International Research

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ELECTRIC POWER RESEARCH INSTITUTE

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Cover: Cooperative R&D ventures with a number of countries throughout the world give EPRI a truly global perspective on problems and technologies of interest to the utility industry. (Photo by Herbert Lanks/Superstock)

International Research at EPRI

For many years now, we have witnessed the evolution of an increasingly interconnected global economy. While American companies have expanded their operations in foreign lands, a growing number of overseas companies have opened U.S. offices. So much in the way of expertise, hardware, and manufacturing processes crosses national borders these days that it is a challenge for consumers to pinpoint the domestic origin of many commonplace products.

The electric utility industry is no exception to the globalization phenomenon. Large multinational firms headquartered in other countries have begun to dominate the market for generation and transmission equipment. Meanwhile, U.S. utilities are investing in overseas projects and—through EPRI—are collaborating at an unprecedented level on research and development with utility organizations around the world.

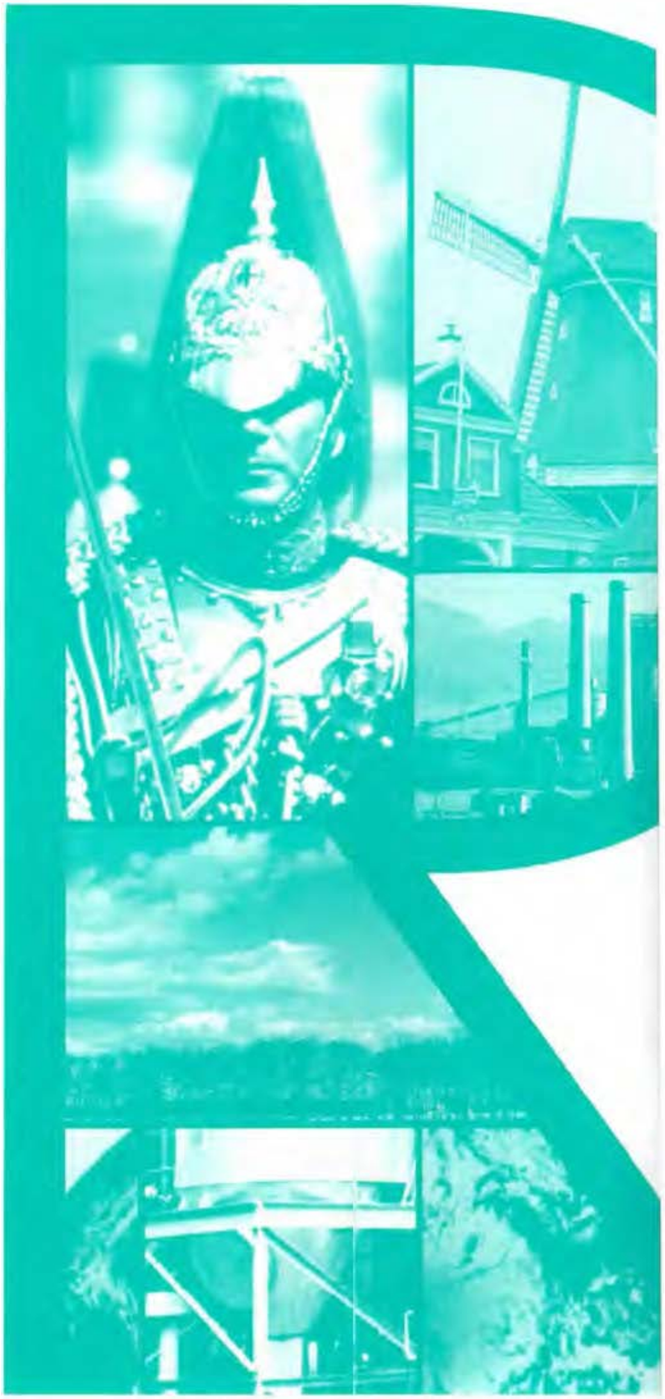
Although international cooperation is far from new to EPRI, today there are more reasons than ever to have an international perspective when it comes to R&D in the utility industry. One key reason is the growing number of industry issues—including global climate change, nuclear safety, and emissions control—that transcend national borders. If such issues are to be dealt with efficiently and effectively, they must be confronted jointly by utilities around the globe through the sharing of knowledge and the pooling of R&D resources.

Our work with overseas utility organizations—especially in recent years—has shown us not only that our interests are becoming more similar, but also that these international groups often provide valuable expertise and fresh perspectives that help us with our domestic problems too. We have a great deal to gain by working with utility groups in other countries, and by the same token, we would have much to lose by choosing not to collaborate.

To ensure that EPRI's international relationships provide the most valuable input for the Institute and its members, we recently adopted some new mechanisms and established a more businesslike approach to these interactions, as described in greater detail in the cover story. We look forward to the outcome of these initiatives and anticipate that, as an expansion of EPRI's productive international cooperation, they will help us continue to provide our members with innovative solutions to address their most pressing needs.

Jay B. Kopelman

Jay Kopelman
Manager, International Activities
Office of Commercialization & Business Development



RESEARCH UPDATE

DEPARTMENTS

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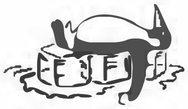

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by Leslie Lamarre

Tapping the Intern

THE STORY IN BRIEF

International collaboration has been a part of EPRI's approach to R&D since the Institute's beginnings almost 20 years ago. Through its partnerships with utility organizations around the world, EPRI has increased the productivity of its own work while making some valuable contributions to the R&D programs of overseas groups. As industry issues have become more global in recent years, EPRI has taken advantage of the international R&D resource to work jointly on issues of common concern. While increasing its involvement in international collaboration, the Institute has also formalized the nature of this activity to ensure that EPRI and its members receive an equitable return for the information and expertise provided to R&D entities outside the United States.

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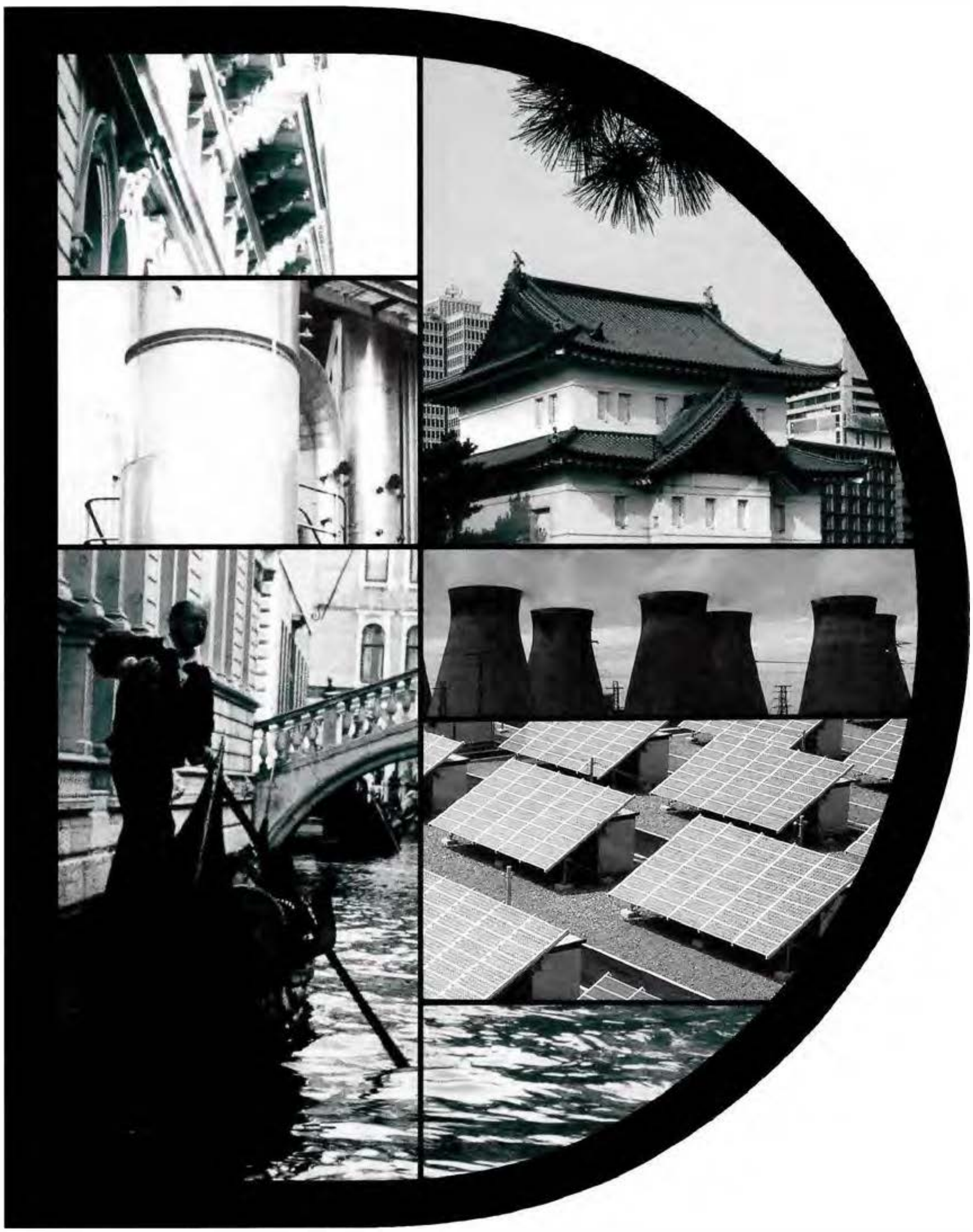


WELCOME TO FRANCE, a country only four-fifths the size of Texas that is home to the world's largest electric utility. It is a society that derives more than 75% of its electric power from nuclear reactors, producing twice as much nuclear energy, per capita, as the United States and three times as much as Japan. Today France is as well known for its high-speed electric trains—the fastest in the world—as it is for its Bordeaux.

Four thousand miles across the globe is India, where industries must operate in staggered shifts to get the electricity they need to function. The country suffers an 8.5% electricity shortage, which increases to 18% during periods of peak demand. Covering an area about one-third the size of the United States, India contains three and a half times the U.S. population. About 75% of these people live in villages, many of which do not have electricity.

The issues confronting electric utilities in these two countries are vastly different. But energy experts in both believe there's much to be gained in working closely with EPRI. Electricité de France, the world's largest electric utility, is now in its tenth year of a working relationship with the Institute. Today this partnership involves 25 projects on topics ranging from global warming to materials research. So far, India's relationship with the Institute, established in 1990, is limited to an information exchange agreement. But a delegation of high-level government officials recently visited EPRI with hopes of establishing more-intimate ties.

"EPRI has always been involved with international utilities, but recent activity has begun to make the Institute a true internationally collaborative research and development organization," says Jay Kopelman, EPRI's manager for international activities. "Not only has EPRI increased its involvement with utilities overseas, but it has formalized the nature of that involvement to help ensure that it gets comparable value back for what it gives out, be it in the

Leslie Lamarre

Ron May

form of expertise, information, technology, financing, or a combination of these benefits."

Part of this more structured activity is a new pilot program through which international utility organizations become affiliates of EPRI. EPRI has also opened two offices overseas—in Birmingham, England, and Melbourne, Australia—to help manage the relationships with the affiliates and enhance the flow of technology from the affiliates and other utility organizations in these regions back to EPRI.

"I see these efforts as the first stage in the globalization of EPRI's activities on a more formal basis," says Dwain Spencer, vice president for the Office of Commercialization & Business Development, which oversees the Institute's involvement in the international arena.

"Knowledge and its scientific and technological products have become a global asset, with no single country holding a monopoly position," says Kurt Yeager, EPRI's senior vice president for technical operations. "It is therefore essential that EPRI strengthen its worldwide relations on behalf of our members and affiliates to ensure that they have access to the cutting edge of the international knowledge resource and are able to more effectively harvest that resource."

Why go global?

EPRI's increased international involvement is propelled in part by the growing number of industry issues that are not defined by national borders. When it comes to such concerns as global warming, nuclear safety, and the need for increased efficiency in the use and delivery of electricity, many in the industry believe that an international response is not an option but a necessity.

"The scope of the issues facing the electric power industry throughout the world requires collaborative efforts to resolve them," Spencer told an audience at an International Energy Agency conference in Hungary early this year. "Many of these issues initially drew the U.S. electric utilities together to form EPRI. It is now clear that similar motivations are bringing the world electric community together."

Over the past 15 years, EPRI has been instrumental in developing a number of international programs to work on such critical concerns. One current example is the Model Evaluation Consortium for Climate Assessment (MECCA) project. MECCA, which represents just one facet of EPRI's climate change research strategy, involves a consortium of utility, academic, and government groups from the United States, Japan, France, Italy, and the Netherlands. The project was undertaken to quantify the plausible ranges of climate change—as predicted by computer models—so that policymakers would understand the economic risks associated with various options for limiting greenhouse gas emissions.

Collaborative projects like MECCA represent more than a united concern, however. They are a reflection of the globalization that has swept the business world in recent years. This movement has had a significant impact on the utility industry, transforming national manufacturing firms into multinational giants and prompting U.S. utilities to establish subsidiaries to invest in power plants overseas. Almost involuntarily, the economies of far-flung countries have become more integrated. For many organizations that want to stay ahead today, an international perspective is mandatory. Just as companies around the globe have jumped national borders to tap new markets and to gain access to technology and skilled labor, EPRI has sought to keep up with the state of the art in the industry worldwide.

Indeed, EPRI has learned a lot from working with international utility organizations over the years. Both France and Japan have a significant amount of nuclear generating capacity, from which they have gained vast operating experience that has provided valuable lessons for U.S. utilities; Britain has produced some of the world's leaders in materials research; and German utilities, which face stringent environmental regulations, are experienced in applying advanced technology to control nitrogen oxides. Even countries that are grappling with severe issues in the power industry have shown they have something to offer. For instance, EPRI researchers have learned from the Soviet practice of adding oxygen to the feedwater of fossil-fired boilers to control corrosion. EPRI is now testing this technology in two U.S. fossil plants.

"It is clear that science and engineering know no geographic boundaries and that new ideas and technologies are constantly emerging in our industry," says Tony Armor, director of EPRI's Fossil Power Plants Department. "EPRI recognizes this and is reaching out across the world to bring the best advanced technologies to its members." Just within his department, Armor notes, a number of technologies that were developed in other countries have been imported over the years. One example is the above-mentioned oxygenated chemistry system, first applied in Russia and Germany. Another is an acoustic system for detecting leaks in utility boiler tubes. Originally employed at utilities in Italy and England, this system is now being used at more than 50 U.S. utilities.

EPRI's collaboration with international utility organizations has offered a number of advantages. Not only has it dispersed the financial burden of major research projects, but it has also pooled the cumulative operating experiences of those involved, offering valuable lessons from a wide variety of utility systems. In addition, it has provided access to demonstration and test facilities that have no counterparts in the United States. For instance, through its overseas work in pressurized fluidized-bed combustion (PFBC), EPRI has taken advantage of existing facilities in England, Germany, Finland, and Sweden. These countries have been heavily involved in the development of PFBC technology, a relatively new, high-efficiency option for generating power cleanly from coal. According to Steven Drenker, EPRI's program manager for fluidized-bed

EPRI R&D AROUND THE WORLD

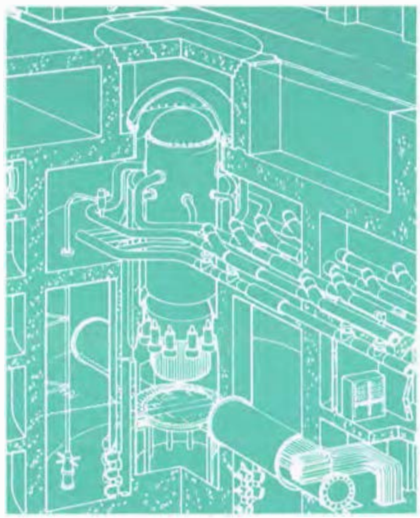
EPRI's technical divisions are working with utility organizations from many different countries. Here are highlights of some of their projects.

Through a joint project with Japanese utility organizations, EPRI has tested equipment at this photovoltaic research and testing facility in Japan.

