampling criteria and techniques are well defined by the American Society for Testing and Materials (ASTM), a standard three-stage sampling system is frequently a maintenance item. A normal sampling and analysis cycle takes at least 48 hours to complete and frequently, several days. This process means that a utility carefully following prescribed sampling standards may have a reasonable estimate of the mean properties of the coal but will sacrifice a significant amount of time getting that estimate. In fact, the coal lot sampled often will have been cleaned, shipped, or burned by the time the utility receives the laboratory results.

In addition, coal is not homogeneous; in fact, it is quite heterogeneous. Its properties can change very quickly from point to point in a given lot, so estimates of mean properties are not always useful. Short-term (1–12 hours) coal variability cannot be estimated at all by using ASTM techniques, but researchers have found that coal sulfur content, for example, can vary by as much as 25% within 20 minutes. Because determining coal quality is uncertain, EPRI and others have developed techniques for analyzing coal properties continuously, nonintrusively, nondestructively, and with few or no sampling requirements.

Analyzer development and demonstrations

EPRI began investigating on-line coal analysis techniques in the late 1970s. Science Applications International Corp. (SAIC) carried out this research, which led to the development of a CONAC system. The system was developed to explore the capabilities of this new technology, identify areas for further research, and provide technical guidance for future analyzer users and manufacturers. The CONAC system was installed at TVA's Paradise coal-cleaning plant for comprehensive evaluation in September 1983 (RP983). Results from this demonstration project are summarized in an *EPRI Journal* article (July/August 1986, pp. 44–45) and will be detailed in a future EPRI report.

In 1983 Detroit Edison acquired an on-line sulfur meter for blending coals by sulfur content to meet newly mandated plant SO_2 emission levels at its Monroe plant (RP2574). Based on technology developed by EPRI and SAIC, the sulfur meter analyzes a sample of coal as the fuel is conveyed to the power plant bunkers. The analyzer determines the sulfur content and signals that value to operators, who can control reclamation rates from the various stockpiles in the Monroe coal yard (Figure 1). This feedback control configuration allows operators to deliver coal with a consistent sulfur level to the power plant bunkers.

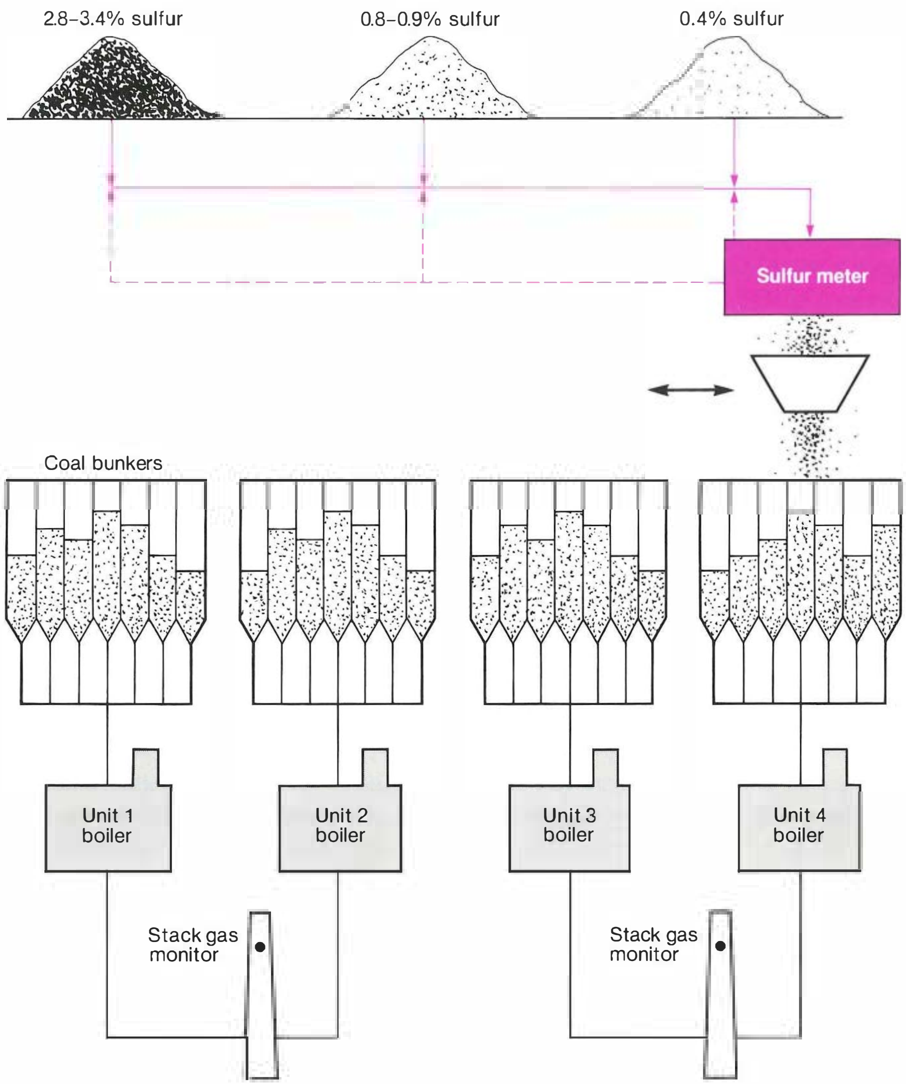
In addition to ensuring that environmental constraints are met, this arrangement has other advantages. Premium quality, low-sulfur coal required by such utilities as Detroit Edison to meet environmental regulations usually costs more than high-sulfur coal. By using the sulfur meter, Detroit Edison was able to meet emission targets confidently and to simultaneously minimize its use of more-expensive coal. Detroit Edison personnel calculated that the saving in coal costs for a single year (1984) was $2.9 million. The utility is currently evaluating the positive effect of burning a coal with a uniform sulfur level on ESP performance and unit load. The details of Detroit Edison's successful efforts to employ real-time sulfur information are related in CS-2441.

These demonstration projects, coupled with data gathered from other utility experiences, show that coal analyzers provide the following benefits.

- They are capable of accurately measuring coal properties to at least the levels specified by ASTM.
- They can simplify or eliminate sampling requirements by measuring at flow rates of up to 500 t/h.
- They can determine coal variability by providing quality analyses in less than three minutes.

Further, utility personnel can operate analyzers reliably in a power plant environment.

Figure 1 **This coal flow diagram for the Monroe plant shows the position of the sulfur meter in relation to the coal piles, bunkers, and boilers. Reclamation is achieved at the feeder set points, and the coal is fed to the bunkers at variable rates.**



Implementation status

EPRI's research and development in on-line coal analysis has spurred the commercial maturation of a range of analyzers with varying capabilities. The analyzers vary by what they measure, how well and how quickly they measure, and their cost. All analyzers reduce sampling requirements: some require no sampling; others require only minimal sampling.

Single-constituent analyzers that measure ash, sulfur, or moisture are available; comprehensive analyzers, such as the CONAC system, that measure these three constituents plus heating value, carbon, hydrogen, nitrogen, chlorine, and ash composition are available. Costs range from less than $100,000 for a simple moisture analyzer to more than $500,000 for a comprehensive analyzer of the CONAC type.

Currently 23 analyzers are installed in commercial service in North America. Lower-cost, more-simple analyzers installed at coal mines or mining facilities (16 of the 23 analyzers are installed at mining sites) predominate. Although this installation pattern is attributable in part to the fact that there are significantly more coal mines than power stations, it also points to two underlying issues that EPRI is currently addressing. First, virtually every utility installation of an on-line coal analyzer to date has been a first-of-a-kind application. Second, evaluating the benefits of a utility application is generally more complex than defining the benefits to a coal producer.

The first situation means that few control packages are commercially available that can use the increased quality and quantity of the information now available. Installations in which effective real-time coal quality information has been used have required the utilities to develop complete control strategies.

For example, TVA has a sulfur meter installed at its Paradise coal-cleaning plant. The purpose of this equipment is to monitor coal sulfur content as the coal exits the cleaning plant to ensure that its level does not exceed plant emission standards. The real-time sulfur information is relayed to the cleaning plant, where operators can act to hold the sulfur level steady. However, TVA and its contractor, Praxis Engineers, had to develop the process decision logic because decisions of this nature had never been made before.

EPRI and TVA are currently determining whether additional benefits could be realized by supplying TVA's control logic with more coal quality information, including information about coal heating value and moisture and ash concentrations. Investigators will compare added benefits with the increased costs of obtaining that information from a more comprehensive analyzer. An optimal information level will be selected for the Paradise cleaning plant, but the methodology and information assessment techniques can be modified for other cleaning plants

Regarding the second issue—quantifying coal analyzer benefits to a utility—many coal producers sort coal by quality or blend coal to meet utility quality specifications. Both applications require relatively simple control actions and reactions. But a utility that wants to reduce boiler slagging by detecting a problem coal must consider many issues, including the following.

- What causes slagging? Is the problem a result of high ash loading, or is slagging the result of a "bad" ash constituent?
- Once the cause of the slagging is identified, where should the analyzer be located: at the coal receiving station, where slagging coal can be tracked in the coal yard, or on the main plant feed belt, where the problem coal can be detected and unit operations staff alerted?
- What are the economics associated with slagging? Is the utility forced to derate the boiler or to shed load? Does the boiler have to be derated during peak demand hours? What is the marginal cost of electricity for the utility? Can the coal supplier be assessed equitable penalties for delivering nonspecification coal?

Potential applications

EPRI researchers are starting projects that will address the two issues identified above by developing a series of application guidelines for several utility operations. The guidelines will allow a utility to evaluate a given application technically and economically and, if the evaluation is positive, procure an analyzer. The utility will be able to verify the results of the completed analyses through a series of short tests of the analyzer.

The guidelines will provide a method for evaluating in detail the costs and benefits of a potential utility application. They will identify and develop control strategies and calculate the cost of various control actions. Each guideline will highlight the number of different constituents an analyzer must measure and specify the accuracy and frequency of each measurement. These performance criteria will be the heart of a commercial procurement guideline for an on-line coal analyzer for each of the applications.

EPRI is now identifying the types of projects that will have the greatest benefit to utilities. These projects and results will be highlighted in a future *EPRI Journal*.

Overhead Electric Transmission

Transmission Line Design

by Paul Lyons, Richard Kennon, and Jim Hall, Electrical Systems Division

A transmission line is a linear structural system that must traverse long distances over widely varying terrain. The first task facing the designer is to determine the application environment. Because of the length of any transmission system, this effort is a considerable one. Most structural loading parameters are weather-related and therefore stochastic (random) in nature. EPRI research has developed probabilistic methods for quantifying both structural loads and component capabilities. Using these techniques, a designer can work toward a design that is consistently reliable throughout its length.

The second task is optimizing the complete system. EPRI is developing such a capability that is far more comprehensive and easy to use than any other method. Overall optimization includes conductor selection, preliminary tower spotting, selection of everyday working tension, and selection of tower family.

In the area of component design, EPRI is using state-of-the-art software and test facilities. Although this concept is not new in most areas of product design, it has not been an option for transmission line designers. EPRI's extensive test program, used to verify software, now makes it possible for individual utilities to perform specific tests in support of their overall design effort.

Reliability-based design

Transmission line design requires that two primary sets of design criteria, electrical

ABSTRACT *The demands placed on transmission lines make their final design a compromise, at best. Balancing these demands to meet all expectations has long been a time-consuming, difficult process for utility engineers. Now, however, modern computer techniques enable engineers to shorten the process; they can achieve a blend of reliability, economy, and acceptance from a desktop computer. EPRI's methods also include full-scale testing at its Transmission Line Mechanical Research Center.*

and structural, be satisfied. The present design criteria of wood structures for transmission lines are considerably less developed and more approximate than are electrical criteria. Electrical designers formally recognize the element of uncertainty as it influences design by computing the probabilities of power outages caused by various phenomena and the resulting system reliability.