This cylindrical pulse-jet baghouse in Australia was part of a pilot demonstration project with the Electricity Commission of New South Wales.

Established to quantify the plausible ranges of climate change predicted by computer models, the Model Evaluation Consortium for Climate Assessment involves utility, academic, and government groups from five countries.

The Advanced Light Water Reactor Program, which currently involves utilities from eight overseas countries, has produced four reactor designs, including this one by General Electric.



Ontario Hydro is participating in an EPRI project aimed at developing advanced and efficient electrotechnologies for wastewater treatment plants.

The Cool Water project provided the first commercial-scale demonstration of integrated gasification–combined-cycle technology. A Japanese consortium of private companies helped fund the project.

A seismic research project with Taiwan Power produced this 1/4-scale model of a pressurized water reactor containment building in Lotung, Taiwan.

Live-line testing with BC Hydro and Ontario Hydro.

combustion, they have invested some $200 million in PFBC test facilities since the late 1970s. By comparison, EPRI has spent about $12 million for testing at these plants.

"By piggybacking on top of the enormous investment that has already been made, we're really leveraging the R&D dollars of our members," says Drenker. Through its participation in an International Energy Agency project in Sweden, EPRI is helping to test two hot gas filters that may improve PFBC technology. Organizations from seven countries are participating in this $15 million project. Because EPRI's pioneering work in hot gas filter technology contributes valuable expertise to the project, the Institute's share amounts to only 3% of the total cost. However, the Institute and its members derive the full benefits of the technology improvements resulting from the work.

Looking back

EPRI has been involved with international organizations since the first years of its existence. "There was a fundamental philosophy when EPRI was established that it was going to try to get all of the best information—scientific, engineering, and technical—anywhere in the world, bring it all together, and synthesize it to provide the American utility industry with the best insight as to what's going on and what it ought to be doing," says Chauncey Starr, the Institute's founder and first president. "EPRI's ambition, right from the very beginning, was to encompass the world's knowledge and experience."

According to Starr, EPRI's international involvement not only increased the total fund of knowledge the Institute had to offer its members, but also enhanced EPRI's international reputation as a reliable and authoritative source of information. The Institute's earliest relationships with international utilities involved an open exchange of information, typically outlined in a memorandum of understanding. The idea was to maintain a quid pro quo exchange through joint workshops and meetings and through publications put out by both parties. Early exchanges were established with utilities in England, Taiwan, and the Soviet Union, among other countries. No money changed hands in these collaborations. As Starr puts it, "It was a pooling of knowledge rather than a pooling of resources."

Gradually the Institute's relationships with international entities evolved to include the cofunding of projects, the sharing of facilities for testing and demonstration, and even the loaning of employees. As such efforts progressed, EPRI's reputation spread around the globe. "EPRI became very well known internationally," says Kopelman. "It

Judy Bellah

Xavier Zimbardo/Gamma Liaison

Benn Mitchell/Image Bank

grew to be as well known and widely respected in many foreign nations as it had become in the United States."

In the late 1970s, EPRI initiated a project that took the concept of international involvement to an unprecedented level for the Institute. That project was the first commercial-scale demonstration of integrated gasification–combined-cycle (IGCC) technology. Known as the Cool Water project because of its location at a Southern California Edison plant by that name, this demonstration was undertaken to illustrate that coal can be used to generate electricity cleanly without the use of energy-wasting flue gas scrubbers. A Japanese consortium of private companies contributed $30 million to the project, roughly 10% of the total cost; U.S. manufacturing companies contributed $170 million; and EPRI provided about $70 million.

"This was the first time the private sector on an international basis totally funded a large-scale facility to demonstrate a new technology," says Spencer, explaining that the U.S. Department of Energy had played a significant role in funding EPRI's previous demonstration projects. "The Cool Water project brought our expertise and the required financial capability together to demonstrate a new technology that otherwise would not have been demonstrated."

The IGCC plant, which came on-line in 1984, exceeded its environmental and operational performance objectives and clearly demonstrated the technology to be a viable option. Spencer, who was EPRI's vice president for advanced power systems at the time and oversaw the demonstration, says IGCC is now the world's front-running candidate for the advanced utilization of coal. "Based on what we hear from the Chinese, the Japanese, the French, and the British, it is clear that we have changed the viewpoint of the whole world on what is the most important advanced coal technology," he says.

The first commercial utility IGCC unit is scheduled to come on-line in the Netherlands in 1994. EPRI will be monitoring this project both through its long collaborative association with Shell, the system developer, and through the Dutch utilities that will operate the facility. Two other commercial units in the United States—one at Potomac Electric Power and one at Tampa Electric—are scheduled to be operating by the turn of the century.

Beyond Cool Water

Since the era of the Cool Water project, international collaboration at EPRI has entered a new dimension of major, multinational undertakings. While information exchange agreements and less formal relationships still exist, the Institute now regularly enters into larger-scale agreements involving more-intimate collaboration. By far the biggest current example is the Advanced Light Water Reactor Program. Initiated a decade ago, the ALWR program aims to develop design requirements for the next generation of safe nuclear reactors. Today the program is jointly funded by U.S. utilities (through EPRI), the U.S. Department of Energy, U.S. reactor vendors, and international utilities. With a collaborative budget of nearly $600 million, it is the largest management project in the history of the Institute.

"Designing safer, more reliable nuclear reactors is an issue that many countries face, because they are all going to have to add capacity before the end of the century or soon afterward," says Ted Marston, director for advanced reactors development in EPRI's Nuclear Power Division. "It makes sense to work on this issue jointly. Why waste resources duplicating efforts when we can accomplish so much more by working together?"

So far, utilities in eight overseas countries (Italy, the Netherlands, Japan, France, Germany, Spain, England, and Belgium) are participating in the latest phase of the ALWR program. Each is contributing about $9 million in funds and other resources—including expertise, operating experience, test results, and in many cases employees. (Taiwan and Korea participated in earlier phases of the program.) About one-third of the 30-

EPRI AFFILIATES

PowerGen plc
One of two privatized electric generating companies in England

Capacity: 18,000 MW (fossil fired)
EPRI affiliate as of April 1, 1991

Azienda Energetica Municipale (AEM)
An Italian utility located in Milan

Capacity: 1036 MW (60% hydro and the rest oil and gas fired)
EPRI affiliate as of July 1, 1991

British Columbia Hydro (BC Hydro)
The provincial utility of British Columbia

Capacity: 10,500 MW (almost entirely hydro)
EPRI affiliate as of July 1, 1992

State Electricity Commission of Victoria (SECV)
Generation, transmission, and distribution company that supplies the state of Victoria in Australia

Capacity: Approximately 8000 MW (mainly coal fired with some hydro and some gas fired)
EPRI affiliate as of February 1, 1992

NV tot Keuring van Elektrotechnische Materialen (KEMA)
The R&D organization for electric utilities in Holland

Capacity: The country's four generating companies have about 15,000 MW of capacity (roughly 7250 MW coal fired, 7250 MW gas fired, and 500 MW nuclear)
EPRI affiliate as of July 1, 1992

member ALWR staff is on loan to EPRI from utilities in these countries. Another third of the ALWR staff is on loan from domestic utilities, while the remaining third is made up of EPRI employees.

The current phase of the ALWR program involves the actual design of the advanced passive reactor, using a comprehensive set of requirements developed in an earlier phase of the program. The goal is to complete this design phase in 1995 so that the first reactor based on those specifications can be built, licensed, and operating by about the year 2000. To help ensure the licensability of the new design, EPRI has worked closely with the Nuclear Regulatory Commission, which has reviewed all 42,000 design and technical requirements.

"I think the design has been positively influenced by the international contributors," says Marston, noting that most of the participant countries have large nuclear investments and much operating experience. "Whenever we found a better mousetrap, we incorporated it into the requirements." New features resulting from the design of the passive plant will be tested at facilities—in Japan, Italy, and Switzerland—specifically built for the needs of the ALWR.

Among the enhancements to the design was a suggestion from a Spanish participant to use dc power directly from the reactor's backup power source, eliminating a converter. According to George Bockhold of EPRI, project manager for the ALWR effort, this suggestion has helped improve the reliability and economics of the instrumentation and control systems. Since dc power is compatible with modern instrumentation and control systems, the power converter is not needed.

The Italians, the British, and the French have also contributed valuable information to the project. Utilities in the UK and France are building new nuclear power plants, and as a result their designs include advanced, digital technology. Such technology is being incorporated into the ALWR design to make the man-machine interface more user-friendly. The operating experience of the European utilities has demonstrated that using microcomputers to conduct many small tasks is preferable to using one large mainframe computer system to control everything in a plant. As these utilities have learned, mainframe computer systems are not fast enough to control the thousands of tasks required in a nuclear power plant.

The ALWR program is just one of many international activities of the Nuclear Power Division, which employs more than 70% of the Institute's international on-loan staff members. "There's a very large segment of our work today for which it has become almost mandatory that we have international cooperation," says John Taylor, vice president for the division. "Just from the viewpoint of safety issues, there's a strong movement in the industry worldwide to share information, and for good reason. Take the Chernobyl accident: even though that system is nothing like the ones we use in the United States, incorporating characteristics that would never have been permitted and licensed in this country, the event generated very, very bad publicity for our nuclear power industry. We have a lot of common objectives across the world, and if we share the work that's needed to resolve these issues, we're all better off for it."

Quid pro quo

Originally EPRI maintained a policy of openness in its exchanges. Then, in the early 1980s, the Institute adopted a policy on international collaboration that emphasizes the importance of having quid pro quo arrangements. Since that time, EPRI has tightened up on the information it releases to overseas organizations, cutting down on the number of reports it sends out and in general restricting access to its research results. The aim is to ensure that EPRI and its members are getting a return of value for what the Institute gives out.

"In examining the international relationships that had been established, we found that some situations were not equitable," says Milt Klein, a consultant for EPRI who, before his retirement, was the Institute's vice president for industry relations and information services. "We learned that being open with our research results was not an effective way to get information from others. We found that we must—in effect—bargain with them."

EPRI eliminated some information exchange agreements that it didn't consider useful to the Institute. At one time there were 25 information exchange agreements in place that involved more than one division. Today there are 14 such agreements, and these will be pared down over the course of this year. The changes have affected more in-depth collaborations as well. "We are becoming much more businesslike about requiring a clear quid pro quo from any international project-related agreement so that there's a clear flow of information and data, or a sharing of unique experimental facilities that EPRI wouldn't otherwise be able to make use of," says Spencer.

Also helping to ensure that EPRI gets enough back for what it gives out, the Institute has established a more formal channel through which information flows to and from some international utility organizations. This new channel is the International Affiliates Program, managed by Jay Kopelman. Approved on a pilot basis by the Board of Directors in December of 1990, the program currently involves utility groups from Britain, Italy, Australia, Canada, and the Netherlands.

Rather than jointly funding projects with EPRI, the affiliates buy into specific research areas. Within the programs they invest in, the affiliates receive results of EPRI's R&D. However, they must also provide reverse technology transfer, releasing information to EPRI from their own, counterpart programs. "While a global perspective on R&D is going to become ever more significant in the coming decades, it is important to understand that EPRI's work is still very heavily focused on its members' needs," says Ric Rudman, the Institute's senior vice president for business operations. "The insights and expertise derived from international research will offer clear practical benefits to EPRI's member utilities and their ratepayers."

EPRI is particularly interested in the R&D programs of international utilities that have grown considerably in size and sophistication. Today some foreign utility R&D operations are much larger than those of any single American utility. In some cases, individual programs are comparable to or larger than EPRI's programs in the same field. For instance, Tokyo Electric Power's budget for nuclear R&D is bigger than that of EPRI's Nuclear Power Division.

To oversee these affiliate relationships and help enhance the flow of technology from the international utility organizations to EPRI, the Institute this spring established two offices overseas. Al Dolbec of the Generation & Storage Division heads the office in Birmingham, England, while Owen Tassicker, also of G&S, heads the office in Melbourne, Australia. Both locations are equipped with videoconferencing capability and will oversee the technical relations with EPRI's new international affiliates and provide a basis for broader international activities. The Melbourne office's sphere of activity will extend to nearby New Zealand and to countries of southern Asia, including Japan, Taiwan, and Korea. The Birmingham office will oversee relations across the United Kingdom and the European continent.

"It is essential to have overseas offices, because we are a global presence already," says George Preston, vice president for generation and storage. "In order to provide our domestic members with the full benefit of our international activities—from our affiliate relations to our R&D projects—it's critical that we have somebody on the spot."

According to Preston, PowerGen, a British utility that became EPRI's first affiliate in April 1991, has considerable experience in nondestructive evaluation, component life assessment, gas turbine combined-cycle plants, materials, and control of nitrogen oxide emissions. While EPRI also has experience in these areas, PowerGen's data and expertise will augment the Institute's programs and accelerate its R&D results, Preston says. "The new affiliates offer EPRI members the opportunity to transfer technology from international organizations to U.S. industry. That's what warrants the effort to recruit affiliates and establish overseas offices. The revenue enhancements to our U.S. R&D programs are of secondary interest."

New opportunities

Traditionally, EPRI has pursued relationships with advanced, industrialized countries perceived as possessing valuable experience and expertise that could flow back to the Institute and its members. But it is becoming apparent that there are a number of benefits EPRI and its members can derive from working with developing countries too.

As Narain Hingorani, vice president for electrical systems, points out, many developing countries are growing rapidly and urgently need to increase their electric generating capacity. Differences in the geography of these countries and in their electrical systems offer new opportunities to demonstrate emerging technologies. Such opportunities may not exist in the United States.

India, for example, is a prime location for dispersed generation, a concept that has been slow to catch on in the United States because the U.S. generation system is already well developed. Dispersed generation involves the use of many small generating units strategically located to meet a relatively low demand. Solar-powered dispersed generation is an ideal candidate for electrifying the 600,000 villages scattered throughout India. For a good part of the year, these villages receive 12 hours of sunshine daily.

"When we want to introduce a technology, there has to be a large enough market," says Hingorani. "Small generation is important to all of us. But for some types of small generation, such as solar power, the economics are not right to introduce the technology in this country. In a country like India you can introduce the technology much sooner, and once you do that, the cost will come down and the technology will become viable for application in other countries."

Developing countries also present

Rob Nickelsberg/Gamma Liaison

TPS, U.S./Superstock

Leslie Lamarre

growing market opportunities. According to the U.S. Agency for International Development, the market for electric power equipment and services in developing countries will range from $370 billion to $900 billion over the next two decades. As Deborah Bleviss, executive director of the International Institute for Energy Conservation, points out, one strong segment of this market is energy efficiency. "These countries cannot afford to grow at the rate that they're projected to grow," Bleviss says. "They're going to need a significant amount of energy efficiency, so there's a very strong financial drive for those that provide the necessary energy efficiency goods and services to take advantage of the market."

Already, EPRI has begun to seek overseas market opportunities for some efficiency-related products produced by the Customer Systems Division. Through a unique business agreement signed late last year, EPRI has appointed an international consulting firm as its agent for licensing a number of demand-side management software codes and reports outside the United States and Canada. At this time the products are being marketed primarily in Europe (including Eastern Europe) and Australia. However, the potential exists for further opportunities in the developing world.

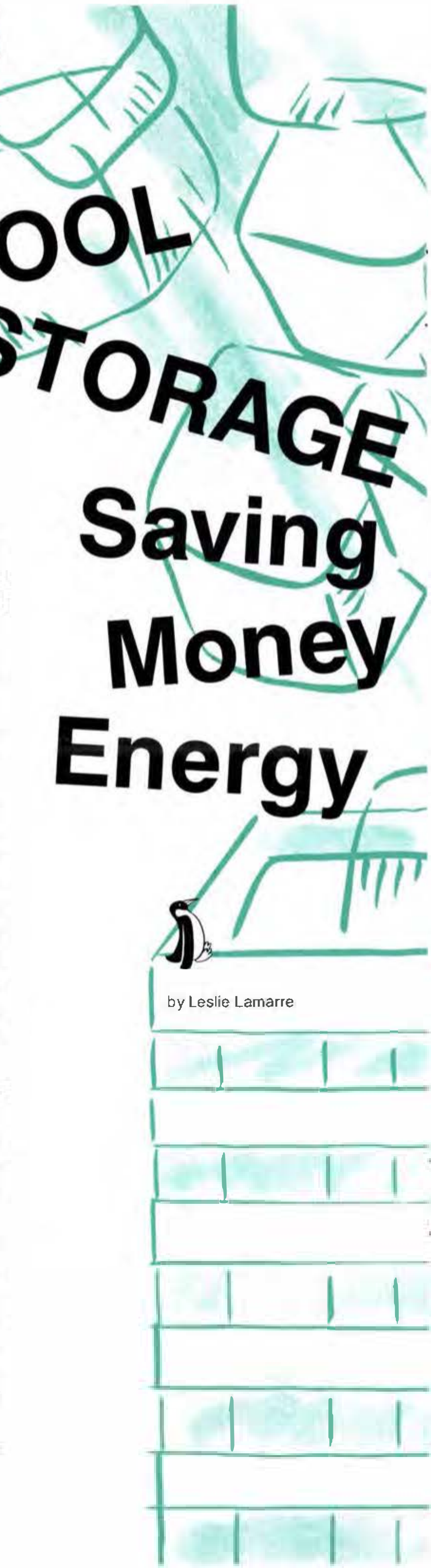
Both Eastern European and developing countries lag behind the United States in computer technology and could benefit from a number of EPRI's software programs and workstations, such as those geared toward the design of more-efficient transmission systems. However, many of these countries don't have the resources to purchase and apply this technology. EPRI is currently communicating with outside agencies that may be able to provide some funding for projects in these countries. Among the possible sources are international financing agencies like the World Bank.

Despite the financial challenges that come with projects in the developing world, many believe they represent an avenue of both opportunity and responsibility for EPRI. Over the next two decades, a significant increase in electricity generation will be needed to sustain the world's burgeoning population. Since much of this growth is occurring in the developing world, it makes sense to apply the advanced knowledge, skills, and technologies already developed by the industrialized world. The motivation is as much practical as it is altruistic. After all, effective emissions management, operating procedures, and nuclear safety practices will benefit the industry, as well as society, worldwide.

"It is essential to our shared global destiny that the lesser-developed countries not apply obsolete, inefficient technology we have already discarded," says Kurt Yeager of EPRI. "Through its international technical relations, EPRI can facilitate opportunities for U.S. utilities and industry to develop business ventures providing the most productive technology for the world at large. Technological innovation through electricity provides society the best means to balance finite resources, including the environment, against a rapidly expanding global population whose economic aspirations are constantly moving higher. Achieving this balance will be a major challenge of the twenty-first century."

Work with developing countries is just in the early phases of consideration at EPRI, and it will be some time before the Institute determines whether to launch any major initiatives in this area. Regardless of what the Institute decides to do, however, many have high hopes for what it can accomplish. "I think there's a market niche for EPRI's capability on an international basis," says Spencer. "I think we're hitting the market at exactly the right time. With our strong technical staff and intellectual property base, EPRI could make a significant contribution to many countries." ■

Background information for this article was provided by Jay Kopelman and Dwain Spencer, Office of Commercialization & Business Development; Tony Armor, Generation & Storage Division; and Ted Marston, Nuclear Power Division.



COOL STORAGE

Saving Money Energy

by Leslie Lamarre

SPACE COOLING HAS COME A LONG WAY SINCE THE 1950s, when movie theaters used to advertise that they were air-conditioned. This was well before the emergence of residential air conditioning, and the ads succeeded in luring crowds from their homes on hot summer days.

Today nearly all new homes in the warmer regions of the country are built with air conditioning. And in commercial and industrial buildings, air conditioning is critical, given the need to sustain worker productivity and ensure the smooth operation of sensitive computer equipment. Indeed, the use of space conditioning has increased so much over the past four decades that during the summer months it now accounts for nearly half of the peak electric load consumed by the commercial sector.

But keeping customers cool does not have to push electric generating capacity to its limits. Cool storage technology (also called thermal energy storage) allows building owners to generate cooling during utilities' off-peak hours, when demand for electricity is relatively low. The cooling is simply stored in a thermal medium—water, ice, or eutectic salt—until it is released as needed during the day. Cool storage systems can provide either full or partial cooling. Partial storage systems supplement cooling generated by conventional air conditioning systems.

Cool storage technology was around during the days of the country's first air-conditioned movie theaters. In fact, some of these theaters employed cool storage rather than conventional air conditioning systems. Part of the advantage from the customer's perspective was that the technology eliminated the need for expensive, large-capacity air conditioning systems capable of cooling a large space over a short period of time. Using cool storage also made it unnecessary to install additional electric power capacity to run the massive compressors of the air conditioning systems.

The cool storage systems in place today help reduce peak demand for utilities while simultaneously making good use of generation, transmission, and distribution capacity that is typically underutilized during the off-peak hours. For large electricity consumers, the systems yield savings in demand charges, which are based on the greatest electric load demanded in a given month. In addition, they allow customers to take advantage of cheaper rates available during utilities' off-peak hours.

In fact, low off-peak rates and the correspondingly low electricity bills have made cool storage system operation so cost-effective that until recently there was no strong economic justification to maximize the efficiency of the systems. Instead, research and development engineers have focused on improving reliability and reducing the capital cost of the systems to keep them competitive with conventional air conditioning systems on the market.

In recent years, however, the R&D emphasis has changed. Environmental concerns and increased utility involvement in promoting energy-saving technologies for demand-side management have made efficiency a top priority. In a reflection of this shift, EPRI, which has funded cool storage research and development since 1980, mounted an aggressive campaign two years ago to improve the efficiency of thermal energy storage.

EPRI-developed cool storage systems that are just as efficient as conventional air conditioning equipment—and in some cases more efficient—are already available. Now the Institute is working on a number of hardware and software modifications that will save even more energy. As a result of these efforts, according to EPRI's experts, by 1996 the market will feature cool storage systems that are 10% more efficient than the majority of the conventional air conditioning equipment installed to provide the same amount of cooling.

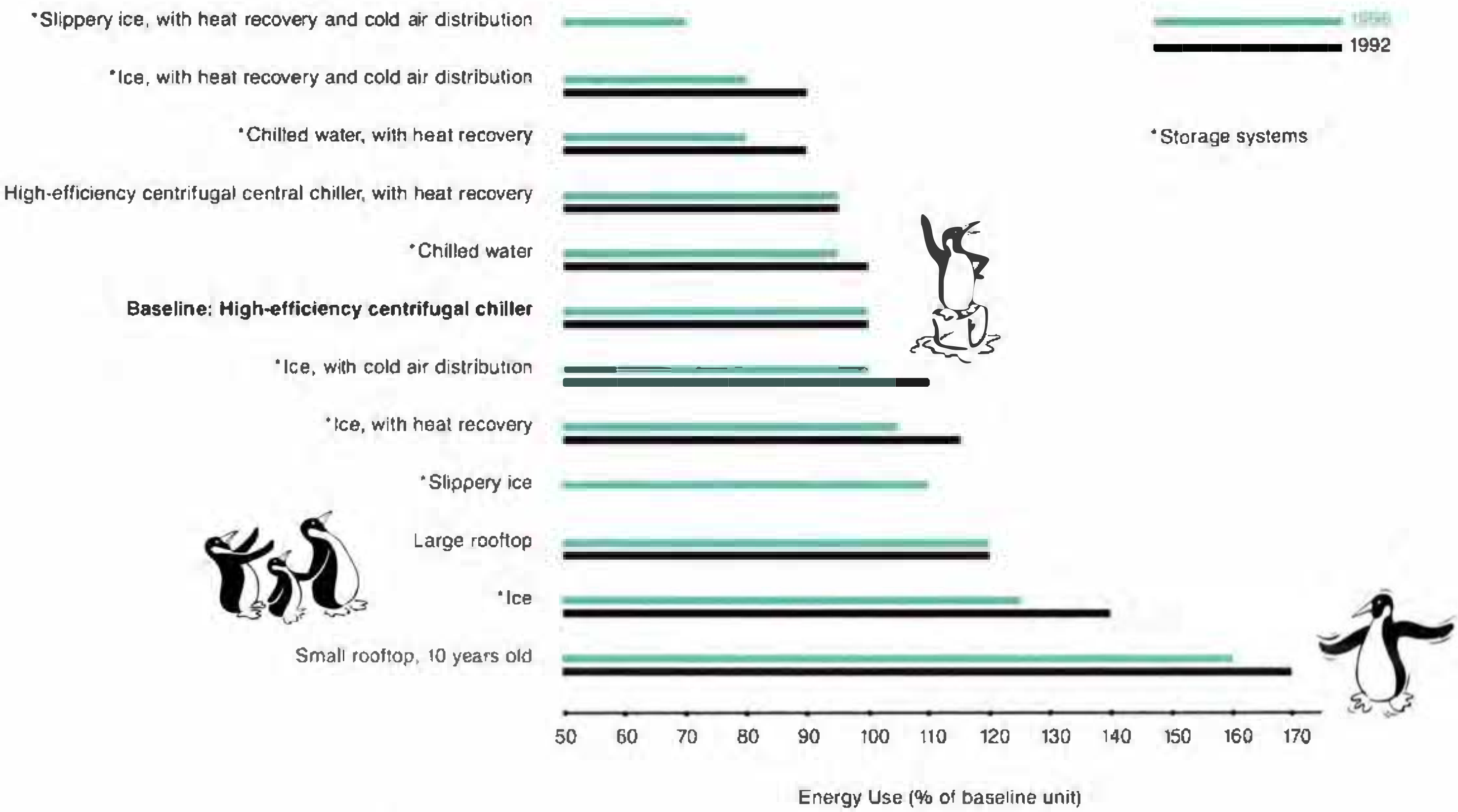
"We want people to understand that

and

THE STORY IN BRIEF

For nearly half a century, cool storage systems in this country have been helping utilities shift load off-peak, saving money for commercial and industrial customers. But because cool storage has been regarded primarily as a load-shifting tool, its benefits for energy efficiency have been overlooked. In fact, cool storage systems available today are just as efficient as conventional air conditioning equipment—and in some cases more efficient. EPRI has undertaken a number of projects to further improve the efficiency of cool storage technology and to encourage utilities to include these systems in their demand-side management programs.

THE EFFICIENCY COMPARISON Cool storage technology is just as efficient as, and in some cases more efficient than, conventional air conditioning equipment. To indicate efficiency, this graph shows the average annual energy consumption of eight storage systems and four nonstorage systems for the commercial sector. The high-efficiency centrifugal central chiller—the most efficient nonstorage option available today—is the baseline technology against which all the others are compared in terms of energy use. The values shown account for total system energy use (for space heating, cooling, and ventilating) and assume electric resistance supplemental heat; they will vary, depending on climate and maintenance.



cool storage technology is efficient," says Morton Blatt, manager of the Commercial Program in EPRI's Customer Systems Division. "We want to make sure utilities know that they can save energy by including this technology in their demand-side management programs."

Innovations in storage

Cool storage technology got its start in the dairy industry in the 1940s, when the milk pasteurization process was introduced. In this process, milk is heated to 180°F and must be cooled swiftly in order to prevent bacteria growth and maintain a high-quality flavor.

The technology developed to perform this task consisted of a water-filled storage tank containing a serpentine coil through which refrigerant was circulated. Ice accumulated on the coil, chilling the water around it. Chilled water was diverted from the tank to a heat exchanger as needed to cool the milk.

Over the past four decades, cool storage technology has become much more sophisticated and efficient. Across the country today, nearly 2000 chilled-water, ice, and eutectic salt systems store more than 4 million ton-hours of cooling for commercial and industrial buildings. Together they shift an estimated 425,000 kW (425 MW) of electric power from on-peak to off-peak periods. "Although this is a good start, we have barely begun to tap the potential 100,000 MW that could be shifted off-peak through widespread use of this technology," says Ron Wendland, manager of thermal storage technology at EPRI.

In many ways, cool storage systems are inherently efficient. Because they produce cooling ahead of time and not on an as-needed basis, they do not regularly cycle on and off. This means that they run at nearly full load, or peak efficiency, whenever they are charging or cooling. By comparison, conventional air conditioning units, which constantly cycle on and off, operate at maximum efficiency less than 25% of the time on an annual basis. EPRI field tests and computer simulations have shown that the noncycling factor alone reduces energy consumption by 10% annually.

Cool storage systems save additional energy by using electricity generated by baseload power plants. These plants, which provide power during utilities' off-peak periods, are on average 25% more efficient than power plants used to meet peak demand. Another benefit is that less energy is lost through the use of utility transmission and distribution systems during off-peak, nighttime periods. This is due to the lower ambient temperatures and the lighter electricity load transported by the systems during these hours.

Similarly, electric chillers operate 5–10% more efficiently when outdoor temperatures are relatively low. Most or all of a cool storage system's chiller operation can occur at night to take advantage of the lower temperatures. In fact, in some dry climates that experience low humidity at night, the cost of cooling can be significantly reduced by bypassing the compressor and using only the cooling tower. The tower uses 17% of the energy consumed by the compressor to perform the same amount of cooling.

Cool storage systems can provide free space heating under some circumstances. Even during the winter months, large office buildings require some cooling of interior spaces. The heat generated in charging a cool storage tank at night can be rejected into the building rather than into the outdoor air. At a 550,000-square-foot office building outside of Dallas, heat recovery from an ice storage system supplies about two-thirds of the annual heating energy.

Naturally, cool storage has some efficiency drawbacks as well. The most significant of these is the energy lost during storage through the natural heat gain in the storage tank over time. However, this is a problem that can be rectified relatively easily. Extensive field and laboratory monitoring conducted by EPRI shows that storage tanks that are properly insulated and installed experience thermal losses that typically are less than 2% of the system's total output.

Opportunities of ice

Of the three types of cool storage systems available today, ice storage offers the greatest opportunities for increased efficiency. This is partly due to the amount of energy lost in the ice-making processes currently employed in these systems. As ice builds up on the heat exchanger surface, it begins to act as insulation, reducing efficiency by about 10%. Some units "harvest" the ice by defrosting the heat exchanger with hot gas so that the ice drops off the surface. But this hot gas defrost cycle also reduces efficiency by about 10%.

To address this problem, EPRI has developed and patented the so-called slippery ice process, which prevents ice from adhering to the surface of heat exchangers. In this process, calcium magnesium acetate, a substance similar to the chemical used for de-icing aircraft, is added to the water. The use of this additive causes ice to form in the liquid pool, away from the heat exchanger surface, and results in a slushy type of substance that will not cling to metal.

EPRI has tested the slippery ice process extensively in a laboratory at the University of Missouri and has examined methods for enhancing the process. Paul Mueller Corporation, a major ice storage system manufacturer, is building an ice storage system for EPRI that will employ the slippery ice process. The system is scheduled to be installed at a building owned by the Chevron Corporation in Dublin, California, this September.

Aside from reducing the amount of energy wasted in the ice-making process, the slippery ice technique may help significantly cut the capital cost of ice-based cool storage systems. The reason is that slippery ice eliminates the need for the defrost cycle, which exerts 120–180 pounds of pressure on evaporator surfaces every 15 minutes. To withstand the stress of this pressure, current evaporators are built with thick and costly 17-gage stainless steel, a major contributor to the equipment cost. Without the pressure resulting from the defrost cycle, a much thinner and less expensive steel could be used, significantly reducing the capital cost of the system. In fact, it could even become cost-effective to add more of the thinner evaporator surface to further improve the unit's energy efficiency by 5–10%.

Additional potential for increased efficiency in ice storage systems exists in the air distribution system. This opportunity is unique to ice storage because of the lower water temperatures that are readily available. In fact, water supplied to the cooling coils of ice-based storage systems is about 12°F colder than that supplied to the coils of nonstorage air conditioning systems. This means that the air ultimately delivered from the cooling coils to the conditioned space is also much colder, typically ranging from 42 to 48°F, compared with 55°F.

The lower temperatures generated by ice storage systems mean that less air must be distributed to achieve the same amount of cooling. In other words, distribution components, such as ducts and fans, can be downsized. Not only does this save on costs for the materials required to build the distribution systems, but it also reduces the amount of energy used to operate the systems. In fact, EPRI research shows that the smaller fans use as little as 50% of the energy consumed by the larger fans.