Procedures for designing wood transmission poles, however, are generally based on a combination of past experience and industry custom. Structural engineers usually account for variations in wood pole characteristics by selecting average material properties and conservative load factors and design loads. In response to utility recognition of a need for major improvements in both design practices and material property information, EPRI initiated RP1352 to develop reliability-based design (RBD) procedures for wood utility poles. This work is now complete, and the results are ready for use by utilities, according to Paul Lyons, project manager.

Reliability-based Design of Transmission Line Structures (EL-4793) presents the results of this project and related research studies from around the world in a form that enables designers to use RBD procedures efficiently in everyday design practice. In addition, the report serves as a resource by making available up-to-date data on such items as properties of utility line structure components, wind loading, and available computer software to both designers and developers of design documents. The report provides step-by-step procedures for individual designs of utility line structures, and designers can use it as a single source of background information on RBD procedures in general.

"The organizations that apply RBD will gain many advantages," says Lyons. "First, RBD methods use a more complete and realistic description of the actual conditions of design and structural performance." Second, according to Lyons, the RBD procedure is information sensitive. It can accept new data and identify the limitations and deficiencies of present data. The utility willing to invest in carefully planned and managed programs for gathering and evaluating weather, soil properties, and materials data applicable to its service area will be able to incorporate these new data into design and will benefit thereby.

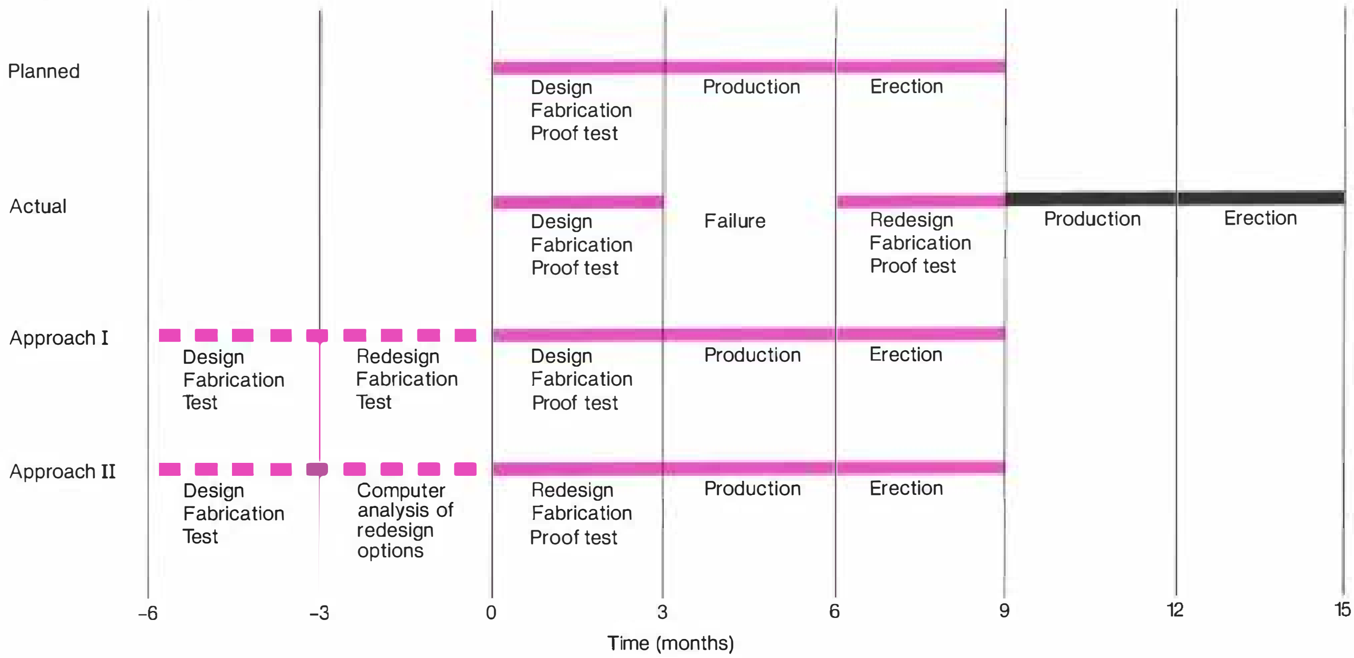
The third, and potentially most important, advantage of using RBD techniques is that they provide a powerful set of management tools with many applications beyond the design of new construction. Personnel can make structural decisions on reconductoring, rebuilding, and major maintenance and can compute the reliability of existing transmission structures before and after proposed reconductoring. "The overall benefit of RBD is that it combines better control of construction and maintenance costs with reduced risk of structural failure," states Lyons. "To take maximum advantage of the benefits of RBD methods, utilities should begin now to integrate these design techniques into their approach to wood pole structure design, upgrading, and maintenance."

Transmission line optimization

Historically, the process of optimizing transmission lines has been limited to conductor selection based on costs for construction, materials, and losses. This process normally takes place early in the design cycle, well before any detailed design has started. Structure spotting, on the other hand, usually takes place during the detailed design stage. EPRI's project (on transmission line optimization, RP2151) has long had the goal of integrating the two. Recent studies by Power Technologies indicate that results from the structure spotting can have an important effect on conductor selection. In addition, conductor tension has a different effect on cost in a structure-spotting study than it does in the usual optimization study. To truly optimize the overall design of a transmission line, the engineer must spot the structures early—during the initial study phase.

The computer program developed earlier in this project for conducting optimization studies is called TLOP. At present, TLOP incorporates a number of separate calculation routines and data bases that allow the user to consider the widest possible number of solutions to the problem of line design. A designer can study terrain effects by inputting structure family information. This can be predicted at the beginning of the study, or it can be obtained from a structure spotting study. To make structure spotting easier, EPRI has obtained the central computation algorithm from a well-known tower spotting program. This routine, named

Figure 1 Transmission line design process. In the actual sequence an unexpected failure can delay production and result in an uneconomical fix because of pressure to get the system designed and installed. EPRI approach I calls for a planned sequence of design tests in which failures are planned. It calls for starting the process about six months earlier and prevents the delay shown in the typical actual situation. Although this approach optimizes a design somewhat, cost and time constraints limit full optimization. In approach II designers use analysis software to reduce the amount of full-scale testing required. In a sense, the engineer can conduct any number of "tests" on the computer. This approach is made possible by the development of advanced analysis software that uses the results of the first test to improve the computer model.



TLSPOT, is being incorporated into TLOP to automate optimization, including terrain effects. EPRI does not intend to add the engineering features to TLSPOT that would make it suitable for detailed site engineering. These functions would not serve any research purpose, and they are available elsewhere.

The concept of including the terrain effect (i.e., structure spotting) in the preliminary optimization study is a departure from past practices. "Studies indicate that it can make a significant difference in the outcome," reports Richard Kennon, program manager. This phase of the research is expected to be complete and the revised software issued in mid 1988.

Component design

The Overhead Transmission Lines Program at EPRI introduced a revolutionary new way to design minimum-cost transmission lines. The new method first applies the best analytic tools available, then tests these designs in the laboratory, repeating this sequence as many times as it takes to fully optimize a design (Figure 1). This process previously took many iterations and was clearly not practical for a large, complex structural system, such as a transmission line.

"Now, however, two new tools combine to make this a viable strategy for the transmission line engineer who is either designing a new line or upgrading an existing line at minimum cost," states Kennon. The new tools are design laboratories and state-of-the-art analytic methods.

First, there are two cost-effective laboratories engineers can use to develop optimal designs. The older of the two is the High-Voltage Transmission Research Center in Lenox, Massachusetts. This facility is staffed with renowned experts in all aspects of insulation and environmental effects of overhead transmission lines, who can help engineers with their unusual combination of knowledge, skills, and experience in experiments. All aspects of the line electrical performance can be tested so that performance can be proved before the line is designed and built.

The newer laboratory is the Transmission Line Mechanical Research Center in Haslet, Texas. Before the advent of this facility, no one had the necessary resources to experiment on full-scale structures. The work done here during the past three and a half years has been truly pioneering. The control and instrumentation developed is uniquely efficient and revealing. Fully operational equipment, in service since last June, gives the test and design engineer instant information on the behavior of a structure during test. More than three years of testing has proved beyond any doubt that few complex structures behave as predicted. "But our ability to observe behavior in detail and in real time is the indispensable new ingredient that makes the TLMRC a design laboratory," says Kennon.

However, no laboratory is cost-effective if the designer has to make too many trips to it—that is, if he or she has to travel frequently between the laboratory and the design office. In a real sense, EPRI's design and test program makes that trip back and forth many times for the designer. The results of all this effort reside in a unique package of computer programs called TLWorkstation.* These programs start with preliminary design and costing studies and then progress to detailed analyses of insulation, environmental effects, conductor selection and sagging, structures, foundation design, tower spotting, and more.

Users can call up every task module through the EXECUTIVE program so that they have only to learn one format. This feature minimizes the effort needed to learn the program and maximizes the time users can spend doing the actual job.

Further, each of the TASK modules has been developed and validated with the results of full-scale testing either at the laboratories or on utility systems. Combining the full-scale test data and the most up-to-date analysis software provides the best computer simulation of a structure that can be used to study design options. This combination has allowed the developers, for instance, to build into the structural analysis module behavior models, derived from testing, that result in more accurate prediction of structural performance. "This built-in experience base makes it possible to maximize the effectiveness of any utility's engineers either at the computer terminal or in the laboratory," claims Kennon.

*TLWorkstation is an EPRI trademark.

Ecological Effects

Assessing Potential Toxicity in Aquatic Ecosystems

by Donald Porcella, Environment Division

ABSTRACT *At present, researchers cannot predict the ecologic effects of many chemicals associated with utility activities. Different concentrations of chemicals interact with fluctuating environmental factors, which makes it difficult to assign causes to changes—for example, in animal populations. The objective of this project is to develop a mechanistic approach for predicting the ecologic effect of toxicants on fish and other aquatic animals. Research to date has concentrated on three elements: selenium, arsenic, and mercury. The results have emphasized the importance of measuring specific chemical species of these elements for understanding the biogeochemistry. Planned research on bioaccumulation is aimed at providing utilities with a predictive tool for assessing toxic effects.*

Utility activities can result in contamination of surface waters by ash-derived metals, by combustion-volatilized mercury, by coal-gasification residuals, and by biocides. Certain inorganic and organic chemicals concern utilities because of their potential for toxicity and bioaccumulation. Unfortunately, researchers do not know the biologically important chemical species for many substances, the ambient concentrations that might cause damage, or the significant factors that affect cycling and ecologic effects. The need for well-founded and cost-effective regulations governing the use of these chemicals requires that researchers learn more about their ecologic effects and the cycling processes that affect them. The objective of EPRI's project on animal responses to interacting stresses (ARTIS) is to study cycling processes and ecologic effects together and to develop techniques for predicting the effects of chemicals from utilities. The final product of this research will be a mechanistic model that predicts ecologic effects from data on discharge and physical, chemical, and biologic characteristics of receiving water.

Cycling and ecologic effects research

Cycling (biogeochemistry) includes transport, transformation of chemicals, and distribution of substances in physical and biologic media. Researchers study cycling of chemicals of ecologic concern—that is, those chemicals that are toxic, that accumulate, or that affect the toxicity of other chemicals. A toxic chemical may have numerous effects: It can be fatal to organisms, reduce growth and reproduction, and produce abnormalities in various life stages. Bioaccumulation is a process in which chemicals accumulate in organisms by means of the food chain. Bioaccumulated chemicals can be directly toxic to organisms at the lower end of the chain and/or to animals feeding on those organisms. Further, this bioaccumulation could present toxic or carcinogenic risks to humans who eat these animals.

Researchers can predict with acceptable precision the cycling and the effects of many toxicants as long as the environment remains fairly stable. In a varying environment, however, the effects of different toxicants and their interactions with other stresses (e.g., temperature, low dissolved oxygen) are not as easy to predict. This variety increases uncertainty, which consequently increases regulations and control costs. The environmental behavior and effects of some chemicals are more difficult to understand because they have many chemical forms, each of which has different behavior and biologic distribution.