EPRI has monitored projects that illustrate the savings possible through the use of these cold air distribution systems. At the new Seafirst Building in Bellevue, Washington, an ice storage system with cold air distribution is projected to save $56,400 in energy expenses per year. An added benefit is that the smaller ductwork used with the cold air distribution system allowed building designers to reduce floor-to-floor height by 4 inches and construct an extra story. This story contributed 13,000 square feet of rentable floor space to the project. Reduced space requirements for the mechanical rooms contributed another 4000 square feet. Combined, the extra space represents an additional $340,000 per year in rental income for the owner.

To further improve the quality and efficiency of cold air distribution systems, EPRI is working to develop an advanced diffuser that can introduce cold air into spaces without relying on fan-powered mixing boxes. Like the energy-consuming mixing boxes, the advanced diffuser will introduce cold air smoothly so that it does not fall from the ceiling in one mass and create drafts that adversely affect the comfort of building occupants. The diffuser will spread the cold air along the ceiling evenly, enabling it to blend gradually with the room's warmer air.

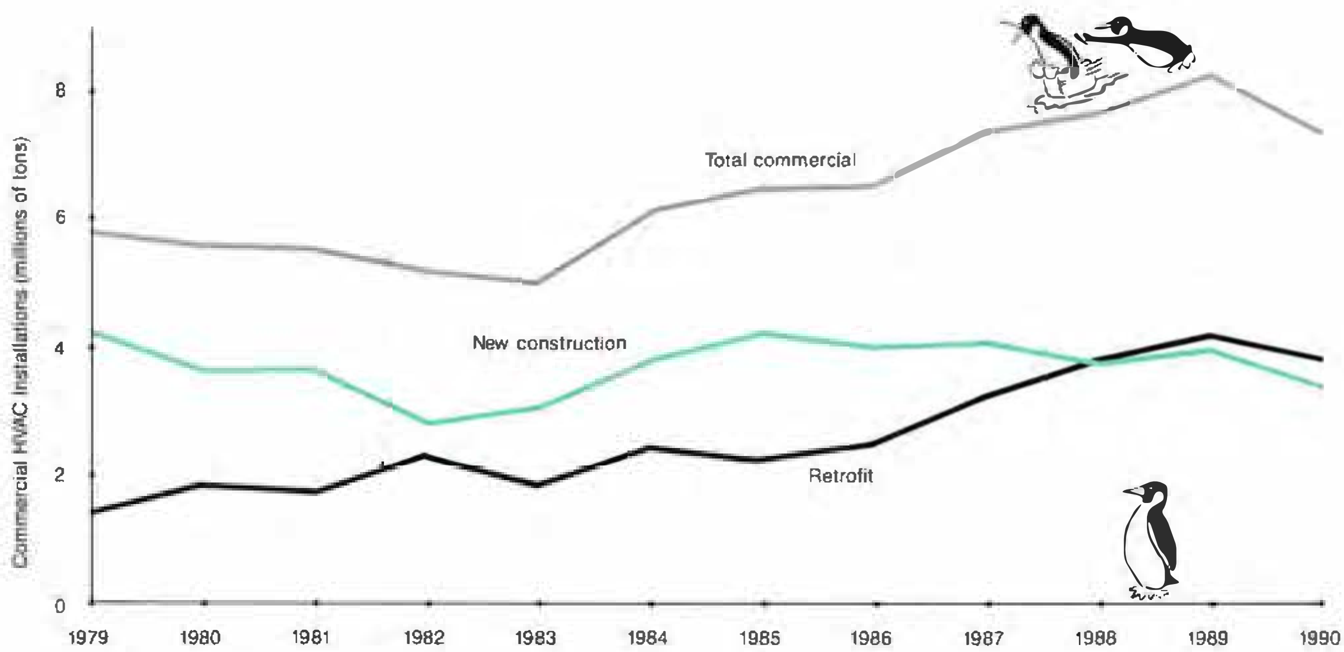
Another aspect of cool storage technology that offers opportunities for increased efficiency is the control system. Without the attention of very knowledgeable and conscientious building operators, cool storage systems are likely to fully charge themselves every day they are in use. Since there are not many days in a given year that require a full charge of the system, some energy is wasted in this process. Also, many cool storage systems perform most efficiently when the stored cooling is completely exhausted before recharging. This requires a fairly accurate prediction of what the cooling needs will be in a given day.

EPRI has developed a cool storage controller and a related software program that optimize the efficiency of chilled-water and ice storage system operations. The controller predicts, 24 hours in advance, the hourly outdoor temperature, the cooling load required, and the building's total electricity demand. It also can measure the amount of cooling capacity in storage and can be programmed with the utility rate structure in order to achieve the lowest operating costs. With this information the controller optimizes the charging and discharging of storage, producing enough cooling to get through a given day. EPRI's patented controller has been commercially available for about two years from Honeywell Corporation. The Institute is currently involved in negotiations that could allow it to license the technology to other companies, making the system more widely available.

Penetrating the market

EPRI researchers believe that cool storage systems would be a valuable addition to utility demand-side management programs. One advantage is that a single installation results in significant demand and energy savings that are largely predictable, both before installation and over the long term. This makes DSM planning and evaluation easier.

But as Wendland notes, cool storage technology has typically been left out of DSM programs. "Because cool storage has been almost singularly identified with utility benefits such as load shifting and valley filling, the technology's use as a



COMMERCIAL MARKET TRENDS A growing number of aging air conditioning systems, combined with a sluggish economy, are helping to boost the retrofit heating, ventilating, and air conditioning market. EPRI's researchers believe this market offers the best potential for the widespread introduction of cool storage systems.

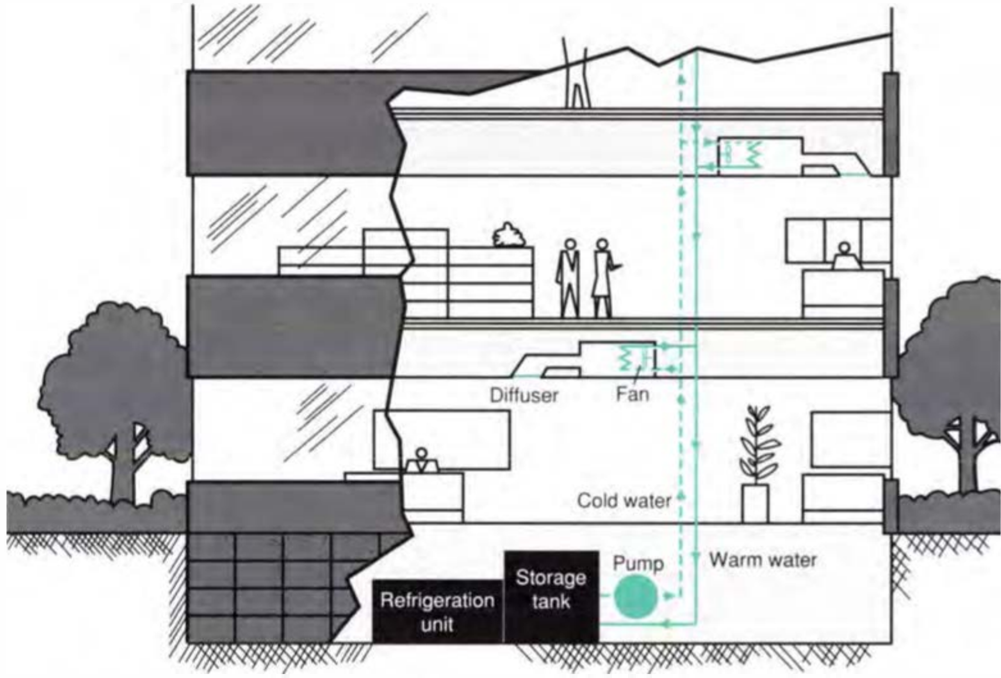
conservation strategy has been overlooked and underestimated," he says.

To promote the wider use of cool storage technology, EPRI is putting more emphasis on the retrofit market. "One of the reasons we feel the retrofit market is very important is that it now exceeds the new construction market," says Wendland. Roughly half of the existing commercial air conditioning in the United States consists of rooftop equipment, according to Wendland, and many of the first batch of rooftop systems installed 20 or more years ago now need to be upgraded or replaced. These older rooftop units consume 25–100% more energy than currently available conventional air conditioning systems and cool storage alternatives.

EPRI is examining various approaches to retrofitting existing rooftop units economically; several demonstration projects are under way. In addition, the Institute is documenting before-and-after energy consumption on retrofit projects involving chilled-water, ice, and eutectic salt systems.

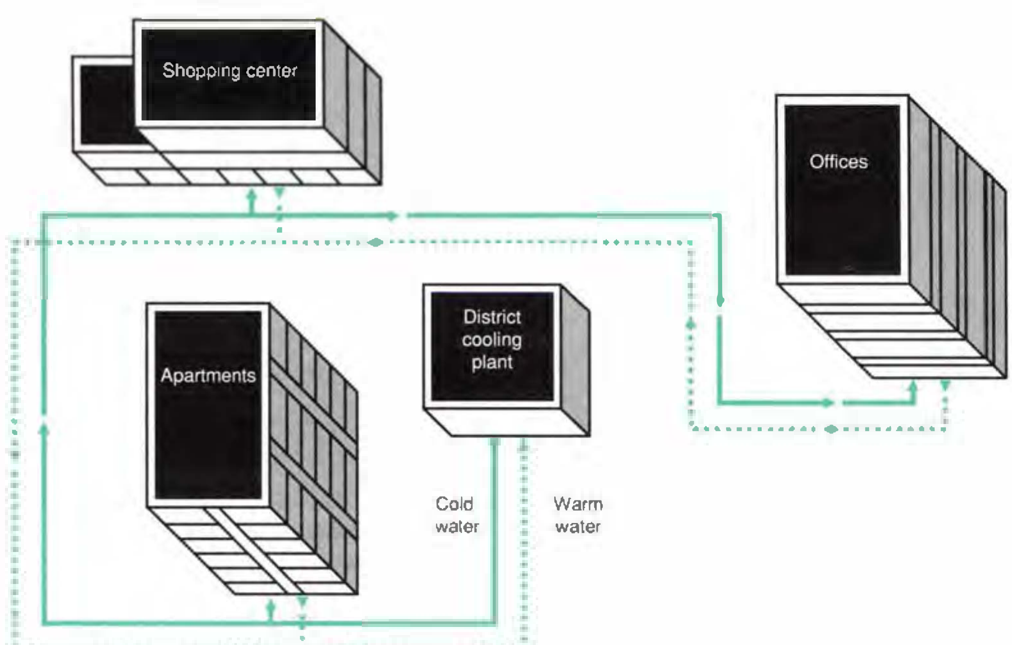
In one of these projects, the owners of a Texas Instruments plant in Dallas retrofitted a conventional central air conditioning system to accommodate a chilled-water cool storage system. The implementation of this system, along with related improvements to the distribution system, reduced the facility's on-peak demand by 2900 kW, or 33%, and central chiller electricity use by 10%. In another project—at the Henry C. Beck Middle School in Cherry Hill, New Jersey—a failing 84-ton rooftop air conditioning unit was converted to an ice storage system. The retrofit used the existing equipment, including the supply fan, coils, and ducts, saving about $25,000 in capital costs. In its first year of service, the retrofit system reduced on-peak demand by as much as 39% and energy use by as much as 12%.

EPRI is exploring other avenues that may help bring additional cool storage technology to the marketplace. One potential application that could take advantage of the new slippery ice process is district cooling. District cooling systems centralize cooling generation in one cooling plant that provides air conditioning to a



THE COOL STORAGE SYSTEM Cool storage systems differ from conventional air conditioners primarily in that they include a storage tank. The tank contains a thermal medium (water, ice, or eutectic salt) that stores cooling generated by the refrigeration unit. When cooling is needed, a water solution from the storage tank is circulated in a pipe system that runs throughout the building. The storage capacity effectively decouples the refrigeration process from the building load, allowing building owners to generate cooling during utilities' off-peak hours, when electricity demand and rates are relatively low.

DISTRICT COOLING The basic components of cool storage systems also exist in district cooling systems, which use a central plant to cool nearby buildings. District cooling systems are employed in the United States, but they are far more common in Europe at this time. EPRI believes district cooling would be a profitable business opportunity for many utilities because they could sell cooling while tapping generation capacity that typically goes unused in the off-peak hours.



COOLING THE COMMERCIAL AND INDUSTRIAL SECTORS Across the country today, nearly 2000 cool storage systems provide cooling in commercial and industrial buildings. Together these systems store more than 4 million ton-hours of cooling, shifting an estimated 425,000 kW of electric power from on-peak to off-peak periods. A few of the buildings with cool storage are pictured below.

Best Products corporate headquarters in Richmond, Virginia

Home of EPRI's regional office outside Dallas, Texas

Westbrook Corporate Center near Chicago, Illinois

group of buildings or customers. Although such systems are more prevalent in Europe, they are also employed in this country, most commonly on college campuses.

According to Wendland, the slush produced by the slippery ice process could be pumped directly through district cooling systems, which normally distribute chilled water. Because the slush consists of both water and ice, it has greater cooling capacity than chilled water alone, so less of it would be required to accomplish the same amount of cooling. A reduction in the amount of material flowing through the district cooling systems would mean that pipes, pumps, and other system components could be downsized, saving significantly on both capital and operating costs. Wendland estimates that pipe size and pumping energy could be reduced by a factor of 4.

EPRI is exploring the application of slippery ice in district cooling through a project cofunded with Northern States Power and Argonne National Laboratory. Other utilities interested in cool storage have been invited to participate. As Wendland points out, district cooling could present a profitable new business for many utilities. "A utility can get the best of everything out of this," he says. "It can make the cooling at night, when its baseload plants are underutilized, and it can benefit from the sale of the cooling."

CFCs and education

District cooling plants may also help address another issue: chlorofluorocarbons (CFCs). The production of CFCs, which function as refrigerants in air conditioning

and cool storage systems, is currently being phased out through international mandates because CFCs destroy the ozone layer in the upper atmosphere and contribute to the greenhouse effect.

EPRI is spending $2 million a year to develop CFC substitutes that can be used with both conventional air conditioning systems and cool storage systems. But in the meantime, says Wendland, ammonia is an attractive alternative for application in district cooling plants that employ cool storage. Although ammonia can be hazardous to humans, it is an efficient, environmentally benign refrigerant, Wendland says. District cooling systems would confine the circulation of the substance to large isolated plants.

For the same reason, ammonia is also an attractive substitute for individual cool storage systems. Unlike conventional air conditioning systems, cool storage technology does not circulate refrigerant in coils that run through occupied buildings. Instead, these systems circulate chilled water through the buildings while the refrigerant is confined to machinery located outside. Any accidental leak of ammonia would therefore occur in the open air, away from people.

Already, several ice storage systems installed in the industrial sector use ammonia as a refrigerant. Food processing facilities, petrochemical manufacturing plants, and refrigerated warehouses all have employed systems that use ammonia. EPRI is studying the application of ammonia in cool storage systems and is compiling educational materials on how to apply ammonia properly in such systems. One important consideration is to keep the apparatus that circulates the ammonia away from places, such as sidewalks, frequented by people.

Information transfer has always been an important facet of EPRI's work in cool storage. "A lot of people don't realize that cool storage systems aren't just a compressor and a storage tank," says Wendland. "In order to optimize your system and make it more cost-effective, you have to completely rethink the entire heating, ventilating, and air conditioning system and in some cases even the building structure itself, as was the case in the Seafirst project [discussed earlier]. And you're dealing with many different people: engineers, building owners, utilities, architects, contractors, and building operators. There are a lot of variables that have to be brought together."

EPRI has a keen interest in providing high-quality technology transfer for cool storage, since any system designed, installed, or operated improperly is a bad reflection on the technology overall. In an effort to offer comprehensive technology transfer services, EPRI in 1989 established the Thermal Storage Applications Research Center at the University of Wisconsin at Madison.

Accessible to members through a toll-free number (800-858-3774), the center performs and manages applications-oriented research and provides member utilities and their customers with information on cool-storage-related DSM opportunities. Its utility services include technical training seminars and applications troubleshooting on critical projects with commercial customers. The center also functions as a liaison to manufacturers, professional organizations, and other research groups.

Wendland stresses that EPRI's role in cool storage education is just as significant as its technical role. "We can develop all kinds of wonderful improvements that will make this technology more efficient," he says. "But unless the right information is getting to the appropriate people, these systems may not illustrate the full benefits that cool storage has to offer utilities and their customers. We want to make sure everyone that opts for this technology gets to experience the true extent of its energy efficiency and cost-effectiveness." ■

Background information for this article was provided by Ron Wendland and Morton Blatt, Customer Systems Division.

by Taylor Moore

THE STORY IN BRIEF CFCs and other refrigerants that can destroy the earth's protective ozone layer are on the way out, under both international agreement and new U.S. laws. The move will mean big changes in the design and cost of all types of cooling and refrigeration equipment, including those used in cars, homes, and businesses. Electricity used for indoor cooling and refrigeration accounts for a major share of utility industry revenue, so utilities have much at stake in ensuring that suitable alternative refrigerants are identified and developed for all the major equipment categories without substantial sacrifices in energy efficiency. On behalf of the utility industry, EPRI has launched a long-term, collaborative effort with refrigerant producers and equipment manufacturers to develop new refrigerants, as well as a full range of non-ozone-depleting systems to use them, by around the end of this decade.

CHLOROFLUOROCARBONS (CFCs) AND RELATED COMPOUNDS called hydrochlorofluorocarbons (HCFCs) are the essential working fluids in virtually all electrically driven vapor-compression systems that keep food fresh or frozen and homes, buildings, and vehicles comfortably air-conditioned. There is growing evidence, however, of damage to the earth's protective ozone layer by chlorine from CFCs (and, to a lesser extent, HCFCs) used as refrigerants, blowing agents, and solvents and by bromine from halon gases used as fire extinguishants. As a result, these chemicals are being phased out of commercial use even faster than the pace set in a 1987 international agreement sparked by satellite images of a springtime ozone hole over Antarctica.

In that accord—the Montreal Protocol on Substances That Deplete the Ozone Layer—over 35 countries agreed to cut the production and use of CFCs and halons in half by mid-1998. But since then, evidence of even faster and more widespread destruction of the ozone layer has spurred an accelerated phaseout of CFCs in this and other developed countries, in an increasingly urgent attempt to reduce the level of stratospheric chlorine over the next several decades. These efforts will eventually bring changes that will probably affect the cost and operating efficiency of everyone's refrigerator, freezer, and home or car air conditioner. Fortunately, there are reasonable prospects for success in the development of suitable, non-ozone-depleting alternative refrigerants for such applications as refrigerators, freezers, and auto air conditioners.

But perhaps more problematic for indoor air conditioning and chiller manufacturers—as well as for utilities, who depend on the sale of electricity for these types of equipment for a major share of their revenue—is that efforts to save the ozone layer by eliminating CFCs and halons will eventually also extend to HCFCs. These refrigerants are used in all unitary heat pumps and air conditioners in homes and businesses, as well as in positive-displacement chillers for cooling commercial buildings. One HCFC com-

Refrigerants for an Ozone-Safe World

NASA

pound is also the favored near-term replacement refrigerant for low-pressure centrifugal chillers, which up to now have used a CFC.

Because HCFCs contain hydrogen, they decompose in the atmosphere years sooner than CFCs (which persist for decades) and are only one-twentieth to one-fiftieth as damaging to the ozone layer. Yet HCFCs are still of enough concern that policymakers believe they too must eventually be eliminated.

Major chemical companies that produce CFCs and HCFCs, such as DuPont, Allied-Signal, and ICI Chemicals, are intensively pursuing the development of alternative compounds, primarily hydrofluorocarbons (HFCs), that do not contain chlorine and thus do not damage stratospheric ozone. But it is expected to take about a decade to fully develop and bring new refrigerants—and equipment optimized for their use in various applications—into commercial production.

Until recently, HCFCs were seen as the chemical saving grace that would enable a transition to more environmentally benign substitutes for most of the existing $135 billion of nonautomotive compressor-based installed cooling equipment. However, as evidence has mounted that ozone depletion is occurring at possibly twice the rate projected by models and over wider areas of the globe—not just in the southern polar region, as previously observed, but even in the midlatitudes—the timetables for the phaseout of CFCs have been stepped up, and additional ones for HCFCs are being set.

Echoing the position of refrigerant manufacturers who have endorsed an accelerated phaseout of CFCs, President Bush earlier this year moved to ban CFC production for new equipment by the end of 1995—five years earlier than called for in the 1990 Clean Air Act, provisions of which were intended to codify the Montreal Protocol but in fact went even further. One major manufacturer has already stopped making CFCs, sourcing new orders from another producer. A follow-up international accord to the Montreal Protocol contained only voluntary provisions for HCFCs, but the Clean Air Act calls for a production freeze in this country beginning in 2015, which will lead to a ban on their use in new heating and air conditioning equipment beginning in 2020. The U.S. Environmental Protection Agency (EPA) is responsible for regulation and enforcement under the provisions of the Clean Air Act.

Refrigerant producers and equipment manufacturing industries are hoping they will be assured of enough time to use HCFCs to get through at least one product development cycle. That would provide some transition before another redesign to accommodate a completely new, as-yet unidentified, refrigerant compound (with unknown efficiency and cost implications).

But if being destructive to ozone weren't bad enough, CFCs—and, to a much lesser extent, HCFCs and even HFCs—can also contribute to possible global warming as so-called greenhouse gases. The extent of global emissions of CFCs and their concentration in the atmosphere are orders of magnitude less than those of the major greenhouse gas, carbon dioxide; yet per molecule, CFCs are 10,000 times more effective at absorbing infrared radiation than is CO_2—and they do it within a window of infrared wavelengths not absorbed by CO_2 or water vapor. HCFCs and HFCs also absorb infrared energy, but not nearly as effectively as CFCs.

While their ozone-depletion potential is the main reason CFCs and HCFCs are on a fast track to prohibition, their potential role in global warming—as well as the role of possible substitutes—further complicates scientific assessment and regulatory policymaking regarding time frames for phaseout and the acceptability of new refrigerants.

In terms of direct emissions of greenhouse gases, CFCs released into the atmosphere up to now have come mainly from automobile air conditioners and commercial refrigeration systems. They represent only about a quarter of total greenhouse emissions, while CO_2 accounts for more than half. Far more important as a potential contribution to global warming for nearly all vapor-compression equipment over its life cycle are indirect emissions of CO_2 from fossil-fuel-based electricity generation. Since this potential contribution is a function of energy efficiency, experts say it is critically important that energy efficiency not be compromised as the next generation of equipment is designed to use ozonesafe refrigerants.

The fate of CFCs and its eventual extension to HCFCs as a result of their role in ozone depletion and potential greenhouse warming have prompted one major refrigerant producer to announce its intention to stop selling HCFC-22 for use in new equipment manufactured after 2005. Meanwhile, the Natural Resources Defense Council (NRDC), an environmental organization that has often succeeded in forcing more-aggressive terms into EPA regulatory policy, has petitioned the agency to ban the use of HCFC-22 for new equipment after 2000 and for existing equipment after 2005. Such pressure may also affect the prospects for accelerated phaseout of HCFC-123, the favored replacement for CFC-11, which is used in most centrifugal chillers. Yet there are currently no available alternatives for HCFC-22 in heat pump and cooling applications, and none for HCFC-123.

The clock is ticking

Will the phaseout of HCFC-22 be accelerated? The EPA is expected to issue regulations spelling out a timetable for HCFCs sometime after a United Nations Environment Program review of the Montreal Protocol this November in Copenhagen. While the NRDC is trying to force a phaseout of HCFC-22 for new equipment beginning in 2000, the Air-Conditioning and Refrigeration Institute (ARI), representing equipment manufacturers, has proposed 2010 as a basis for a more rational transition.

"If there isn't the security of having HCFC-22 around for some time in the future, users are less likely to move away from CFCs," says Mark Menzer, ARI's vice president for research and technology. "Moreover, right now there are no proven substitutes for HCFC-22 that you could actually design a heat pump or air conditioning system to use."

Finding and developing substitutes is a protracted process. "Since it takes at least

REFRIGERANT APPLICATIONS AND ELECTRICITY USE It is estimated that more than $50 billion in annual utility revenue comes from the sale of electricity to run refrigerators, freezers, heat pumps, air conditioners, and chillers across all end-use sectors. CFCs, which have been the preferred refrigerants and insulation-blowing agents for much of this equipment, are on an accelerated phaseout schedule because of their potential to damage stratospheric ozone. HCFCs are somewhat less damaging to ozone and until recently were thought to offer an interim solution to the loss of CFCs. But HCFCs are also slated for eventual phaseout early in the next century, and there are no proven alternatives for most applications in which HCFC-22 is now widely used.

Application	Refrigerant	Electricity Use (billion kWh/yr)	Percentage of Total 1988 Electricity Use
Refrigerators, freezers	CFC-11, CFC-12	177	6.9
Unitary air conditioners, heat pumps	HCFC-22	262	10.2
Chillers	CFC-11, CFC-12, HCFC-22	59	2.3
Commercial refrigeration	CFC-12, CFC-502, HCFC-22	50	1.9
Industrial refrigeration	CFC-12, CFC-502, HCFC-22, ammonia	55	2.1
TOTAL		603	23.4

10 to 12 years to develop a new refrigerant all the way through toxicity testing and equipment development, there is really very little time to respond to the anticipated phaseout of HCFCs," says Powell Joyner, technical manager for advanced residential projects in EPRI's Customer Systems Division. "Only 2 to 3 years ago, people in the HVAC industry thought HCFC-22 was going to be the solution to their problems, but in a relatively short time it will be gone, like CFCs." EPRI is playing a key role in ensuring that alternative refrigerants and the equipment to use them are developed.

Although CFCs are not gone from the market yet, it has suddenly become more difficult to deal with their continued use in auto air conditioners. As of July 1, 1992, it is illegal to intentionally release CFCs to the atmosphere, and EPA regulations require service shops to recover and recycle CFCs with costly machines; violators are assessed stiff penalties. Any consumer who has recently tried to buy a can of CFC-12 (R-12) to recharge an auto air conditioner has most likely felt the pinch of that refrigerant's sudden drop in availability and its inflated price.

Next year, U.S. automakers are expected to begin producing models with redesigned air conditioners that run on HFC-134a by using different compressors and larger evaporators and condensers. Refrigerant producers are scaling up recently built HFC-134a pilot-scale facilities to satisfy the expected demand. For existing cars, though, the high cost of retrofitting units to use HFC-134a is likely to be prohibitive, so most motorists will have to go to service shops to get recycled CFC-12, which will remain available for some time.

But the added costs and difficulties of converting auto air conditioners to run on non-ozone-depleting refrigerants will seem modest compared with the technical challenges and possible implications of redesigning nearly all other vapor-compression-based refrigeration and cooling equipment in an atmosphere of confusion and uncertainty over the possibility of even further refrigerant restrictions.

Annual revenues from U.S. sales of refrigerants for all applications are estimated at about $250 million and represent a small fraction of the overall business of the chemical companies that make refrigerants. Further up the pyramid of refrigerant-dependent revenue, the manufacture and installation of all air conditioning equipment and commercial chillers amounts to $20 billion yearly in revenue. But considering that the electric utility industry gets over $50 billion, or 23% of its revenues, annually from the sale of electricity to run vapor-compression-based refrigeration and heating and cooling systems, it's not hard to see which industry has the most at stake in the global response to ozone-depleting refrigerants.

The outlook for advanced compressors and HFC-134a to enable a transition from CFCs is perhaps somewhat more encouraging in the case of home refrigerators than in other applications. Refrigerator and compressor manufacturers are making progress and generating considerable technical innovation in responding to a multidimensional challenge: the phaseout of CFCs is coming at about the same time that tough new federal energy efficiency standards take effect. Manufacturers are developing several new approaches to advanced compressors that can run on HFC-134a.

The EPA, meanwhile, has encouraged the use of HFC-152a in refrigerators because it has less potential to contribute to direct global warming than HFC-134a. So far, manufacturers have shown little interest in developing equipment to use this alternative because of its flammability. Yet there is considerable consternation among manufacturers over the uncertainty surrounding potential substitute refrigerants, given the EPA's ultimate authority to specify acceptable compounds for particular applications. The agency is conducting an ongoing assessment of the global warming potential of candidate alternatives, and there is concern that a compound judged acceptable in the near term may later be ruled unacceptable.

EPRI and several utilities are actively involved in cooperative efforts with appliance makers to develop CFC-free refrigerators and supermarket refrigeration systems. Various utilities are also involved in the so-called Golden Carrot incentive program to develop superefficient—and CFC-free—domestic refrigerators. A notable example of the effort in supermarket refrigeration is the recent demonstration, led by the New York State Energy Research and Development Authority and cosponsored by EPRI in conjunction with that state's utilities, of an HFC-134a-based air conditioning and midtemperature refrigeration system in a new Glens Falls, New York, supermarket. The advanced system features innovative screw and open-drive compressors.

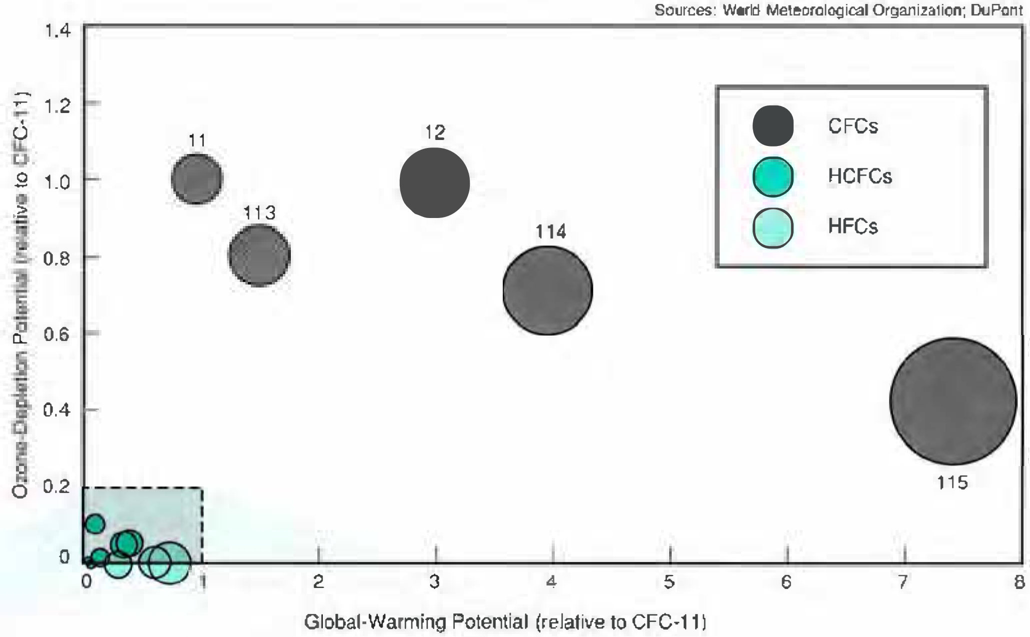
But for electric heat pumps, unitary (residential, window, and rooftop) air conditioning systems, and chillers, the technical and financial challenges of accommodating the switch to ozone-safe refrigerants that also have low potential to contribute to global warming seem more problematic. Many of the manufacturers of heating and cooling systems also produce a variety of gas-fired cooling systems. And in Japan, gas-fired absorption chillers have already gained a dominant market share. U.S. chiller manufacturers could focus on producing such equipment for the American market, considering that each of them already has a joint venture or import marketing agreement with Japanese manufacturers.