Three poorly understood elements are selenium, arsenic, and mercury. These elements have both natural and anthropogenic sources. Most of the utility contribution comes from coal combustion. Selenium and arsenic are concentrated in coal ash, from which they can be leached into water, but mercury is released into the atmosphere, from which it may be deposited onto watersheds and surface water. Researchers are just now beginning to understand the natural cycles, the geochemically important forms, and the quantity and kinetics of transfer among different forms of these three elements. All three are distributed by biologic processes, and generally the organic forms are more toxic than the inorganic forms. However, researchers still do not know the rates of biologic uptake and release for each chemical species or their effects on natural populations in combination with other toxicants or stresses.

Initially, the ARTIS project is focusing on these three elements, and the approach developed for their study will provide methods applicable to other toxic chemicals. The concept requires a mechanistic model for integrating cycling and biologic effects. Because variables, such as temperature and oxygen, affect transfer and transformation of the elements as well as responses of aquatic organisms, the model will include these potential stresses. Multiple toxicants stress natural communities, and project personnel will integrate these interactions into the model. ARTIS has three steps.

- Development of analytic methods for measuring ambient concentrations of important species of the three elements
- Use of these methods to analyze the chemical species of importance to fish and other aquatic flora and fauna
- Study of bioaccumulation and biologic effects of the important chemical forms by using organisms selected for their importance to aquatic ecosystems

Using the results, researchers will develop a dynamic mechanistic model that combines biogeochemistry and population models for predicting ecologic effects from discharge and receiving water data. Project personnel will not simulate biochemical transformations within organisms. As part of the modeling effort they will investigate methods for estimating uncertainty.

Selenium and arsenic

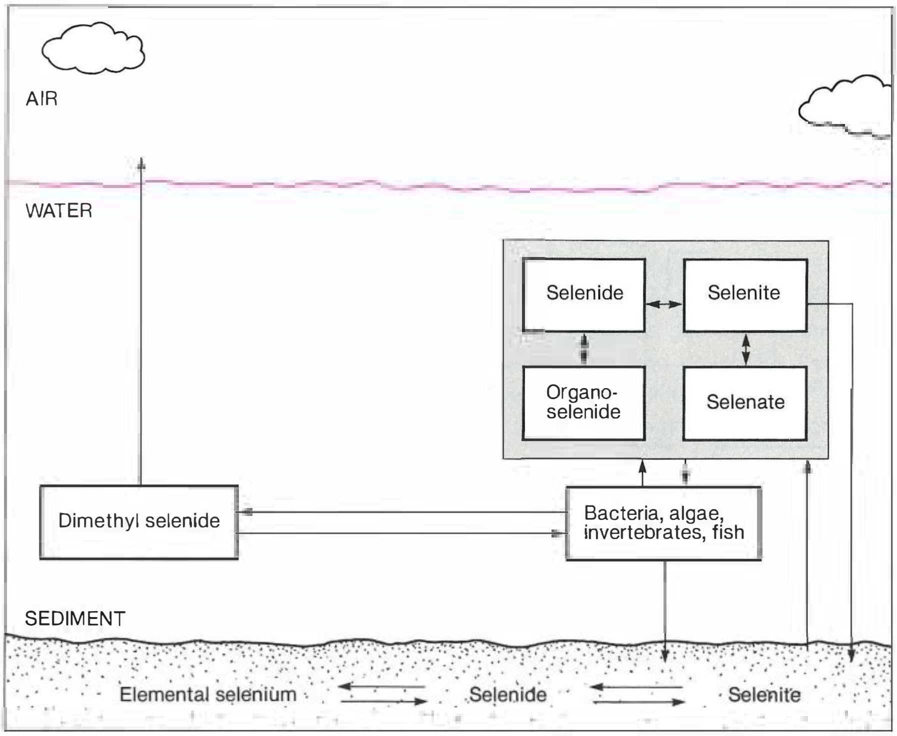
Selenium can occur as selenate, selenite, selenide, organic selenides, and elemental selenium (Figure 1). Transformations of selenium in nature are controlled by reduction and oxidation (redox), as well as by dissolution-precipitation and acid-base reactions. Many of these reactions are biologically controlled and do not reach equilibrium. EPRI's selenium research began in 1978 with a toxicologic investigation of selenate, which is the thermodynamically stable form of selenium in oxygenated environments. The initial results showed that selenate is not toxic at environmental concentrations. In fact, it is the least toxic form of selenium. Because toxic effects were observed in cooling-lake environments and selenium was the apparent cause, it was apparent that other forms of selenium (organic selenides) were responsible for the effects.

The major conclusion of these early studies was crucial to the ongoing work: For relevant toxicologic study of ecologically important chemicals, cycling research is needed to identify typical ambient concentrations of the biologically important chemical species of selenium.

EA-4641, Vol. 1, describes methods for measuring the selenium species—selenate, selenite, and the reduced selenium forms (selenides and elemental selenium). Recent improvements in gas chromatograph techniques allow the separation of selenide and elemental selenium and the measurement of dimethyl selenium, the latter a significant part (up to 30%) of the mass balance of selenium in some aquatic ecosystems. Because the chemical analog for selenium is sulfur, techniques have also been developed (RP2020-01) for sulfur speciation in sediments at environmental concentrations.

EPRI's researchers are quantifying the selenium cycle by biogeochemical investigations in three cooling lakes, in which biologists had observed declining fish populations. Two lakes are in North Carolina: Hyco Reservoir receives a steady flow from an ash pond; the flow to Belews Reservoir was terminated in mid 1985. The third lake, Martin cooling pond in Texas, received a large spill of ash material, which settled to the lake bottom. Hyco represents a steady-state situation. Belews represents a change—a sudden decrease in inflow—and changing concentrations in the lake reflect lake sediment release and other geochemical reactions. Martin is a special case; sediments are the main source of

Figure 1 Selenium cycle in freshwater ecosystems, showing major compartments and transfers between the gas, water, and solid phases.



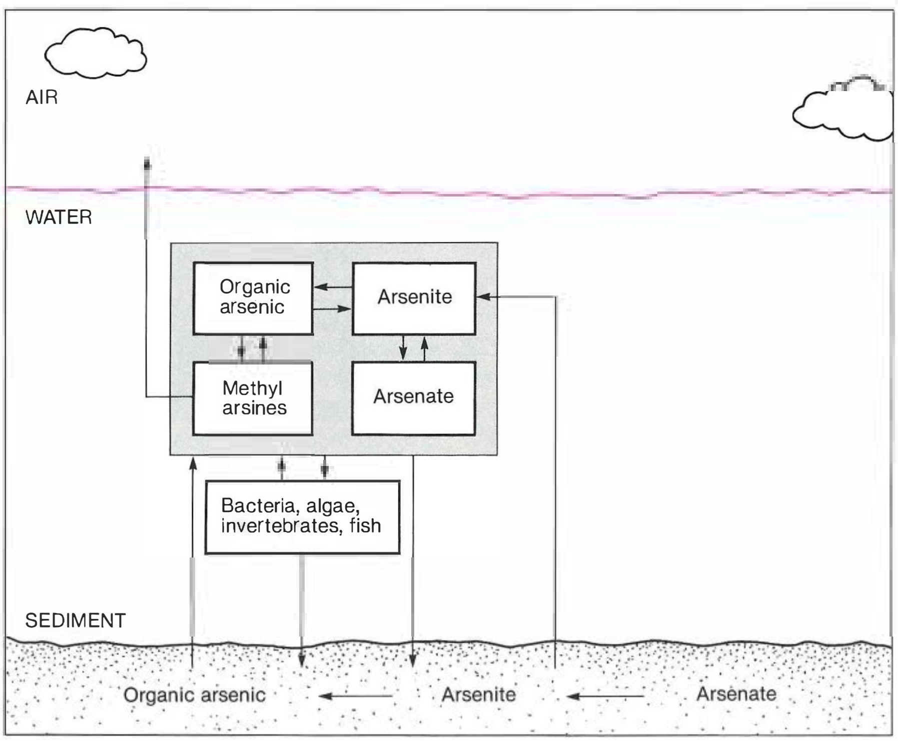


Figure 2 Arsenic cycle in freshwater ecosystems has compartments analogous to those of selenium but different rates and processes.

selenium species. In addition, the water chemistry of the Texas lake is different from the low-ionic-strength water of North Carolina, and this may affect selenium cycling. Researchers are also studying control (i.e., reference) lakes to compare cycling in the cooling ponds with lakes, where there are no ash leachates.

Some of the initial results of this field research illustrated the value of looking at other water quality constituents. For example, selenite is the dominant chemical form of selenium most of the year and throughout the water column in all three cooling reservoirs. However, during late summer of 1985 all the oxygen in the deep water of Hyco Reservoir was consumed, coinciding with large decreases in selenite. One initial hypothesis was that ferrous selenite precipitated and settled into the sediment. However, recent analysis indicates that the sediment contained nearly equal amounts of elemental selenium and ferroselite ($FeSe_2$). The final report for this phase of the research is expected by mid 1988.

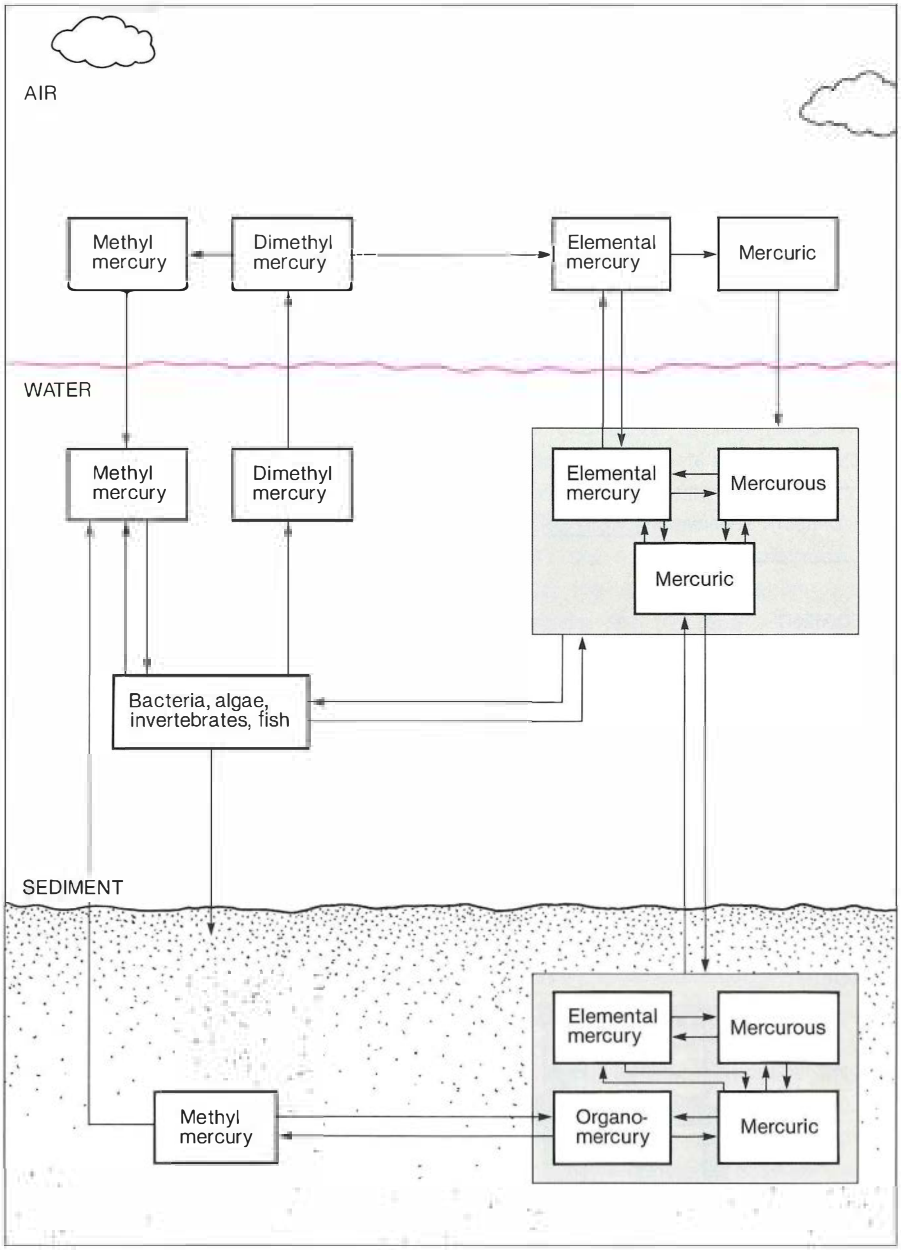
One significant result that emphasized the need for selenium field studies came from related work on selenium equilibrium modeling (RP2020-03). These models usually do not predict the behavior of selenium in natural systems because selenium is not at equilibrium. However, the predictions do provide a reference point for comparing equilibrium and observed concentrations. In this case, only a minimal number of the thermodynamic constants have been measured, and thermodynamic modeling based on literature data sets is inappropriate.