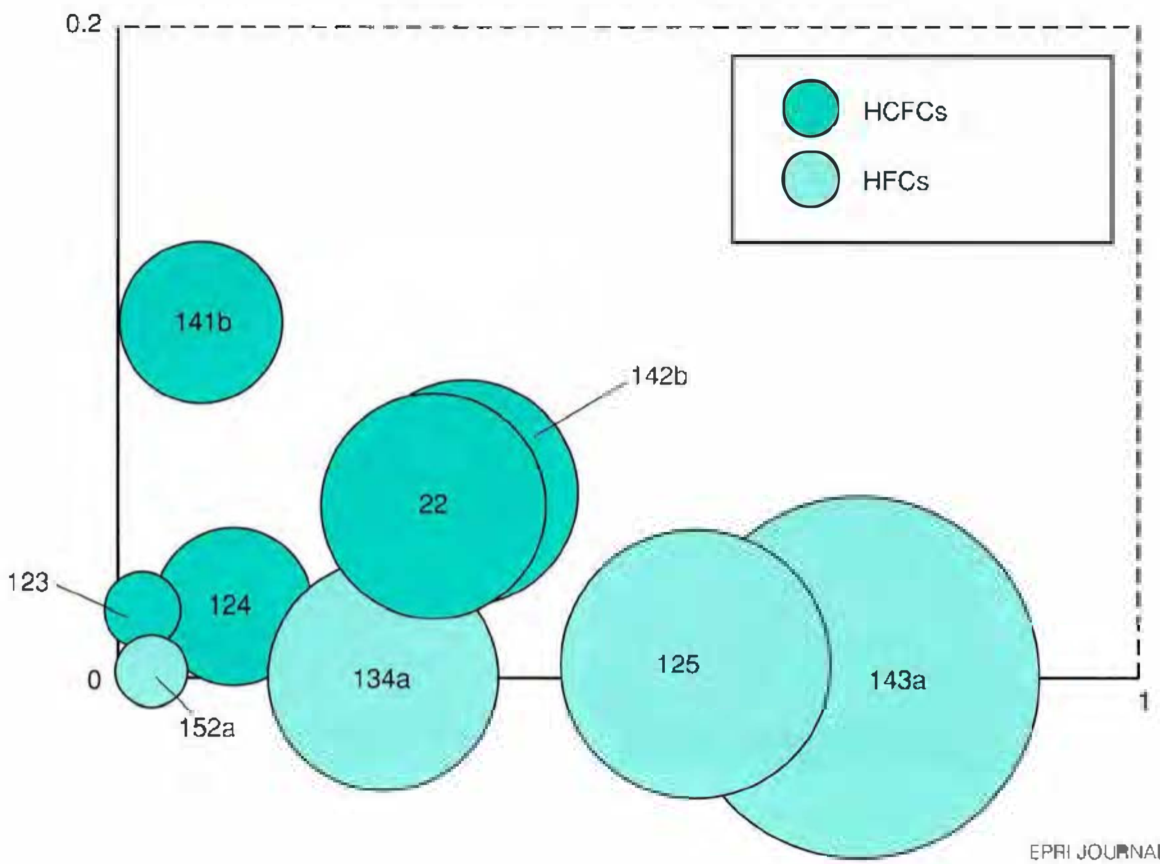
In the case of air conditioning systems, "it is possible that equipment manufacturers may be forced to adopt a refrigerant that may be a satisfactory alternative to HCFC-22 for unitary air conditioners but is less than optimal for heat pumps," says Arvo Lannus, residential program manager in EPRI's Customer Systems Division. "This could cause increased U.S. energy consumption, marketplace confusion, and fewer heat pump manufacturers and thus accelerate the loss of electric heating market share."

Not only do utilities have the most to lose from the lack of suitable alternatives to CFCs in terms of the implications for revenue and market share; they also have the most to lose if substitute refrigerants turn out to be less energy-efficient. Because about two-thirds of the country's electricity is generated with fossil fuels, even a small decrease in the energy effi-

OZONE-DEPLETION AND GLOBAL WARMING POTENTIALS: A RELATIVE MATTER Different refrigerants have different potentials to destroy stratospheric ozone or contribute to possible global warming, depending on their chemical composition and their residence time in the atmosphere. With CFCs soon to be out of the picture commercially, regulators and policymakers have turned their attention to the relative potentials of HCFCs, which are expected to be eventually phased out after 2000, and HFCs. Because they contain no chlorine and thus have zero ozone-depletion potential, HFCs are a promising class of alternatives. But their ability to absorb infrared radiation as greenhouse gases, although not as great as that of CFCs, makes their ultimate acceptability as CFC/HCFC replacements uncertain. The sizes of the circles represent relative atmospheric lifetimes.

Sources: World Meteorological Organization; DuPont





ciency of installed refrigeration and cooling equipment could translate to substantial increases in utility emissions of CO_2 from increased fossil-fired generation.

A recent study at Oak Ridge National Laboratory (ORNL) evaluated the relative equivalent contributions of direct CFC emissions and indirect energy-related carbon emissions to the global warming potential associated with 10 major applications of refrigerants and insulation. It highlighted the importance of energy efficiency in a total life-cycle evaluation of global warming potential. The analysis was part of a collaborative effort sponsored by the Alternative Fluorocarbons Environmental Acceptability Study—a consortium of major chemical companies—and the government.

The ORNL study found that the greatest proportionate reductions in equivalent warming impact will come from replacing CFCs in commercial refrigeration, in auto air conditioning, and in roof insulation for commercial buildings. The first two applications have up to now involved equipment with typical refrigerant loss rates of 25–30% per year (although new designs could reduce losses by an order of magnitude); in the third case, a lot of blowing agent is used. As a result, direct chemical emissions account for about one-third of the total equivalent warming impact of each of these three applications. For new equipment designs, the insulation that uses HCFCs or HFCs as alternative blowing agents will have to be at least as energy-efficient as the insulation that uses CFCs, and it must also have low global warming potential itself.

For most other applications, including refrigerators, chillers, air conditioners, heat pumps, and other types of insulation (including that used in refrigerators and freezers), by far the greatest equivalent warming impact comes not from direct emissions of CFCs or HCFCs but from CO_2, produced indirectly through the generation of electricity to power the equipment. The study highlighted the opportunities for reducing direct emissions in a few applications through new technology, but in most applications, new technologies would have to be equal to (or better than) HCFC/HFC options in efficiency and comparable in cost to actually lead to lower overall warming impact. "Further constraints on the HCFC and HFC alternatives could be counterproductive from a global warming point of view," the ORNL researchers noted.

"Manufacturers of home refrigerators and commercial refrigerators are doing a remarkable job of responding to the challenge of the CFC phaseout by developing models that use, for example, HFC-134a, and are also as energy-efficient as current equipment—in these applications we can expect to maintain comparable overall efficiencies. But there really is a danger of losing energy efficiency in present applications of HCFC-22, such as heat pumps or central air conditioning," says Steven Fischer, a building equipment researcher in ORNL's energy division.

Fischer says manufacturers' data gathered by ARI for the alternative fluorocarbon study indicate that if, for example, HFC-134a had to be used as a less-than-optimal substitute for HCFC-22, heat pumps and air conditioners made to sell at today's costs would consume anywhere from 10% to 35% more electricity in heating and 20% to 30% more in cooling.

Response to the CFC/HCFC phaseout

Since 1988, EPRI has supported research on new refrigerants (some of it cosponsored with the EPA) at Clemson University, the University of Tennessee, and the National Institute of Standards and Technology (NIST). EPRI has also been working with refrigerant and equipment manufacturers to identify alternative chemicals and evaluate thermodynamic cycles for positive-displacement and centrifugal chillers with zero ozone-depletion potential.

But, according to Joyner, "research aimed at resolving the HCFC alternatives problem needs a national focus. The divergent roles and business interests of equipment manufacturers and the policies and charters of the Department of Energy, EPA, and NIST and the national laboratories cause them to pursue different aspects of the problem."

To respond to a possibly accelerated phaseout of HCFCs, notably HCFC-22, and to ensure that the transition to non-ozone-depleting refrigerants does not wipe out much of the success of energy conservation efforts by causing increased energy use, EPRI has consolidated and expanded its research in this area. The result is a comprehensive 10-year, $23 million effort to develop non-ozone-depleting heating and cooling systems. It is anticipated that additional universities, research centers, and manufacturers will become involved in the work with EPRI as part of vertically integrated industry teams.

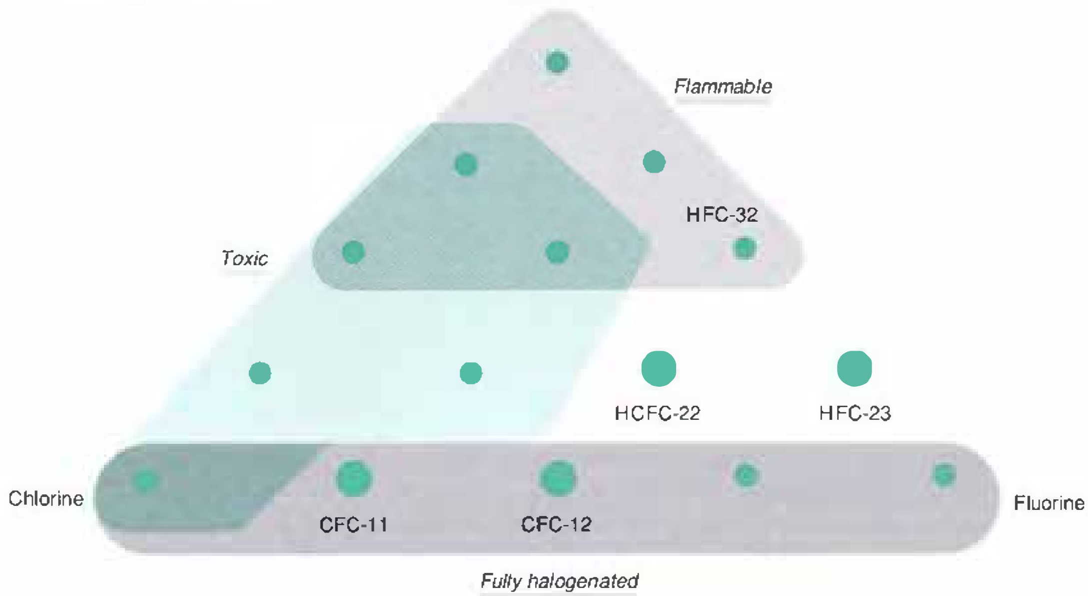
The broad goal is to catalyze substantial collaboration with equipment manufacturers, and also to work with chemical producers, in identifying suitable refrigerants and in developing for all major applications equipment and systems that do not damage the ozone layer and have only minimal potential global warming impact. More-specific—and ambitious—goals call for collaboratively developed non-ozone-depleting equipment to account for a substantial share of the market for new heat pumps, air conditioners, and chillers within five years of their introduction at the turn of the century.

The ultimate expected outcome of the EPRI initiative—the widespread adoption of environmentally acceptable heat pumps and chillers—will depend heavily on the identification of suitable refrigerants, clear choices for which have not yet emerged. As a result, the first phase of the work will involve characterization studies for a broad range of fluids. These will be followed by evaluations of the potential performance of candidate refrigerants in heat pumps and chillers with analytical cycle models, coupled with experimental measurements from breadboard systems.

In the second phase of the project, equipment development will be undertaken with participating manufacturers to produce unitary air-source and water-source heat pumps and reciprocating, screw, and centrifugal chillers for selected residential and commercial applications. Manufacturers are likely to include many of the companies with which EPRI is already actively engaged in R&D, including

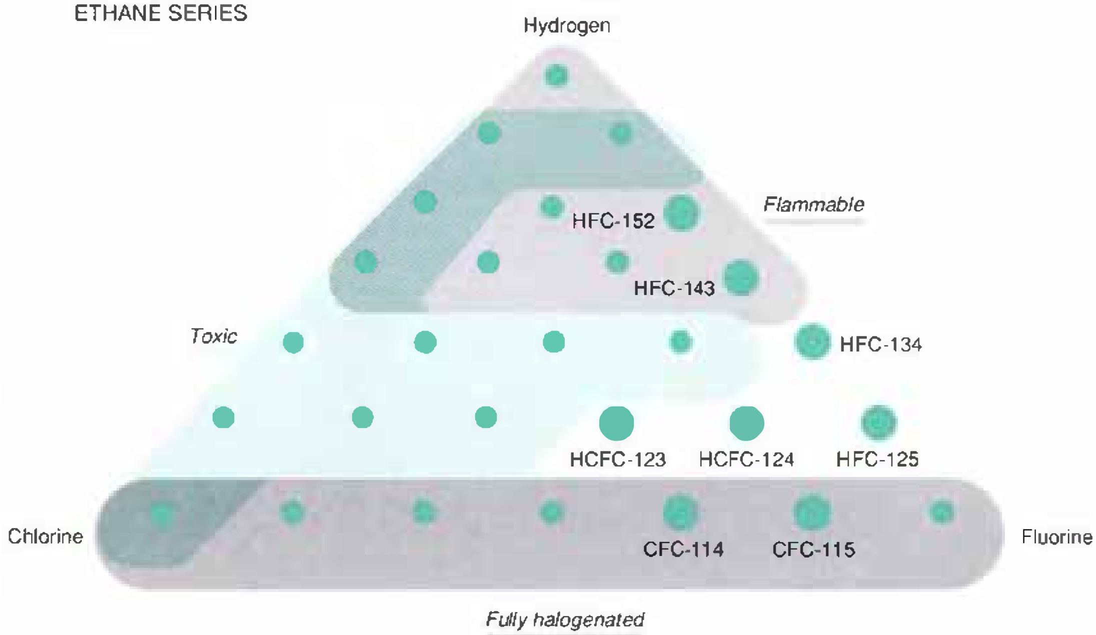
MOLECULAR CHEMISTRY DEFINES THE POSSIBILITIES CFCs and HCFCs are made up of simple, one- and two-carbon methane and ethane molecules with varying numbers of attached chlorine, fluorine, and hydrogen atoms. The molecular simplicity of these compounds makes them easy to produce. But the fully halogenated compounds, which contain no hydrogen atoms, have been deemed unacceptable because of their ozone-depletion potential, and other compositions within the methane and ethane series are unacceptable because they are flammable or toxic. Acceptable alternatives are being pursued, including new compounds and also mixtures in which a compound that might otherwise have safety drawbacks is blended with another refrigerant. EPRI and the Environmental Protection Agency have cosponsored research that has identified nearly a dozen compounds in the more-complicated propane and ether series for detailed evaluation as potential replacement refrigerants. Meanwhile, all the major chemical companies that produce refrigerants are building new facilities to produce hydrofluorocarbons, such as HFC-134a.

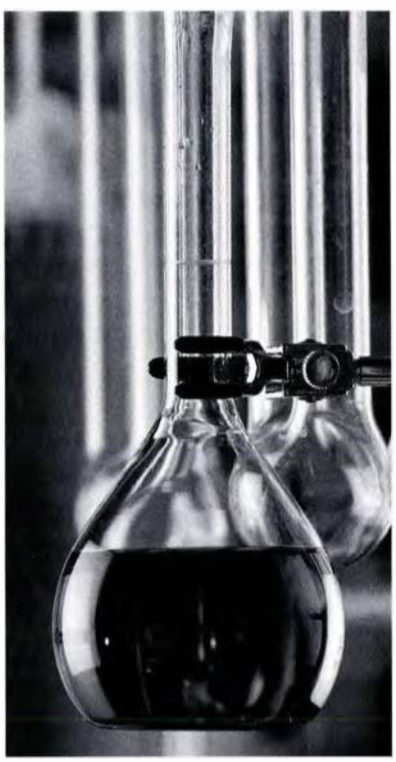
METHANE SERIES



Source: Allied-Signal

ETHANE SERIES





Ron May

Lennox, Trane, York, and Carrier.

Before this recent expansion of activity, EPRI was already sponsoring work by Trane and York to develop non-ozone-depleting positive-displacement heat pumps and chillers and was working with Trane, York, and refrigerant producer Allied-Signal to develop non-ozone-depleting centrifugal chillers. "It's critically important for refrigerant manufacturers to identify and understand the machine design and engineering issues associated with equipment changes that will be needed to deal with the changes in refrigerants," says Wayne Krill, a senior project manager in EPRI's Customer Systems Division. "If this work is done right, there may be opportunities to improve equipment performance and efficiency in ways that wouldn't have been possible without a change in refrigerants."

The range of equipment applications eventually developed under the comprehensive research effort may include split-system, rooftop, ground-loop, and in-building water loop heat pump and air conditioning systems, as well as water-cooled and air-cooled chillers. In the final phase, EPRI plans to actively involve member utilities—for example, by using tailored collaboration to mount field demonstrations of production units. Technology transfer and promotion activities will be conducted with the manufacturers.