In 1988 EPRI plans to begin laboratory and field studies to develop a mathematical model that describes the effects of ambient water concentrations of selenium and a second toxicant (such as arsenic) on survival, growth, reproduction, abnormalities, and bioaccumulation for selected phytoplankton, zooplankton, benthic organisms, and fish. The effects of other stresses will be evaluated simultaneously with the bioaccumulation and effects experiments. Much work has been done under previous EPRI contracts and by utilities themselves. For example, Carolina Power & Light studied quantitative relationships between effects on bluegill life stages and concentrations of varying forms of selenium. EPRI funded the research on the larval phase (RP2020-06). This work will provide an important base for future investigations.

At the beginning of the selenium work, researchers thought that arsenic would represent an ecologic risk that might influence interpretation of selenium effects. Under RP2020-02, methods for analyzing the significant forms of arsenic were developed (EA-4641, Vol. 2) and are now used in studies of arsenic geochemistry (RP2020-03). The arsenic cycle has a complex behavior similar to that of selenium (Figure 2). The chemical analog for arsenic is phosphorus, which is an important nutrient in lake ecosystems, where it is often the limiting factor for productivity. In fact, arsenic can interfere with phosphorus measurements. With few exceptions, arsenic chemical species do not reach concentrations in receiving waters that are toxic to organisms, and bioaccumulation does not appear sufficient to represent a threat to human health.

The arsenic work is coordinated with the selenium research. Simultaneous sampling of water, sediment, and suspended particulate matter at each of the test and control lakes ensures comparability of results. An additional benefit from studying arsenic arises from the observation that redox pairs of arsenic (e.g., arsenate-arsenite) help define conditions governing the behavior of selenium redox pairs. For example, when low concentrations of dissolved oxygen result in selenite removal, arsenite increases to concentrations an order of magnitude higher than typically observed. By comparing the arsenite-arsenate pair to the selenite-selenate pair, researchers gain a better understanding of the redox conditions present in the lake ecosystem. The ecologic effects of the high concentrations of arsenite, however, remain unknown.

Figure 3 Mercury cycle in freshwater ecosystems. Transfer between inorganic and organic forms affects toxicity and phase distribution (e.g., whether mercury enters the atmosphere).



Mercury

Researchers are concerned about mercury because one hypothesis makes a direct link between acid deposition and excessive mercury in fish. However, mercury biogeochemistry research at EPRI will not begin until a current project shows whether mercury bioaccumulation in fish is associated with low-pH water (RP2020-05). The research, performed in cooperation with the Environmental Protection Agency (EPA), involves several coordinated steps. Earlier, EPA analyzed lakes for pH, acid-neutralizing capacity, cations, anions, and aluminum species during phases I and II of the National Surface Water Survey. EPA's contractors collected fish from a pH-weighted random sample of lakes in Michigan's Upper Peninsula. EPRI contractors will analyze these fish samples for total and organic forms of mercury (fish typically contain about 90% methyl mercury). In addition, EPRI contractors have amassed a large data base of fish mercury measurements and water quality and fish mercury concentrations. Results will provide information about relationships between water quality and fish mercury concentrations. Other projects related to the mercury project are coordinated with RP2020-05, including measurements of trace metals in the same lakes from which the fish are collected, a project jointly funded by EPRI (RP2020-07) and EPA , measurement of mercury accumulation in game-fish, a project funded by EPA, and the effect of water quality on the presence or absence of fish, funded by EPA.

Mercury behavior is complex (Figure 3), and the element has significant organic forms that pose major risks to humans. However, unlike selenium and arsenic, anionic forms do not occur, nor do chemical analogs for mercury appear to play any role in mercury behavior. One of the major unresolved mercury issues is the difficulty of measuring ambient concentrations of organic mercury species, especially methyl mercury, in water samples. Water concentrations are the link between sources and exposure of biota, and in many lakes fish bioaccumulation levels are sufficient to suggest risks to human health even when water concentrations are below chemical detection limits. A recent EPRI report (EA-5197) describes advances in measurement techniques for mercury species in sediment and water samples and concludes that techniques do not exist for methyl mercury that are sensitive enough for biogeochemical work.

Under EPRI contract RP2020-04, the Swedish Environmental Research Laboratory is developing a new technique that appears promising for concentrating aqueous methyl mercury for analysis. These researchers have provided data indicating that methyl mercury may be formed abiotically in humic soils, a hypothesis that other investigators had dismissed.

Assessment

Utilities need the capability to assess the direct and indirect effects of their activities on the environment. To make these assessments, they have to know the relative effect of different environmental chemicals on natural communities with an acceptable level of uncertainty both for toxic effects and for nontoxic bioaccumulation that might pose risks to humans. Then they can take measures to control environmental releases or design appropriate cleanup measures for existing problems.

Mechanistic models developed in ARTIS will be useful to the specific problems posed by selenium, arsenic, and mercury. Even more important, researchers will have developed and demonstrated the general applicability of the mechanistic approach for assessing ecologic effects caused by other toxic chemicals.

Fuel Cells

High-Efficiency Steam Reformer Tests

by Daniel Rastler, Advanced Power Systems Division

EPRI is conducting research to develop, test, and verify the performance and durability of fuel-processing components suitable for use in a multimegawatt fuel cell power plant (RP2192-1). This project is part of a larger national program sponsored by Westinghouse Electric and DOE to develop technology and systems that would be technically and economically feasible for application in a 7.5-MW fuel cell power plant.

Phosphoric acid fuel cells are projected for operation as cycling, intermediate-duty power generators capable of load following and frequent thermal cycles. These operating characteristics place unique requirements on the plant's fuel processing system, which converts fuel (natural gas or other light hydrocarbons) and steam into a hydrogen-rich gas for use in the fuel cell. The major component in the fuel processing system is the steam reformer, which is used to catalytically convert the raw fuel into a hydrogen and carbon monoxide synthesis gas.

Commercially available steam reformers cannot meet the efficiency, size, transient response, thermal cycling, and cost requirements of a fuel cell system. As a result, it has been necessary to develop a new type of steam reformer, one that would be suitable for fuel cell applications.

The Westinghouse air-cooled fuel cell plant design was used as the basis for this development effort. Haldor Topsoe, Inc., and its parent company, Haldor Topsoe A/S of Copenhagen, Denmark, joined the program as the major subcontractor for the requisite technology and for reformer development. In addition, the parent company joined the program as a cosponsor. The following specific project tasks were established.

- Define a reformer conceptual design that would satisfy fuel cell requirements
- Prepare a detailed design of a reformer module test article
- Procure, fabricate, and install a full-scale test article
- Design and construct a reformer module test facility to enable demonstration of the test article
- Demonstrate the performance, operability, and durability of the reformer module test article

Reformer design

A new and patented steam reformer (Figure 1) was designed by using Haldor Topsoe's proprietary computer simulation model. A key feature of the new design, called the heat exchange reformer, is that it combines the advantages of countercurrent and co-current heat transfer to more accurately control hot metal wall temperatures and to increase overall reformer efficiency.

The reformer consists of a pressure vessel and an internal catalyst basket that contains two catalyst beds. The catalyst basket consists of a number of concentric cylinders; it is a separate structure and can be removed to provide easy access to the catalyst and to facilitate inspection and maintenance. The reformer burner is located at the bottom of the pressure vessel.

Process feed (steam and natural gas) enters the pressure vessel and is passed downward through the first catalyst bed; there it receives heat from the partly cooled combustion gas and the exiting product gas, both in countercurrent flow with the process feed. The process gas from the first catalyst bed is then transferred to the top of the second catalyst bed through a number of interbed transfer tubes. The process gas flows downward through the second catalyst bed, receiving heat from the hot combustion gas in cocurrent flow with the process gas. The product gas exiting the second catalyst bed is finally passed through an annular space, where it transfers part of its heat back to the process gas flowing in the first catalyst bed.

A modular reformer design was chosen because it offered high reliability and advantages in operating flexibility and maintainability. A conceptual design of a 7.5-MW reformer consists of six individual 1.25-MW modules operating in parallel. The design allows for a module to be isolated, inspected, and maintained without compromising power plant availability.

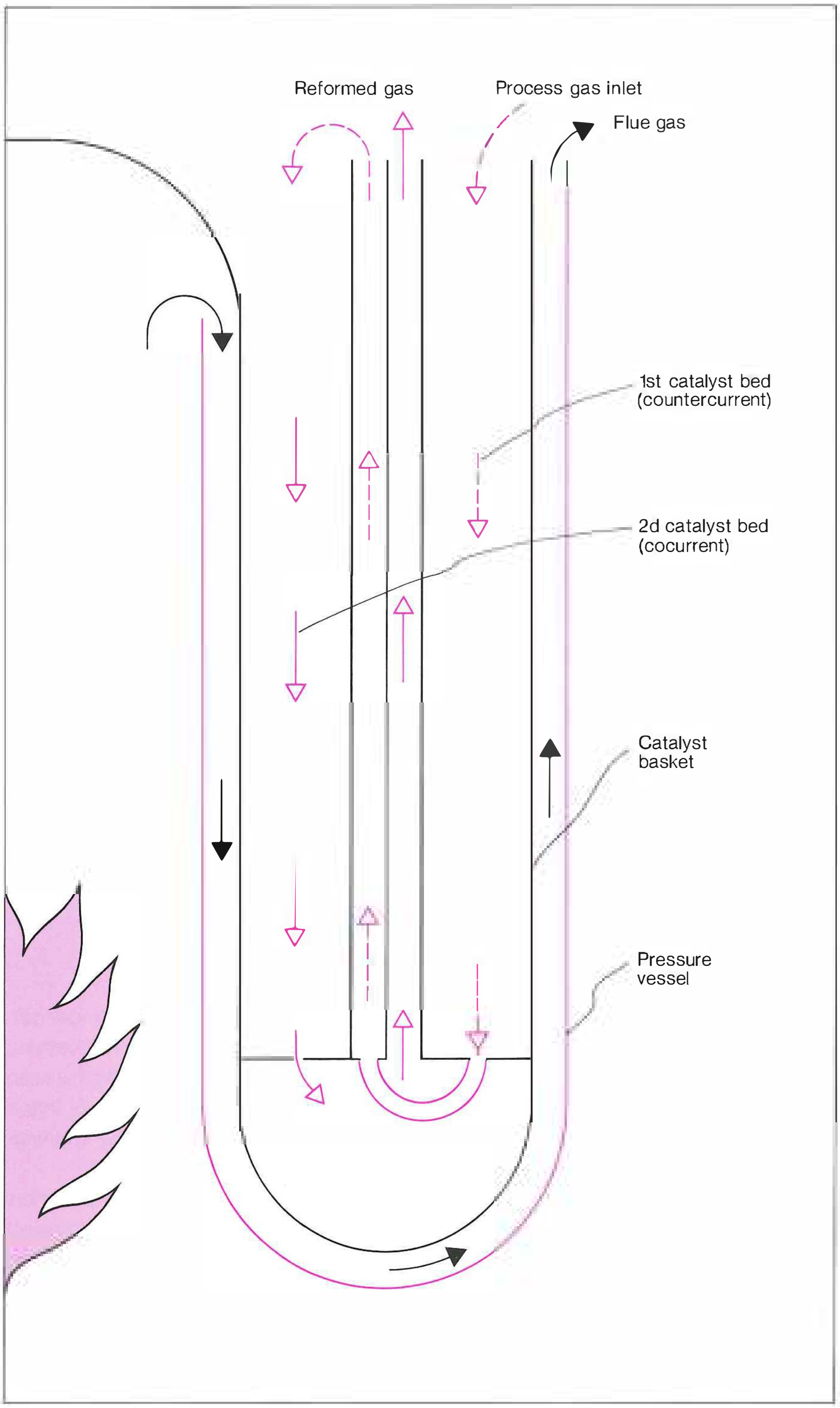


Figure 1 The heat exchanger reformer. An internal catalyst basket contains two catalyst beds; the burner is at the bottom of the pressure vessel. This new, patented design provides better control of hot metal wall temperatures and higher efficiency by combining the advantages of countercurrent and cocurrent heat transfer.

Demonstration tests

A full-scale 1.25-MW test article was fabricated and installed in 1985 at Haldor Topsoe's Bayport test facility near Houston,

ABSTRACT *Phosphoric acid fuel cell (PAFC) power plants offer electric utilities a new generating option that is highly efficient, modular, environmentally benign, and easily sited. To expedite their commerical introduction, EPRI is sponsoring development and verification tests of key PAFC power plant components to ensure their suitability for utility applications. To demonstrate the design, a full-scale (1.25-MW equivalent hydrogen) high-efficiency steam reformer module was fabricated and tested. Results after 3400 hours of operational tests are extremely encouraging.*

Texas (Figure 2). Demonstration tests were initiated in March 1986 and continued through October 1987. Their purpose is to confirm the feasibility of the reformer design, to conduct performance testing at steady-state and transient conditions, to map performance at part-load and standby conditions, and to assess the controllability, maintainability, and mechanical design features of the full-scale module.

A total of 2280 operating hours with the burner lighted were accumulated during the 1986 test period and 1140 hours in 1987. This operation comprised 21 cold starts and 192 thermal cycles. The first tests in 1986 were proof-of-concept tests. They confirmed that the combined cocurrent and countercurrent heat transfer approach works well and provides the desired decrease in hot metal wall temperatures. Test data also confirmed that Haldor Topsoe's computer design model could simulate the experimental data very well. In the initial test runs, 100% capacity was demonstrated with two types of burners.

Detailed mechanical inspections, including dismantling of internals and unloading of catalyst, were conducted after approximately 750 and 2280 hours of operation. The pressure shell and internals were in good condition, and there were no hot spots on the catalyst basket. However, some minor repairs and design modifications of the internal refractory materials were necessary.

In the second series of tests, the maximum capacity of the module was established to be 937,000 ft^3/d (26,530 m^3/d) equivalent hydrogen or 113% of design rating. At maximum capacity, further increase was restricted by the auxiliary equipment in the test facility and not by the reformer itself. The pressure drop of the process gas improved by ~10 psi (69 MPa) as a result of changing to a lower-pressure-drop catalyst. The second catalyst bed continued to contribute most of the observed pressure drop.

Standby, transient, and cycling tests were conducted in the fall of 1986. Those tests confirmed that the reformer temperatures were stable and controllable and that there were no significant heat waves during the up and down load ramps.

Daily cycling and additional transient tests continued in 1987 to confirm the durability of the reformer module because cyclic operation imposes thermal and mechanical stresses that can limit design life. The module was tested under an accelerated daily cycling profile for six weeks. The operating profile consisted of hourly load changes from 25% to 100% load and from 100% back to 25% load. This continued for 16 hours each day. During the remaining 8 hours, the unit was held at 25% load. On Fridays the

Figure 2 Full-scale 1.25-MW reformer module and supporting test facility installed near Houston, Texas. Natural gas and steam are catalytically converted into a hydrogen gas, the majority of which is flared to the atmosphere during a test. The EPRI test facility will be available to interested companies for special tests in 1988.

unit was shut down for the weekend and restarted late each Sunday evening.

A total of 138 complete cycles (load changes from 25% to 100% to 25%), 10 warm starts, and 8 cold starts were successfully recorded during this phase of the test program. Two other important transient tests were conducted in two separate runs. In one run, load was changed from 25% to 75% in 30 seconds; in a second run, load changed from 25% to 100% in 42 seconds. Again the data confirmed that temperatures remained stable and controllable and that there were no significant heat waves or pressure waves during the transients.

In another test, a cold hard start was conducted. The reformer was started up from cold metal to minimum load (25%) in three hours. This is a significant achievement for steam reforming technology and will be important for utility fuel cell power plant applications. The design data obtained from these transient tests can be used to design more-rapid feed-forward control systems for commercial applications.

Analyses of the data sets taken during the test program show that the heat exchange reformer's performance was excellent and very close to design specifications. The novel cocurrent-countercurrent heat transfer approach provided for low metal wall temperatures and very high efficiencies. In no instances were excessive metal temperatures observed.

The combustion efficiency of the reformer is above 80% at rated capacity; that is, more than 80% of the fired heat duty is transferred to the process and less than 20% leaves the reformer with the flue gas or as heat loss. This measured combustion efficiency is significantly better than that found in conventional, industrial reformers, which have efficiencies on the order of 50%. This improvement in efficiency confirms the heat transfer effectiveness of the reformer.

Natural gas conversion efficiency versus load was also excellent, ranging from above 60% at loads of about 30% to near 90% at higher loads. The measured internal temperature profiles agreed well with computer model predictions. These results confirm that the parameters used in the computer model were valid and that the Haldor Topsoe model can be used to optimize the reformer performance for other fuel cell system requirements, such as conversion, pressure drop, or inlet-outlet temperatures.

The cycling and durability tests were completed in early August. In early September a mechanical inspection of the unit was conducted to assess the effect of the accelerated-cycling transient tests. Again, the reformer's internals were found to be in excellent mechanical condition. Following that inspection, the second catalyst bed was reloaded with a developmental low-pressure-drop catalyst, which offers the potential to significantly increase the capacity of the module. The reformer was operated in this configuration at 100% load for two continuous weeks (400 hours) at steady-state conditions to assess the performance and pressure drop characteristics of the new low ΔP catalyst.

The activity and conversion characteristics of the new catalyst were found to be good and similar to the earlier baseline catalyst. Most important, however, the pressure drop in the second catalyst bed was reduced by 80% when compared with the baseline catalyst. Although the long-term durability of this new catalyst remains to be demonstrated, these initial steady-state results are very promising.

This research resulted in the successful accomplishment of the project objectives. A high-efficiency, modular fuel processor was developed that is suitable for a wide range of fuel cell applications. Over 3400 hours of steady-state and cycling tests confirmed the performance of the reformer and the soundness of its mechanical design. All the original design specifications provided by Westinghouse have been satisfied; thus the reformer is suitable for use in the planned 1.5-MW pilot power plant program. The Haldor Topsoe–EPRI reformer technology is available for other fuel cell and industrial applications.

Further endurance testing of the new low ΔP catalyst will continue to improve the current design basis of the test article and to increase the likelihood of commercialization. Further information is available in AP-5319.

Air Quality Research

Risk Management for Airborne Toxics

by Tom Wilson, Environment Division

Among the trace substances emitted as by-products of fossil fuel combustion are such inorganic chemicals as arsenic, cadmium, chromium, and nickel, and such organic chemicals as benzo(a)pyrene. Each of these substances is receiving regulatory attention. It is not clear, however, that utility plants release these chemicals in the quantities or forms necessary to cause increased health risk. Nonetheless, regulatory actions initiated because of broad-based concern about such substances (particularly those emitted in larger quantities by nonutility sources) may affect utilities as well. For example, some toxic air pollutants will be listed and ultimately regulated at the federal level under Section 112 of the Clean Air Act. Other actions are being taken in local or regional air quality districts. Increasingly, utility managers at all levels will have to make choices to resolve regula-

ABSTRACT *Environmental issues posed by toxic air pollutants are complex and involve numerous substances and a wide range of sources. Often referred to as air toxics, these pollutants are gaining increasing attention from Congress, EPA, state and local regulatory agencies, and the media; they are a priority issue for environmental groups. Potential toxic air pollutant regulatory actions may have significant financial and operational effects on electric utilities. However, the complex nature and uncertain consequences of these pollutants make this problem particularly difficult to understand and manage. To help utilities with this task, EPRI developed and is in the process of testing a decision analysis model for air toxics risk management.*

tory concerns about toxic air pollutants.

The broad range and rapid pace of activities addressing air toxics suggest that it is time for the utility industry to develop improved methods for understanding, evaluating, and communicating about these issues. To meet these needs, EPRI contracted with Decision Focus (RP2141) to develop the air toxics risk management model (AIRTOX), which provides utility managers, regulatory personnel, and others with tools to help analyze the implications of a wide range of decisions and uncertainties regarding toxic air pollutants.

Utilities are most likely to be concerned with the following questions.

- Are toxic air pollutant regulations needed? If so, what are the best emission control options?
- What are the research and monitoring priorities?
- What are the effects of fuel switching?

AIRTOX provides utilities with the capability to evaluate the complexities that result from multiple substances and multiple sources and to incorporate explicitly uncertain information on such factors as current ambient concentrations, utility emissions, control efficiency, and the relationship between exposure and health effects. In particular, AIRTOX can help put in perspective a utility's contribution to toxic air pollutant emissions, can help explore trade-offs between acting soon and waiting for key research results, and can help evaluate the implications of changing emissions levels over time.

Model structure

The AIRTOX framework consists of a structural model that relates emissions of air toxics to potential health effects and a decision tree model that organizes the scenarios evaluated with the structural model. The framework is designed to be used in conjunction with and to complement existing, more-detailed risk assessment models.

The AIRTOX structural model has five submodels. The source model produces estimates of releases over time that are based on assumptions about future emission profiles and control efficiencies. The transport model uses the estimates of emissions to produce estimates of ambient concentrations at user-defined locations. Human dosage is then determined by the exposure model on the basis of the ambient concentrations and such factors as population activity patterns and respiration rates. The effects model converts dosage to health effects. The evaluation model produces measures of the costs and benefits of alternative decisions.

The basic structure of AIRTOX is similar to that of the air emissions risk assessment model (AERAM), which was developed for EPRI under RP1946. However, their purposes are complementary. AERAM provides detailed physical models of emissions, transport, dosage, and exposure, and it is used to perform detailed analyses of single scenarios. AIRTOX, in comparison, includes much less modeling detail in order to allow analysis of multiple sources and substances over a wide range of scenarios and for the explicit incorporation of uncertainty.

The first module operated in an AIRTOX model run is the source module. This module can be used to illustrate the relationship between the multidimensional but more aggregate modeling approach adopted in AIRTOX and the more detailed, engineering type of approach used in AERAM. To run the source module of AIRTOX, the user must specify one or more emission patterns for each source and each substance of interest. The emission patterns are input as simple curves relating emission levels to time. The user is free to choose any method available to generate these emission data. One approach would be to use the much more detailed mass-balance calculations performed by AERAM's EMIS module, coupled with alternative assumptions of future plant efficiency to produce the input patterns. In this manner, the outputs of a relatively complex modeling process can be incorporated into AIRTOX.

The AIRTOX transport model provides a means of calculating ambient concentrations of the substances of interest in multiple locations. It is similar to the source model in that it can be calibrated to more-detailed models. The generality of the transport model structure means that it can be calibrated either to a standardized air transport model, such as EPA's industrial source complex long-term model (used in AERAM), or to a wide variety of other models, depending on the issue to be addressed.

The exposure model calculates the average exposure level over the model time horizon for each population group of interest. In many risk assessments, an assumption is made that each individual is exposed to a constant concentration of a pollutant. In AIRTOX the user may specify population activity patterns in more detail. For instance, population groups of interest for a specific analysis might be plant workers and others, and receptor locations might be defined as plant, indoors, and outdoors. To determine overall exposure, the user would specify for each population group the fraction of time spent in each of the three locations.