The project's systematic, wide-ranging search for alternative refrigerants incorporates work that was already under way. Joyner says the working fluids that are likely to be of practical interest in the time frame of the expected HCFC phaseout fall into two categories. First are pure refrigerants and also azeotropes—mixtures that behave as a single fluid. Then there are nonazeotropic mixtures, with compositions that vary at different boiling points. EPRI expects to support up to five projects at national research centers and laboratories to thoroughly characterize candidates in terms of their thermophysical and heat transport properties, cycle behavior, compatibility with lubricants, and effects on equipment design.

In earlier work cofunded by EPRI and the EPA, research chemists at Clemson and the University of Tennessee synthesized some 37 fluorinated propanes, butanes, and ethers for evaluation as potential refrigerants. The compounds were of sufficient stability, and were synthesized in sufficient yield and purity, to enable the relevant physical and thermodynamic properties to be measured. In recent Senate subcommittee testimony, Eileen Claussen, who heads the EPA's Office of Air and Radiation, said that of those 37 compounds, 11 (9 hydrofluoropropanes and 2 hydrofluoroethers, none containing chlorine or bromine) have been selected for further study at the agency's Air and Energy Engineering Research Laboratory in North Carolina. These 11 have boiling points and critical temperatures near those of the key CFCs (or may form mixtures with desirable properties).

"Much testing remains to be done on

THE OZONE-FRIENDLY SUPERMARKET A Shop 'n Save store in Glens Falls, New York, is the site of the first large-scale demonstration of HFC-134a for supermarket refrigeration and air conditioning applications. The work is being funded cooperatively by the New York State Energy Research and Development Authority, the Empire State Electric Energy Research Corporation, and EPRI.

Warren Roos

these compounds," said Claussen. "EPA will work cooperatively with industry to ensure distribution of ongoing project and test results and encourage participation in the further evaluation and possible development of these potential alternatives."

The expanded EPRI effort will also take advantage of environmental data gathered in Oak Ridge National Laboratory's recent study of alternative fluorocarbons and of a large thermophysical properties database maintained by NIST. EPRI will contribute and expand information developed through its membership in the Air Conditioning and Refrigeration Center at the University of Illinois and will participate in the acquisition of lubricant and materials compatibility data by ARI.

In work already under way for EPRI before the latest initiative was approved, researchers at NIST evaluated new refrigerant mixtures as potential replacements for HCFC-22, the fluid used in most heat pumps. In separate projects, NIST examined the prospects for refrigerants that could be used in new equipment and the prospects for candidate replacements for existing equipment. The challenge is a tough one indeed, since HCFC-22—like most of the CFCs—has proved to be an ideal refrigerant because of its excellent thermodynamic properties, chemical stability, nonflammability, low toxicity, and low cost. Alternatives not only must match these properties but also must have zero ozone-depletion potential as well as low potential to add to global warming.

Because intensive efforts to date in the refrigeration industry have failed to identify a single-component refrigerant that can match HCFC-22's optimal balance of efficiency and capacity, NIST researchers have been studying mixtures of refrigerants. One binary mixture of R-32, which by itself is flammable, and HFC-134a looks promising for some new equipment and may even be more energy-efficient than HCFC-22 if certain heat exchanger designs are used.

NIST's David Didion explains: "Counterflow heat exchangers are practical equipment modifications for refrigerant-to-liquid machines but not for refrigerant-to-air units. As a result, the R-32/134a mixture is a promising development for ground-source heat pumps, but it is not yet a solution for air-source heat pumps."

Researchers have broadened the search for alternative refrigerants to include ternary and quaternary mixtures. In a related NIST project, researchers are investigating potential candidates that could be applied in existing home heat pumps and other refrigeration systems without requiring significant hardware changes. As before, the process involves computer modeling and laboratory testing with a minibreadboard heat pump. The focus is on identifying mixtures whose properties match those of HCFCs and CFCs as closely as possible. There is no effort, as there was in the first study, to capitalize on the physical properties of mixtures through equipment adaptations.

"For new equipment, you may be able to accept a refrigerant that is less efficient than the preferred substance by compensating for it in the equipment design, although that usually entails higher cost," says Joyner. "But for existing equipment, the implications for increased indirect greenhouse gas emissions mean that alternative refrigerants have to be at least as energy-efficient as what you used before."

To environmental scientists and policymakers, including the EPA regulators who must ultimately rule on the acceptability of each replacement refrigerant for specific applications, probably the most important criteria for consideration are, in descending order, ozone-depletion potential, global warming potential, toxicity, and energy efficiency. But for refrigerant producers and users, other key criteria must be factored into consideration, including flammability and the simplicity and cost of production. Refrigerant producers must pay the high cost of long-term testing of candidates to make sure that the chemicals are not health hazards. And it is equipment manufacturers who bear the brunt of the liability burden and thus are reluctant to accept flammable replacements.

Planning for a ripple effect

Because EPRI expects to be able to work directly with only half a dozen or so of the more than 30 manufacturers that make up the heat pump and chiller manufacturing industry, a key element of EPRI's strategy is an expected ripple effect as competitors seek to match the performance and innovations developed through sponsored research with specific manufacturers. Conceivably, much of the current annual U.S. heat pump market of about a million units could be covered by products developed or licensed from EPRI's initiative if the units perform as well as or better than current models and if the alternative refrigerant provides satisfactory performance for cooling use. Also, the penetration levels for heat pumps in residential markets should grow as an alternative to electric resistance heating.

A big question is whether electric chillers will maintain market share against gas-fired absorption equipment. Annual shipments of centrifugal and positive-displacement chillers number about 11,000, all but a few hundred of which are electrically driven. EPRI expects to undertake advanced development projects with about half of the major U.S. chiller manufacturers.

For now, however, visions of market share and revenue streams are tempered by the sobering knowledge of the existing business that is at stake in supplying and powering vapor-compression cooling and refrigeration systems in a new regime of protection for the global stratosphere. The big challenges of adapting modern life and conveniences to do without chlorine-containing refrigerants mainly still lie ahead. ■

Further reading

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Background information was provided by Powell Joyner and Wayne Krill, Customer Systems Division.

TECH TRANSFER NEWS

Videoconferencing: New Ties to Members, Centers

As part of its ongoing initiative to enhance technology transfer through the use of advanced electronic information systems, EPRI has installed a videoconferencing facility at its Palo Alto headquarters. Already the facility is being put to use routinely for improving communication with member utilities and with EPRI's collaborative work centers throughout the country.

Like facsimile transmission, videoconferencing has been around for many years but has only recently become inexpensive enough for routine business use. In both cases, it was the development of a new generation of powerful integrated circuits that brought about a virtual explosion of commercialization activity. For some older systems, videoconferencing required special telephone circuits that could carry up to 1.5 million digitized bits of information per second, at a cost of several hundred dollars per hour. The new technology employs two standard digitized twisted-pair telephone lines, with a total carrying capacity of 112 kilobits per second. Minimum equipment costs run about $25,000, and the cost of a videoconferencing call is only a few dollars higher than ordinary long-distance charges.

Although the original promise of videoconferencing was that it would cut the travel required of busy executives, recent experience has shown that productivity gains in routine meetings may actually be more important. By making face-to-face meetings spanning the continent possible virtually on demand, videoconferencing enables more people to participate in more deliberations, with much less commitment of time and travel expenses. Already many companies in the electronic and aerospace industries use videoconferencing to bring diverse experts together for engineering and product design. EPRI's initial emphasis is on building stronger ties within the research community of the geographically dispersed electric power industry.

Some of these new ties extend directly to member utilities. Bonneville Power Administration has agreed to a year-long pilot program involving a series of monthly videoconferences with EPRI to discuss a list of specific strategic topics. Because BPA is also connected to the government's FTS teleconferencing network, EPRI participants will have access to a much wider potential audience. Another utility has used a portable videoconferencing unit to enable its senior executives to hold a series of meetings with groups of EPRI staff from four divisions. Test conferences have also taken place with PowerGen, EPRI's international affiliate in the United Kingdom.

As the Institute itself continues to diversify geographically, through its collaborative work centers, videoconferencing is expected to play an increasingly important role in coordinating communication with EPRI headquarters. Every Tuesday, for example, there is a videoconference between Nuclear Power Division staff in Palo Alto and personnel at the Nondestructive Evaluation Center in Charlotte, North Carolina. Every other Friday, it's the Generation & Storage Division's turn. Videoconferencing facilities have been established at EPRI's Washington, D.C., office, the High-Sulfur Test Center in New York, and the Monitoring and Diagnostic Center near Philadelphia. Facilities in other centers are planned for the near future.

In addition to seeing each other, people attending a videoconference can share a variety of graphic information, including slides, documents, computer displays, videotapes, and hand drawings. For high resolution, documents can be transmitted in a freeze-frame mode and stored electronically at either end.

EPRI has arranged with PictureTel, which supplies the Institute's videoconferencing equipment, to offer a discount to member utilities who wish to establish their own facilities. Compatible commercial facilities for videoconferencing are also becoming available in many parts of the country. An informational brochure on EPRI's new videoconferencing capabilities (BR-100655) will be published this September. ■ *EPRI Contact: Sarah Brown, (415) 855-2886*

Bonneville Power Administration's Randall Hardy and EPRI's Dick Balzhiser participated in a long-dis-

News on Nuclear Topics Available On-line

EPRINET, the Institute's electronic information and communications network, has recently added and enhanced news services related to three key nuclear plant issues: low-level waste, radiation control, and plant chemistry. These services offer up-to-the-minute information on industry developments, EPRI research results and products, future events, newly published reports, and new projects.

Low-Level Waste News is aimed at utility radioactive waste managers and individuals involved in developing new disposal facilities. In addition to reporting recent EPRI activities, this news service covers emerging issues at NRC, EPA, DOE, and EEI; provides status reports on state compacts; and includes an up-to-date listing of utility contacts.

Radiation Control News is for utility corporate and plant radiation protection managers and other staff involved in reducing occupational exposure. The service covers industry news, primary chemistry for reducing radiation fields, cobalt reduction, preconditioning, and decontamination.

Nuclear Plant Chemistry News is directed toward corporate and plant chemists, as well as utility staff specialists in other areas—steam generators, materials, and fuel, for example—who need to keep abreast of developments in water chemistry. News is provided on PWR primary-system chemistry, PWR secondary-system chemistry, BWR chemistry, service water, and other chemistry issues.

tance ribbon-cutting ceremony that opened the Institute's pilot videoconference link with BPA in June.

During 1992 EPRINET is available at no charge to all interested users in the United States. Please call the EPRINET Help Desk, (800) 964-8000, to sign on to this service and obtain a user's package. ■

EPRINET Carries CGI Database

A database on nuclear commercial-grade items (CGIs) is available via EPRINET, providing utilities with a centralized, constantly updated source of information for use in evaluating, procuring, and accepting these items for safety-related service. Given the decreasing number of vendors that supply replacement items manufactured under a certified (10CFR50, Appendix B) quality program, the availability and proper use of CGIs have taken on increased importance at operating nuclear plants.

The Nuclear Regulatory Commission requires that when a CGI is to be used in a safety-related application at a nuclear power plant, a utility must first "dedicate" the item for this application by performing a technical evaluation and implementing an EPRI-developed and industry-approved acceptance process. The EPRI/Joint Utility Task Group (JUTG) was created to minimize the financial burden of CGI dedication by developing a consistent approach for implementing these dedication requirements. Technical information generated through this effort is pooled into the CGI Database.

"Several utilities use the CGI Database every day," says Warren Bilanin, manager of EPRI's nuclear plant application activities in Charlotte, North Carolina. "Most important, it saves them time. They don't have to chase down information from all over—and getting the right information amounts to 60–70% of the job. In addition, they can learn what experience other utilities have had with particular products and vendors, which can result in considerable cost savings."

By accessing the CGI Database through EPRINET, utilities can incorporate technical evaluation package information approved by the JUTG, rather than having to develop complete packages for dedicating commercially available items on their own. Also, a utility can query the database for information on the controls a vendor exercises over the manufacture of a CGI, thus learning from the experience of other utilities. In the future, a utility will also be able to obtain information on the procurement history of a vendor or item.

New technical evaluations are added to the CGI Database as they are completed by the JUTG Technical Work Group and approved by the JUTG membership. The JUTG Technical Advisory Group has recently proposed a new menu system for the CGI Database, which is currently being incorporated into the EPRINET format. ■ *EPRI Contact: Tom Mulford, (704) 547-6087*

LILCO Turns to Community for R&D

Long Island Lighting Company has launched a new R&D program aimed at tapping the rich scientific resources in the utility's own backyard. "In a symbolic sense we're opening up the window to let the fresh air of new ideas come in to us from the outside," says Timothy J. Driscoll, LILCO's research and development director. "What we're trying to do is get new thinking to help us solve our energy problems and improve the way we provide service to our customers."

As Driscoll points out, significant scientific developments—such as the creation of the module that took the first men to the moon—have taken place on Long Island. The community has also been home to a number of notable scientists, including a Nobel Prize winner in genetics and the inventor of synthetic insulin.

LILCO's solicitation of last September drew 162 responses, 28 of which were selected for funding. Some of this R&D is already under way. One of the winning projects involves the development of an integrated communications system. The firm handling this job is a defense contractor that has developed similar technology for the U.S. military. Another project involves the creation of a robotic arm that utility line workers can use in installing and maintaining distribution wires.

The new, regionally focused R&D program, called the Long Island Energy R&D Initiative, supplements existing LILCO R&D efforts at the national level (through EPRI and the Gas Research Institute) and at the state level (through the Empire State Electric Energy Research Corporation, or ESEERCO). The program represents 15% of LILCO's R&D budget and includes cofunding from ESEERCO and others.

"We had great cooperation from EPRI in screening the various proposals we got to make certain there was no duplication with the Institute's research," Driscoll says. One nice side benefit of the initiative, he adds, is that it has promoted close partnerships between LILCO and its community. ■

Exploratory Research

Biofilm Formation and Microbial Corrosion

by Robert Goldstein and Donald Porcella, Environment Division

When microscopic organisms grow on surfaces, they form a thin coating, or biofilm, that thickens as the microorganisms multiply. A thick biofilm blocks ambient gases and nutrients from reaching the surface it is colonizing and traps metabolic byproducts in its own matrix. Within each biofilm, local physical and chemical conditions create an environment that is inhospitable to some microorganisms but ideally suited to others.

Over time, the physical and chemical conditions created by biofilms can profoundly affect the surfaces on which they are growing. For example, metal and alloy surfaces corrode much faster when tiny colonies of aerobic bacteria (which oxidize iron) or anaerobic bacteria (which reduce sulfate) live on them. Because corrosion eats away metal surfaces, such microbially influenced corrosion (MIC) can cause water lines to fail, shutting down utility power plant equipment and compromising reliable plant operation. In some cases, water-cooling safety systems have failed before going into service because microorganisms—in contaminated water left in pipes after pressure testing—have corroded system equipment.

Utilities need information about biofilms and their corrosive properties to design reliable power plant operating systems. To provide that information, EPRI is sponsoring basic biofilm research at the University of Tennessee and Montana State University (RP8011-2). There scientists are studying how biofilms form and how interactions between microorganisms determine biofilm properties, including their corrosive potential. This basic research, directed by EPRI's Environment Division and Office of Exploratory & Applied Research, complements ongoing applied research under the Nuclear Power Division. A recently published *Technical Brief* (TB-100152) summarizes the results of applied biofilm research on detecting and controlling MIC at various power plants.

Through basic research, scientists at Tennessee and Montana State are learning how to control biofilm formation. With this knowledge, they will be able to identify specific ways to prevent MIC. For example, if scientists know that certain microorganisms form noncorrosive biofilms, they may be able to prevent MIC by seeding water sources with those microorganisms—displacing others known to form biofilms with more corrosive potential. Moreover, research on biofilms may prove useful in efforts to describe and control other processes involving groups of interdependent microorganisms, or biological consortia.