Given the average exposure level for each population group and the health risk data for each health effect specified, the effects model calculates the number of incidents of each type. Three options for entering health risk data are allowed. The user may enter (1) unit risk estimates for each chemical, population group, and effect of concern; (2) an estimate of the number of health effects incidents per year, based on a specific exposure scenario; or (3) one of six types of standard dose-response functions.

The evaluation model summarizes the results of a run. It can be operated in one of two modes: one where costs and health effects are represented in natural units, and another where health effects are assigned dollar values.

AIRTOX is designed to be applicable to a wide variety of situations. For example, AIRTOX can be applied to a single plant, to all of a single utility's plants in a given region, to a group of utilities' plants in a larger region, or to all plants in the United States. The model can be used to analyze a single substance or to analyze several substances simultaneously. It can be used to analyze both long-term and acute health effects.

Applying the model

AIRTOX can be applied to a wide range of management and regulatory decision options for toxic air pollutants. To facilitate the analysis process, AIRTOX includes a flexible decision tree structure so that a wide range of decision problems can be defined and analyzed. The user can choose the decisions to be addressed and the uncertainties to be included in the analysis and can specify their order in the tree. For example, there may be a near-term regulatory decision, a near-term uncertainty that can be resolved with forthcoming research, and a longer-term control strategy decision. Given

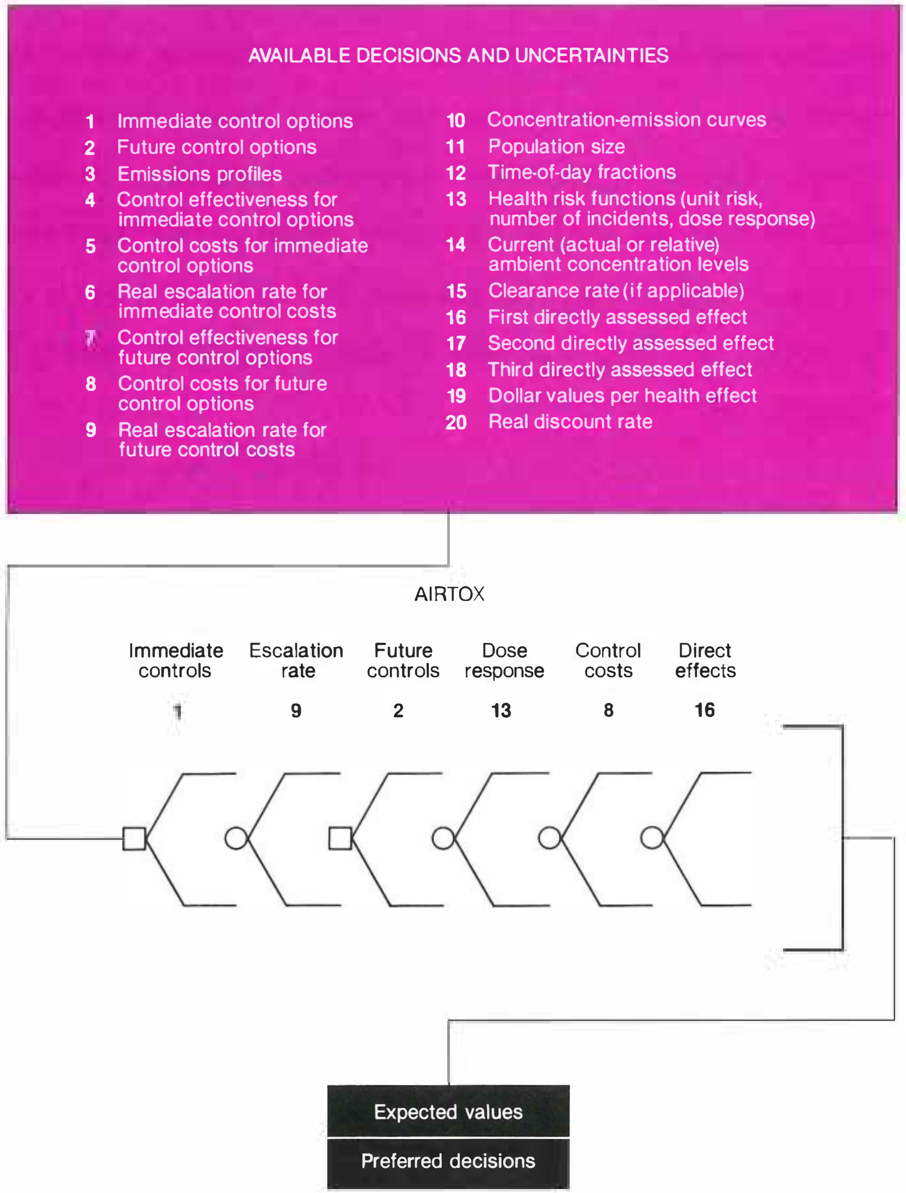


Figure 1 **AIRTOX has a flexible decision tree structure that can be used to define and solve trees tailored to specific air toxics problems. The user chooses the decisions and uncertainties to be considered from the group of 20 options listed. These choices determine the decision tree structure, which AIRTOX solves for the preferred decision.**

the user-specified decision tree structure, the model can calculate the expected costs and benefits of different alternatives, the preferred alternatives both now and after one or more variables are known, the effects of uncertainty in any of the key variables, and the expected value of improved information concerning any of the variables.

The key building block for the decision tree is the set of available decisions and uncertainties listed with Figure 1. It is not feasible (or even desirable) to include all the uncertainties simultaneously. Only the uncertainties likely to affect the decisions should be included. All variables not explicitly included in an analysis are set at their nominal or average values.

Given the available decisions and uncertainties, the user decides which to include, and the model then solves the decision tree. Figure 1 shows how the process works. The decision tree in the figure is a shorthand representation of the full tree. In a full decision tree, each node has a small number of branches and is connected to every branch of the preceding node. The squares denote decisions; the circles, uncertainties. The sequence of the nodes represents the timing of the decisions and uncertainties. The immediate controls decision is made before any of the uncertainties are resolved.

An important benefit of the dynamic model of the decision process used in AIRTOX is that it provides a means of estimating the value of undertaking additional research. If a decision tree is ordered so that research results are not available until after a future decision point, the value of the research to the decision-making process would be zero. The value of having the research results available for consideration in making the future decision is defined as the difference in the expected net benefit when the information is available for the decision and the expected net benefit when it is not available in time. This expected value of perfect information provides an upper bound on the value of such research. Comparing the expected value of information across a number of research issues and options can help target research efforts to best meet utility needs.

Project status

The AIRTOX project was initiated early in 1986 at the urging of utility industry advisers. An initial framework design was developed by mid 1986, and implementation of AIRTOX 1.0 was completed in March 1987. Two utility test applications of the model have been identified and will be completed this year. On the basis of the experiences of these case studies, the AIRTOX-user interface will be enhanced, and linkages with AERAM and other, more-detailed models will be automated.

AIRTOX is ready for further application. Utilities interested in using the system should contact EPRI.

Plant Availability

Fossil Fuel Plant Cycle Chemistry

by Barry Dooley, Coal Combustion Systems Division

Water quality can affect plant operation and cause failure in many ways. Impurities can result in such boiler tube failures as hydrogen damage, caustic gouging, and corrosion fatigue in water walls and economizers. Corrosion fatigue can cause low-pressure turbine blades to fail, and disk cracking can result from stress corrosion. Tube failures in feedwater heaters result from stress corrosion and erosion corrosion. Corrosion product oxides exfoliate or dissolve and are transported into the boiler. Condenser tube failures result from stress corrosion or condensate grooving.

Many units originally designed for baseload generation are now operated in peaking and other cycling service, which subjects these units to more frequent startups or load/pressure swings. Experience has shown that water chemistry varies substantially during these periods and that controlling some parameters within limits established for baseload operation may be impossible. Techniques and approaches for monitoring water chemistry that were originally specified for baseload plants are inadequate when the plants are used in peaking or cycling operation.

Even during periods of sustained baseload operation, units need an effective chemistry surveillance program to protect them from contamination and subsequent equipment damage that results from corrosion or deposition of corrosion products. By developing an understanding of the root causes of failure mechanisms and identifying the sources of the contaminants, it is possible to define water and steam quality limits that can result directly in vast improvements in plant availability.

Cycle chemistry guidelines

Before EPRI issued *Interim Consensus Guidelines on Fossil Plant Cycle Chemistry* (CS-4629), industry groups and manufacturers provided diverse water and steam control limits, setting disparate goals for plant personnel and management for determining operating limits in their plants. Utilities in countries with national guidelines enjoy significantly improved plant availability.

Researchers developed the EPRI consensus guidelines by starting with the required steam composition for turbines, which is ruled by salt and hydroxide solubility based on the saturation line. They based the allowable concentrations of impurities in boiler

ABSTRACT *The purity of boiler water, feedwater, and steam is one of the most important criteria for ensuring component availability and reliability in utility power generating systems. Localized corrosion damage in boilers and steam turbines can result in expensive and sometimes lengthy forced outages. As part of a project to improve control over fossil fuel plant cycle chemistry within established limits, EPRI recently issued interim guidelines for maintaining chemical parameters at critical points throughout the water-steam cycle. By applying the procedures given in the guidelines, utilities can reduce corrosion, scaling, and deposition and can improve plant availability.*

water on mechanical and vaporous carryover. Feedwater impurity levels were made comparable to those for steam to minimize the cost of blowdown.

The guidelines give target values and action levels for critical sample points throughout the water-steam cycle for drum boilers with phosphate and all-volatile treatments and for once-through boilers using all-volatile treatments. Table 1 shows example target values for the economizer inlet of a drum boiler with reheat, using phosphate chemistry.

Project personnel developed the action levels to guide utility operators on possible corrective action in the event of chemistry excursions. They established four levels on the basis of the following criteria.

- Normal (N): Values are consistent with long-term system reliability. A safety margin is provided to avoid concentration of contaminants at surfaces.
- Action level 1: Contaminants could accumulate, resulting in corrosion. Values should be returned to normal levels within one week.
- Action level 2: Impurities will accumulate, resulting in corrosion. Values should be returned to normal levels within 24 hours.
- Action level 3: Rapid corrosion will occur that can be prevented by shutting the unit down within four hours.
- Immediate shutdown: Clear evidence shows rapid boiler tube damage by acid contamination. Immediate shutdown of the unit will prevent such damage.

Operation at the lowest achievable impurity level and with the shortest and least frequent excursions is obviously desirable. The accumulation of impurities in the cycle occurs quickly, and subsequent cleanup and return to appropriate chemistry may take weeks.

One of the key water quality control points for cycle chemistry is the effluent from the makeup water treatment system. The operating guidelines define several parameters (amount of sodium, chloride, sulfate, silica, total organic carbon, and specific conductivity) for monitoring the effluent. In a future project, EPRI will develop guidelines for operation of the makeup water system, which will be compatible with the cycle chemistry guidelines and will include details on improving process efficiency (RP2712-4).

The interim guidelines accommodate differences in unit design. Individual utilities have modified the guidelines to reflect actual plant-specific characteristics and local operating experience. Detailed monitoring of the chemical parameters at six host utility sites will verify whether the interim guidelines are practical and should lower the incidence of corrosion failures (RP2712-3). The monitoring will also determine whether some aspects of chemical control need further development and improvement, includ-

Table 1
SAMPLE TARGET VALUES

Parameter	N	Action Level 1	Action Level 2	Action Level 3
pH, all ferrous metallurgy	9.0–9.6	<9.0 >9.6		
pH, mixed iron-copper metallurgy	8.8–9.3	<8.8 >9.3		
Ammonia	Consistent with pH			
Specific conductivity	Consistent with pH			
Cation conductivity, μS/cm	≤0.2	>0.2 ≤0.35	>0.35 ≤0.65	>0.65
Iron, ppb	≤10	>10		
Copper, ppb	≤2	>2		
Oxygen, ppb	≤5	>5 ≤10	>10 ≤20	>20

ing the use of phosphate chemistry on cycled units, standard amines to control feedwater pH, and hydrazine to scavenge feedwater oxygen. Researchers will also gather data during transients for later development of guidelines for startup, cycling, and peaking operation.

Instrumentation and control measures

EPRI has also published guidelines on instrumentation and control (I/C) for fossil fuel plant cycle chemistry to help utilities improve cycle chemistry monitoring (CS-5164). These guidelines characterize the existing state of the art for I/C and complement the interim consensus guidelines. Chemistry personnel can use them to evaluate and improve present plant capability and practice in sampling, chemistry surveillance techniques, data collection, analysis and control, application of on-line analyzers, and nonbaseload operations.

For each chemical parameter defined in the interim guidelines, there is a detailed guide to the surveillance techniques that are available for monitoring cycle chemistry. The I/C guidelines also give details on the types of on-line monitors and grab sample analysis techniques available.

The key feature of the I/C guidelines is the description of instrumentation at sample points, which is needed for an effective cycle chemistry program. Table 2 suggests minimal levels of on-line water chemistry instrumentation for fossil fuel plants. Class I instrumentation is applicable to virtually all fossil fuel plants. Class II instrumentation should be used to supplement Class I instruments in units operated for cycling duty or subject to frequent startups. Class III instrumentation is applicable to units susceptible to steam and condensate contamination. Class IV instrumentation is optional; utility personnel will have to consider plant-specific characteristics to determine whether instrumentation from this level is desirable.

Table 2
INSTRUMENTATION FOR FOSSIL FUEL PLANT CYCLE CHEMISTRY

Class	Parameter
Class I (Applicable to all plants)	pH, specific conductivity, cation conductivity, degassed cation conductivity
Class II (Applicable to cycling units)	Dissolved oxygen, hydrazine, phosphate
Class III (Applicable to units susceptible to contamination of steam or condensate)	Sodium, silica, chloride
Class IV (Optional and plant-specific)	Alkalinity, hardness, hydrogen, oil, turbidity, sulfite

The I/C guidelines also contain a detailed compilation and description of available practices for extracting and conditioning representative samples of water and steam. Steam sampling is considered the major deficiency, and EPRI plans to test a new nozzle design at a number of host utilities in 1988.

Other activities

Other activities are under way as part of the overall effort to reduce cycle corrosion, scaling, and deposition. One is the preparation of a handbook of water technology (RP1958-1), which EPRI is developing with ASME. This handbook is intended to be a standard reference work for designing and operating steam power systems and for technical training.

A manual on chemical cleaning is available that describes effective methods and approaches used by the industry to clean major components of fossil fuel power plant equipment (CS-3289). The manual emphasizes boilers but includes other components, such as feedwater heaters, condensers, and turbines. It outlines the criteria for determining the need for cleaning, specifies the responsibilities of the cleaning contractor and plant personnel, provides procedural details for efficient cleaning, and presents safety considerations.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Advanced Power Systems		
High-Concentration Module Testing Support (RP1415-21)	$32.800 5 months	EOS Electric Power, Inc./ *F Dostalek*
Instrumentation Requirements: Montioring Gas Turbine Durability (RP2774-3)	$51,300 11 months	Dow Engineering Co./ *C. Dohner*
RAM-Related Data for Utility Gas Turbine Procurement Specifications (RP2917-8)	$235,800 18 months	Creole Production/ *H. Schreiber*
Fracture Mechanics of Concrete Gravity Dams, Static Loading (RP2917-8)	$131,800 18 months	University of Colorado at Boulder/*D Morris*
Scoping Study: Concrete Dam Crack Propagation (RP2917-10)	$43,000 4 months	Anatech International Corp./*D. Morris*
Coal Combustion Systems		
Condenser On-Line Leak Detection System Development (RP1689-19)	$99,900 1 year	Stone & Webster Engineering Corp./*J. Tsou*
Steam Turbine Blade Life Improvement (RP1856-7)	$2,724,700 2 years	Stress Technology, Inc./ *T. McCloskey*
Steam Turbine Rotor Life Assessment (RP2481-6)	$562,700 26 months	Failure Analysis Associates/*J. Byroh*
Demonstration: EPRI Heat Rate Improvement Guidelines at North Lake Unit 2 (RP2818-2)	$240,500 25 months	Texas Utilities Electric Co./*G. Poe*
Demonstration: EPRI Heat Rate Improvement Guidelines at Salem Harbor Unit 4 (RP 2818-4)	$349,000 26 months	New England Power Co./*G. Poe*
Comparative Assessment: Retrofit NO_x Controls for Oil- and Gas-Fired Power Plants (RP2869-2)	$300,000 17 months	Pacific Gas and Electric Co./*D. Eskinazi*
Energy Management and Utilization		
Applications of Electronic Adjustable-Speed Drives (RP1966-24)	$60,200 5 months	Regents of the University of California/*M. Samotyj*
Industrial Heat Pump Manual (RP2783-11)	$107,600 8 months	Linnhoff-March, Inc./ *A. Karp*
Demand-Side Information Service: Management and Technical Support (RP2887-1)	$295,400 3 years	Electrotek Concepts, Inc./ *W. Smith*
Commercial Building, Latent Load Removal Systems (RP2891-3)	$108,800 15 months	Regents of the University of Wisconsin-Madison System/*M. Blatt, R. Wendland*
Soil and Rock Classification: Design of Ground-Coupled Heat Pump Systems (RP2892-3)	$197.800 1 year	STS Consultants, Ltd./ *P. Joyner*
Scoping Study: Glass Industry (RP2893-5)	$44,000 3 months	Science Applications International Corp./ *A. Karp*
Heat Recovery: Steam-Injected Combustion Turbines (RP8000-20)	$40,300 1 year	Regents of the University of California/*B. Louks*
Platinum-Doped Electrocatalysts (RP8002-11)	$321,000 35 months	University of Virginia/ *R. Goldstein*
Internal Load Heat Transfer With Rotation (RP8006-11)	$74,700 34 months	Regents of the University of Michigan/*J. Kim*
Nuclear Power		
Feasibility Study: Applications of Electromagnetic Acoustic Transducers in the Inspection of BWR Mark-I Containment Vessels (RP1570-21)	$75,000 6 months	Innovative Sciences. Inc./*M. Avioli*
Environment-Assisted Cracking of High-Strength Material for Nuclear Applications (RP2181-5)	$480,500 37 months	Massachusetts Institute of Technology/*J. Nelson*
Evaluation: DAW Sorting Performance (RP2412-14)	$71,900 6 months	Anacapa Sciences, Inc./ *P. Robinson*
Mass Transfer Enhancement in Copper Components (RP2420-56)	$95,600 8 months	NEI, International R&D Co., Ltd./*B. Chexal*
Critical Review of Impacts-BRC Code (RP2412-12)	$70,300 3 months	Battelle, Pacific Northwest Laboratories/*P. Robinson*
Erosion/Corrosion in Carbon Steel Feedwater Piping, Phase 1 (RP2420-57)	$83,500 5 months	Arizona State University/ *V. Chexal*
Cofunding: Approaches to Groundwater Quality Modeling (RP2485-10)	$50,000 17 months	National Academy of Sciences/*I. Murarka*
Service Water System Sourcebook (RP2495-3)	$121,400 9 months	Heat Exchanger Systems, Inc./*N. Hirota*
Demonstration: Computer-Aided Engineering Guidelines (RP2514-7)	$95,800 8 months	Commonwealth Research Corp./*J. Carey*
Scaling and Code Uncertainties: Applying Best-Estimate Methodologies to ECC/LOCA (RP2639-2)	$110,600 6 months	Westinghouse Electric Corp./*S. Kalra*
EPRI-CoMO/CRIEPI Collaborative Studies: Inelastic Analysis and Testing (RP2658-21)	$183,200 6 months	Martin Marietta Energy Systems, Inc./*D. Riley*
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Effect of Different Thermal Treatments on Corrosion Resistance of Alloy 690 Tubing (S408-2)	$90,300 17 months	Inco Alloys International, Inc./*C. Shoemaker*
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Planning and Evaluation		
Utility Planning Model Support (RP1819-80)	$119,900 15 months	Arthur Andersen & Co./ *S. Chapel*
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Planning Methods to Assess the Competitive Environment (RP2937)	$199,900 18 months	Putnam, Hayes & Bartlett, Inc /*S. Feher*

New Technical Reports

Requests for copies of reports should be directed to Research Reports Center, P.O. Box 50490, Palo Alto, California 94303; (415) 965-4081. There is no charge for reports requested by EPRI member utilities, U.S. universities, or government agencies. Others in the United States, Mexico, and Canada pay the listed price. Overseas price is double the listed price. Research Reports Center will send a catalog of EPRI reports on request. For information on how to order one-page summaries of reports, contact the EPRI Technical Information Division, P.O. Box 10412, Palo Alto, California 94303; (415) 855-2411.

ADVANCED POWER SYSTEMS

Coal Pyrolysis for Utility Use
AP-5045 Final Report (RP2505); $40
Contractors: Bechtel Group, Inc.; Veba Oel Entwicklungsgesellschaft GmbH; Lummus Crest, Inc.; UOP Inc.; Combustion Engineering, Inc.
EPRI Project Manager: L. Atherton

Capacitive Consolidation for MHD Generators
AP-5139 Final Report (RP2466-8); $32.50
Contractors: University of Virginia; A. Lowenstein
EPRI Project Manager: L. Angello

Flash Crystallization for the Control of Scaling in Geothermal Brine
AP-5153 Final Report (RP1525-3); $32.50
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EPRI Project Manager: J. Bigger

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EPRI Project Manager: H. Schreiber

Formulation of Slurries for Slurry-Fed Coal Gasifiers
AP-5203 Final Report (RP2696-1); $25
Contractor: Brookhaven National Laboratory
EPRI Project Manager: L. Atherton

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AP-5214 Final Report (RP1654-33); $25
Contractor: Mountain States Energy
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Technology Assessment of Ambient-Temperature Lithium Secondary Batteries: Electric Utility and Vehicle Uses
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Contractor: Boone B. Owens, Inc.
EPRI Project Manager: R. Weaver

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AP-5219 Final Report (RP2790-1); $32.50
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EPRI Project Manager: F. Goodman, Jr.

Electrical Behavior of Wind Power Stations
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AP-5221 Final Report (RP1234-1, -2); $55
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Contractor: Energy Systems Associates
EPRI Project Manager: W. Rovesti

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EPRI Project Manager: B. Mehta

Availability Analysis of an Integrated Gasification–Combined Cycle
AP-5276 Final Report (RP1461-1); $32.50
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EPRI Project Manager: A. Lewis

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Modular Modeling System (MMS), Vols. 1–5
CS/NP-3016-CCML Vols 1–3A Computer Code Manual (RP1163-3, RP1184-2); Vol. 4B Proceedings, $85; Vol. 5 Final Report, $40
Contractors: Babcock & Wilcox Co.; Bechtel Group, Inc.; Boeing Computer Services; S. Levy, Inc.; Jaycor
EPRI Project Managers: M. Divakaruni; A. Armor; J. Sursock

Upgrading Upper Kittanning Seam Coal Quality to Improve Power Plant Performance
CS-4866 Interim Report (RP1400-6, -11); $40
Contractors: Raymond Kaiser Engineers, Inc.; Science Applications International Corp.
EPRI Project Managers: C. Harrison; J. Hervol

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CS-5180 Final Report (RP2300-2); $25
Contractor: Stone & Webster Engineering Corp.
EPRI Project Manager: W. Chow

Proceedings: 1986 Seminar on Atmospheric Fluidized-Bed Combustion Technology for Utility Applications
CS-5186 Proceedings (RP1179); $77.50
Contractor: Science Applications International Corp.
EPRI Project Manager: S. Tavoulareas

Electrostatic Precipitator Guidelines, Vols. 1–3
CS-5198 Final Report (RP2243-1); Vols. 1–3 available only as a set, $5000
Contractors: Ebasco Services, Inc.; Southern Electric International; Southern Research Institute
EPRI Project Manager: R. Altman

Use of Coal Ash in Highway Construction: Georgia Demonstration Project
CS-5225 Interim Report (RP2422-4); $32.50
Contractors: Southern Company Services, Inc.; Georgia Power Co.
EPRI Project Manager: D. Golden

Recommended Practices for Operating and Maintaining Steam Surface Condensers
CS-5235 Final Report (RP1689-8); $550
Contractor: Heat Exchanger Systems, Inc.
EPRI Project Manager: J. Tsou

Proceedings: 1986 Power Plant Performance Monitoring and System Dispatch Conference
CS/EL-5251-SR Proceedings (RP1681, RP2153); $500
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EPRI Project Managers: R. Leyse; J. Lamont

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EL-4365-CCM Computer Code Manual; Vol. 2, $40; Vol. 3, $47.50; Vol. 4, $25
Contractor: Institut de Recherche de l'Hydro-Québec
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EL-4911 Final Report (RP1473-10); $32.50
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CS/NP-3016-CCML Vols. 1–3A Computer Code Manual (RP1163-3, RP1184-2); Vol. 4B Proceedings, $85; Vol. 5 Final Report, $40
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EPRI Project Managers: M. Divakaruni; A. Armor; J. Sursock

ARMP-02 Documentation Part II, Chapter 6, Vols. 1–3: CPM-2 Computer Code Manual
NP-4574-CCM Computer Code Manual (RP1252-9); Vol. 1, $32.50; Vol. 2, $40; Vol. 3, $70
Contractor: S. Levy, Inc.
EPRI Project Manager: O. Ozer

ARMP-02 Documentation Part II, Chapter 9, Vols. 1–3: PDQ7-E Computer Code Manual
NP-4574-CCM Computer Code Manual (RP976-3, RP1252-10, RP1690-1, -2); Vol. 1, $32.50; Vol. 2, $47.50; Vol. 3, $32.50
Contractors: Science Applications International Corp.; GRP Consulting; Energy, Inc.
EPRI Project Manager: W. Eich

Thermal Performance Diagnostic Manual for Nuclear Power Plants
NP-4990 Final Report (RP2407-1); Vol. 1, $25
NP-4990P Vols. 2–3, $15,000 for 2 volumes
Contractor: Combustion Engineering, Inc.
EPRI Project Manager: N. Hirota

Validation of Critical Signals for the Safety Parameter Display System
NP-5066M Final Report (RP2292-1); $47.50
NP-5066SL Final Report; Vols. 1–3
Contractors: Babcock & Wilcox Co.; The Charles Stark Draper Laboratory, Inc.
EPRI Project Managers: S. Divakaruni; B. Sun

Computerized Diagnostic Aid–Success Path Monitor
NP-5088 Final Report (RP2402-2); $62.50
Contractor: Combustion Engineering, Inc.
EPRI Project Manager: B. Sun

Hideout of Impurities in Steam Generators During Heat-Up and Power Ascension
NP-5092 Final Report (RPS306-17); $25
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: C. Welty

ESCORE–EPRI Steady-State Core Reload Evaluator Code: General Description
NP-5100 Final Report (RP2061-6, -13); $32.50
Contractor: Combustion Engineering, Inc.
EPRI Project Manager: D. Franklin

A Comparison of Factors Impacting on Radiation Buildup at the Vermont Yankee and Monticello BWRs
NP-5103 Interim Report (RP1934-1); $32.50
Contractor: NWT Corp.
EPRI Project Manager: C. Wood

Plant Layup and Equipment Preservation Sourcebook
NP-5106 Interim Report (RP2815-1); $40
Contractor: Multiple Dynamics Corp.
EPRI Project Manager: R. Burke

Production of Eddy-Current Standards for Caustic Intergranular Corrosion
NP-5109 Final Report (RPS302-10); $32.50
Contractor: Babcock & Wilcox Co.
EPRI Project Managers: J. Paine; R. Pathania

Tests and Analyses of Crack Arrest in Reactor Vessel Materials
NP-5121M Final Report (RP2180-3); $25
Contractor: Combustion Engineering, Inc.
EPRI Project Manager: D. Norris

Hydrodynamics and Heat Transfer Aspects of Corium-Water Interactions
NP-5127 Interim Report (RP1931-2); $47.50
Contractor: Argonne National Laboratory
EPRI Project Manager: M. Merilo

The TN-24P PWR Spent-Fuel Storage Cask: Testing and Analyses
NP-5128 Interim Report (RP2406-4); $40
Contractors: Pacific Northwest Laboratory; Virginia Power; EG&G, Inc., Idaho National Engineering Laboratory
EPRI Project Manager: R. Lambert

Comparative Evaluation of Acoustic Holography Systems
NP-5130 Topical Report (RP1570-2); $25
EPRI Project Manager: M. Behravesh

Zirconium Alloy Oxidation and Hydriding Under Irradiation: Review of Pacific Northwest Laboratories' Test Program Results
NP-5132 Final Report (RP1250-4); $40
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: A. Machiels

Steam Generator Cold Leg Thinning in Operating Plants
NP-5140 Final Report (RPS311-5); $47.50
Contractor: Westinghouse Electric Corp.
EPRI Project Managers: P. Paine; C. Shoemaker

Water Retention in Primary Coolant Systems of PWRs During Severe Accidents
NP-5144 Final Report (RP2600-1); $32.50
Contractor: Science Applications International Corp.
EPRI Project Manager: S. Kalra

Reference Electrode for PWRs
NP-5155 Final Report (RPS303-4); $32.50
Contractor: NWT Corp.
EPRI Project Managers: Y. Solomon; C. Shoemaker

Integral Facility Scaling and Data Relation Methods
NP-5162 Final Report (RP2399); $32.50
Contractor: EG&G Idaho, Inc.
EPRI Project Manager: J. Sursock

Fuel Integrity Consequences of a Misaligned Control Rod Incident
NP-5172M Final Report (RP2229-2); $25;
NP-5172SP Final Report; $10,000
Contractor: Babcock & Wilcox Co.
EPRI Project Managers: D. Franklin; S. Gehl

Detection and Characterization of Defects in Centrifugally Cast Stainless Steel
NP-5173 Final Report (RP2405-10); $40
Contractor: Amdata, Inc.
EPRI Project Manager: S. Liu

NUHOMS Spent-Fuel Storage Demonstration: Program Overview
NP-5174 Interim Report (RP2566-1); $25
Contractor: Carolina Power & Light Co.
EPRI Project Manager: R. Lambert

BWR Pilot Plant Life Extension Study at the Monticello Plant: Phase 1
NP-5181M Final Report (RP2643-2); $32.50
NP-5181SP Vols. 1–3 Final Report; $50,000
Contractor: Northern States Power Co.
EPRI Project Manager: J. Carey

Maintenance of European Nuclear Power Plants
NP-5185-SR Special Report; $40
EPRI Project Manager: R. Burke

PLANNING AND EVALUATION

Project Risk Analysis: A Case Study of Plant Life Extension
P-5087 Final Report (RP2074-1); $25
Contractor: Temple, Barker & Sloane, Inc.
EPRI Project Manager: D. Geraghty

Ninth EPRI Member Utility Survey Results
P-5160-SR Special Report; $32.50
EPRI Project Manager: J. Feher

Strategies for Coping With Drought: Part 2—Planning Techniques and Reliability Assessment
P-5201 Final Report (RP2194-1); $47.50
Contractor: University of Washington
EPRI Project Manager: E. Altouney

Historical Price Premiums for Low-Sulfur Coal in the East
P-5260 Final Report (RP2369-51); $32.50
Contractor: Resource Dynamics Corp.
EPRI Project Manager: J. Platt

CALENDAR

For additional information on the meetings listed below, please contact the person indicated.

DECEMBER

10–11
Regional Workshop: Demand-Side Management
San Diego, California
Contact: William Smith (415) 855-2415

JANUARY

14–15
Workshop: Residential Customer Preference and Behavior
San Diego, California
Contact: Larry Lewis (415) 855-8902

MARCH

9–10
Power Quality for End-Use Applications
San Antonio, Texas
Contact: Marek Samotyj (415) 855-2980

16–18
PWR Primary Chemistry and Radiation Field Control
Berkeley, California
Contact: Chris Wood (415) 855-2379

MAY

3–5
1988 Seminar: FBC Technologies for Utility Applications
Palo Alto, California
Contact: Stratos Tavoulareas
(415) 855-2424

JUNE

6–10
Symposium: Feedwater Heater Technology
Winston-Salem, North Carolina
Contact: John Tsou (415) 855-2220

13–15
Life Extension and Assessment of Fossil Fuel Plants
The Hague, Holland
Contact: Barry Dooley (415) 855-2658

Authors and Articles


Stringer


Sharma


Jaffee


Sullivan


Nelson


Ocken


Block

Exploring the Frontiers of Materials (page 4) was written by Taylor Moore, *Journal* senior feature writer, with guidance from two senior participants in EPRI's materials research management.

John Stringer, named technical director for exploratory research in May of this year, previously managed that growing activity as an adjunct to his principal work in the Materials Support Program. He came to EPRI in 1977 and was named program manager in 1982. Stringer was formerly at the University of Liverpool (England) for 11 years, becoming head of the department of metallurgy and materials science. Still earlier, before a 3-year period with Battelle, Columbus Laboratories, he was a lecturer at Liverpool, where he had earned bachelor's and doctoral degrees in engineering.

Robert Jaffee, now a senior technical adviser, managed the Materials Support Program from 1975 until 1982. Before that he was with Battelle, Columbus Laboratories, for 32 years, becoming its chief materials scientist. A chemical engineering graduate of Illinois Institute of Technology, Jaffee also holds an MS in metallurgy from Harvard University and a PhD in chemical engineering from the University of Maryland. ■

R&D and the Utility Customer (page 16) was written by Ralph Whitaker, *Journal* feature editor, aided by two staff members of EPRI's Industry Relations and Information Services Group.

Bud Nelson, director of regulatory relations since 1980, came to EPRI after nearly 11 years as a member of the Illinois Commerce Commission and of the National Association of Regulatory Utility Commissioners. He was previously with Sundstrand Corp. for over 20 years in factory and financial management. Nelson graduated in economics from Beloit College and earned an MS in business administration at Northern Illinois University.

Richard Block, manager of product applications in the Corporate Communications Division, joined EPRI early this year. He previously was president of Interlab Robotics for four years; still earlier, as a business development consultant, he specialized in commercializing high-tech research results. Block at one time worked for the National Science Foundation. He graduated from Kenyon College and has MS and PhD degrees from Case Western Reserve University. ■

Strategies for Superconductivity (page 24) was written by John Douglas, science writer, with technical information from **Dave Sharma** and other EPRI staff members who took part in a recent workshop on research needed for the power industry to exploit hot superconductors.

Sharma, now a project manager in the Underground Transmission Program, previously managed EPRI projects in plant electrical systems research for 7 years. He came to the Institute in 1980 after 11 years with General Electric and 7 years with an electrical manufacturer in India. Sharma graduated from the Indian Institute of Technology; he also has an MS from the University of Windsor (Ontario) and an MS and a PhD from Rensselaer Polytechnic Institute. ■

Safe Passage for Migrant Fish (page 28) was written by Jon Cohen, science writer, in cooperation with **Charles Sullivan** of EPRI's Advanced Power Systems Division. Sullivan heads the Hydroelectric Generation Program, where he has worked since 1982. From 1977 to 1982 he was a project manager in the Nuclear Power Division. Before joining EPRI, he worked for two years with NRC's Reactor Systems Branch and for six years at Lawrence Livermore Laboratory. Sullivan has a BS and an MS in mechanical engineering from Arizona State University. ■

Just Say No to Cobalt (page 34) was written by John Douglas, science writer, who drew on background information from **Howard Ocken** of EPRI's Nuclear Power Division. Ocken, a project manager in low-level waste and coolant technology research, specializes in measures to reduce radiation fields in power plant systems. Before joining EPRI in 1974, he was a senior engineer for six years at Bettis Atomic Power Laboratory. Ocken graduated in metallurgical engineering from New York University; he also has an MS and a doctorate from Yale. ■

ELECTRIC POWER RESEARCH INSTITUTE
Post Office Box 10412, Palo Alto, California 94303

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