ABSTRACT *Biofilms—colonies of microorganisms growing on surfaces—can greatly accelerate the corrosion rates of metals and alloys in utility water systems. Fundamental EPRI research is showing how mechanisms of biofilm formation, interactions between bacterial species, and metabolic activities control such biofilm properties as corrosive potential. This research is identifying methods to control biofilm development and prevent microbially influenced corrosion. The results should also apply to the control of other processes involving biological consortia, including the bioremediation of contaminated groundwater and soil and the biodesulfurization of coal.*

Until recently, studying biofilm processes has been difficult. Not only are biofilms heterogeneous, but methods of characterizing them have required destructive, rather than in situ, analysis. Scientists have tackled both these problems in the first 18 months of the four-year research project at Tennessee and Montana State. They have developed a system that grows reproducible biofilms, thus minimizing the difficulties that result from comparing heterogeneous samples. They also have demonstrated a set of novel, nondestructive biological and chemical techniques for monitoring biofilm development in situ. These techniques will allow researchers to study the way biofilms develop, metabolize, and hence promote corrosion in their natural environment.

Initial applications of these new growing and monitoring techniques show their potential for increasing basic knowledge about biofilms. Without disturbing the biofilms under study, scientists can combine these techniques to collect simultaneous on-site measurements of biofilm functions and electrochemical properties. Ongoing EPRI-sponsored research focuses on using these measurements to understand the link between microbial activity in biofilms and MIC.

Growing reproducible biofilms

Scientists working to grow biofilms with reproducible characteristics have devised physical flow-through models to simulate biofilm formation. In settings similar to those found in utility freshwater cooling systems, water flows through cells over surfaces that are susceptible to corrosion. Researchers can use a variety of nondestructive biological and chemical techniques in the flow-through cells to monitor on-site bacterial colonization and biofilm activity. They can also use microelectrodes to measure the electrochemical activity associated with biofilm development and corrosion.

During flow-through experiments, researchers introduce microorganisms and nutrients into water flowing over a flat metal plate (coupon). The microorganisms attach to the coupon, creating a biofilm. Using advanced analytical techniques (described below), scientists have demonstrated that it is possible to grow biofilms with reproducible characteristics in flow-through experiments. Furthermore, analysis shows that those characteristics depend on the microbial species introduced and their order of introduction.

There is evidence that the characteristics of biofilms also depend on the surface properties of the metals they colonize. For example, laser confocal microscope images have revealed selective growth of the bacterium *Pseudomonas aeruginosa* along the grain boundaries of a Type 316 stainless steel coupon. Scientists are seeking to better understand the physical and chemical properties of metal surfaces that exert a strong influence on microbial attachment. They are also seeking to control this variable in comparative biofilm analysis by developing metal coupons with identical surface properties.

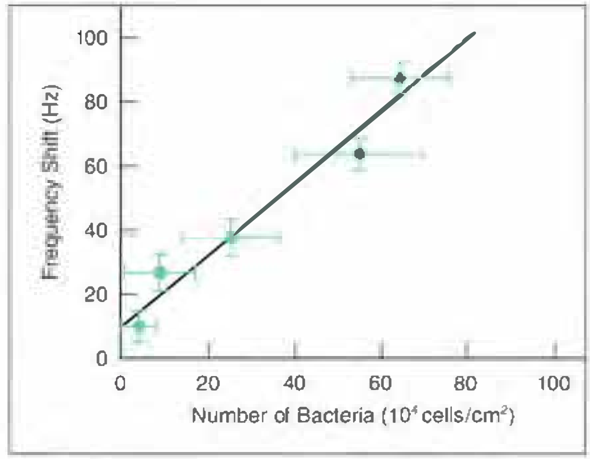
Monitoring biofilm formation and metabolism

Scientists have adapted several nondestructive monitoring techniques to study biofilm formation and metabolism. These techniques involve the use of a quartz crystal microbalance, genetically engineered microorganisms with lux (light-producing) genes, attenuated total reflectance–Fourier transforming infrared (ATR-FT/IR) spectroscopy, and open-circuit potential (OCP) measurements.

The quartz crystal microbalance technique is adapted from a method used to detect contamination in ultrapure environments. In biofilm experiments, it indicates how many bacteria are colonizing a vibrating crystal surface to form a biofilm. The quartz crystal, immersed in solution, vibrates at a known frequency when electrodes on its surface receive alternating voltage. As bacteria colonize the crystal's surface, their weight damps its vibration. When the bacteria become densely attached (10^4 to 10^6 cells per square centimeter), shifts in the crystal's vibration frequency provide a linear measure of the growing biofilm's weight. A traditional, destructive counting method shows that shifts in the crystal's vibration frequency also give a linear measure of the number of bacteria colonizing the crystal (Figure 1).

Scientists are using light emitted from bioluminescent bacteria to locate bacteria in the environment and to monitor physiological processes controlled by certain bacterial genes. To study biofilms, they have created bacteria that fluoresce in the presence of salicylate, an anion easily added to water in a flow-through cell. To create these bacteria, the scientists connect lux (light-producing) genes to an operon (gene se-

Figure 1 A biofilm growing on a quartz crystal microbalance causes the crystal's vibration frequency to decrease. As shown here, there is a linear relationship between the frequency shift induced by the growing film and the number of bacteria in the film, as determined by a destructive counting method. (Adapted from D. C. White et al., "Nondestructive On-line Monitoring of MIC," paper presented at Corrosion/90, National Association of Corrosion Engineers, Las Vegas, Nevada, April 1990.)



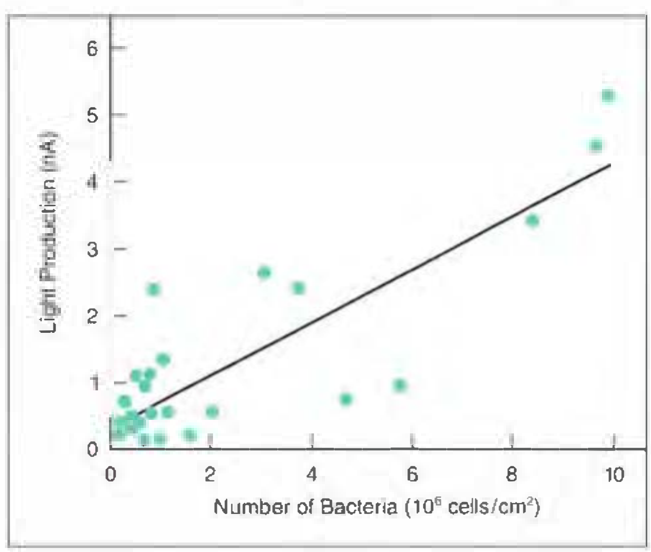
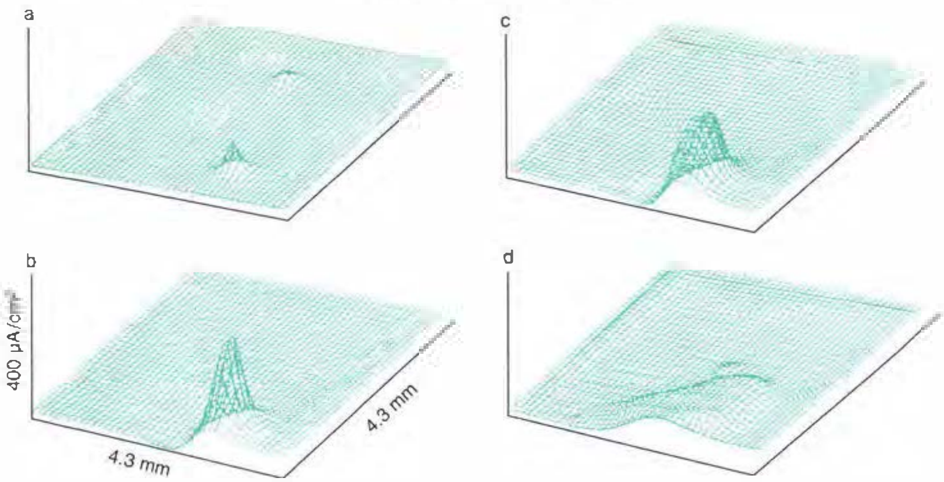


Figure 2 Light emissions from genetically engineered bacteria (photo) are being used to estimate microbial populations, identify specific metabolic activities, and link individual species with corrosion. For example (graph), light emissions from *Pseudomonas fluorescens (lux)* provide a linear measure of the number of bacteria in a biofilm. (Photo courtesy of Gary Sayler, University of Tennessee; graph from D. C. White et al., "Nondestructive On-line Monitoring of MIC," paper presented at Corrosion/90, National Association of Corrosion Engineers, Las Vegas, Nevada, April 1990.)

Figure 3 The scanning vibrating electrode technique can be used to map variations in electrochemical potential over a metal surface, which indicate areas of active corrosion. These maps, for carbon steel exposed to bacteria, show variations after (a) 3 hours, (b) 7 hours, (c) 11.5 hours, and (d) 23 hours. (Reprinted with permission from *Corrosion Science*, Vol. 32, No. 9, Michael J. Franklin et al., "Pitting Corrosion by Bacteria on Carbon Steel, Determined by the Scanning Vibrating Electrode Technique"; © 1991 by Pergamon Press Ltd.)



quence) whose expression (functioning) is triggered by salicylate, and then they insert the engineered operon into the bacterium *Pseudomonas fluorescens*.

The new bacterium—*Pseudomonas fluorescens (lux)*—emits light when exposed to salicylate. In a flow-through cell, these genetically engineered bacteria attach to a stainless steel coupon. When water flowing through the cell contains salicylate, the bacteria emit light, which can be measured through a glass viewing-port by using a flexible liquid light cable and a collimating beam probe. The amount of light emitted by the bacteria serves as a measure of the number of bacteria attached to the stainless steel coupon (Figure 2).

In other species of genetically engineered bacteria, lux genes are connected to operons that regulate production of the extracellular polymers that the bacteria use to adhere to surfaces. With these bacteria, researchers are identifying areas of colonization and growth and investigating the properties of metals and bulk fluids that control bacterial adhesion.

ATR-FT/IR spectroscopy is used to characterize the chemical composition of paints and other thin-film coatings. EPRI-sponsored research has adapted this technique to study the chemical composition of biofilms.

In analyzing biofilms, scientists submerge a germanium or zinc selenide prism in solution and allow bacteria to colonize its surface. Because materials in these prisms are transparent to radiation of infrared wavelengths, the scientists can shoot an infrared beam through the colonized prism. A brief pulse of infrared radiation passes through the prism, travels a short distance into the solution (100–3000 nanometers, depending on prism type), and then reflects back through the prism to an infrared detector. The detector displays an infrared spectrum that shows the chemical composition of the film created by microorganisms and metabolic by-products adhering to the prism's surface. Specific wavelengths indicate the presence of certain metabolic by-products, such as proteins and carbohydrates. As the biofilm grows, energy at those wavelengths increases.

Thus ATR-FT/IR uses spectral energy measurements to correlate increases in specific metabolites with biofilm growth. It also indicates shifts in the chemical composition of a growing biofilm and—because components of the biofilm community have different infrared spectra—identifies changes in community structure.

Scientists use measurements of open-circuit potential to study electrochemical activity in fluid systems. In EPRI-sponsored experiments, researchers have used changes in OCP to monitor the metabolic activity of biofilms growing in flow-through cells. For example, they have studied a cell containing carbon steel coupons and aerobic and anaerobic bacteria extracted from a utility water system site with active MIC. They found that the OCP within the cell changes as biofilm formation progresses. In particular, the OCP change parallels a shift in fluid pH that occurs when growing numbers of bacteria accelerate the metabolism of glucose to the volatile fatty acids acetate and butyrate. Evidence suggests that these fatty acids promote MIC.

Monitoring corrosion

Nondestructive methods of monitoring MIC include the scanning vibrating electrode technique (SVET) and a further adaptation of ATR-FT/IR spectroscopy.

Scientists developed SVET to map electrochemical activity in the nervous system. A platinum wire electrode, vibrating at approximately 200 hertz, detects variations in electrochemical potential over a surface. In neurological studies, the electrode vibrates over nervous tissue; in biofilm studies, it vibrates over an active corrosion site on a metal coupon (Figure 3).

EPRI researchers are using SVET to evaluate the effectiveness of the corrosion inhibitor sodium molybdate. In a flow-through cell containing carbon steel coupons, they found no corrosion over a 27-hour test period when sodium molybdate was present. Without the inhibitor, the same experiment revealed corrosion after only 2 hours. Ongoing SVET experiments are investigating sodium molybdate's potential for inhibiting the corrosive behavior of anaerobic (sulfate-reducing) bacteria.

A further adaptation of ATR-FT/IR spectroscopy allows researchers to use this technique to monitor MIC. In these experiments, bacteria colonize the surface of an infrared-transparent prism coated with a metallic film so thin that a brief pulse of infrared radiation can penetrate it. Once a biofilm is established on this thin metallic surface, infrared spectra can track minute microbially induced changes in the thickness of the metallic film. This technique is so sensitive that it can detect changes of thickness as small as a few atomic layers of copper. Researchers are now investigating methods of coating the prism with a thin film of stainless steel—the most common metal in utility water systems.

An integrated analytical approach

Researchers are applying combinations of the nondestructive techniques described above in order to simultaneously monitor several characteristics of biofilms in flow-through cells.

For example, scientists have made simultaneous measurements with several techniques to study how interactions between microorganisms affect biofilm characteristics. In one set of experiments, they added various combinations of four bacteria—*Pseudomonas fluorescens (lux)* and three other species isolated from a patch of corrosion in a utility water system—to water in a flow-through cell. Light emissions, changes in the OCP, and traditional counting methods all showed that the order in which these bacteria entered the water critically determined the growth rate and composition of the resulting biofilms. This suggests that seeding utility water systems with specific microorganisms might bring biofilm formation and MIC under control.

Using advanced, nondestructive chemical and biological techniques in an integrated approach provides a powerful tool for understanding and possibly controlling MIC. In general, such an approach can lead to a greater understanding of dynamic interactions within biological consortia. This knowledge may help scientists guide processes involving biological consortia in other areas of concern to the utility industry, such as the bioremediation of contaminated groundwater and soil and the biodesulfurization of coal.

Commercial Program

Water-Loop Heat Pump Enhancements

by Morton Blatt and Mukesh Khattar, Customer Systems Division

EPRI has implemented a comprehensive research effort aimed at enhancing and publicizing the benefits that water-loop heat pump (WLHP) systems offer for commercial heating and cooling. Through this effort, EPRI has developed an advanced, high-efficiency WLHP unit, has created guidelines and controls for optimizing WLHP system operation, and is producing a guide for designing, specifying, and installing the systems. Ongoing research activities include analyzing system field-test results, assessing enhancement possibilities, and examining factors that affect heat recovery and efficiency.

ABSTRACT *Versatile, cost-effective, and reliable, water-loop heat pump (WLHP) systems are an attractive option for heating and cooling large and medium-sized commercial buildings. In addition to offering energy efficiency through inherent heat recovery, WLHPs feature low first costs, zoning flexibility, simple controls, and reduced space requirements. Despite these benefits, WLHPs make up only 4% of the commercial heating and cooling market, a far cry from the 40% market share they could capture. EPRI is sponsoring research both to enhance the performance of WLHP systems and to inform utilities and their commercial customers about WLHP advantages.*

The basics

The typical water-loop heat pump system is very simple in concept. It consists of a pipe loop for circulating water and a series of heat pumps—one in each thermal zone—that use the piped water as a heat source or sink. The system also requires a means of removing heat from the pipe loop (typically a cooling tower) and a means of adding heat (typically a boiler).

The cooling tower and the boiler operate as necessary to keep the temperature of the water in the loop within a 60–90°F range. This moderate range allows the use of uninsulated piping, which significantly reduces installed costs. And because each heat pump can perform both heating and cooling, it is possible to use a two-pipe system rather than the usual four-pipe system—further cutting distribution system costs.

The WLHP's efficiency is particularly evident when a building has simultaneous heating and cooling needs. This situation often occurs in larger buildings with perimeter areas that need heating in colder weather and core areas that need year-round cooling. In these cases, the WLHP units that are cooling add heat to the loop and those that are heating extract heat from the loop, thus reducing boiler and cooling-tower operation (Figure 1).

High-efficiency WLHP

EPRI and the Trane Company have developed a high-efficiency WLHP with advanced

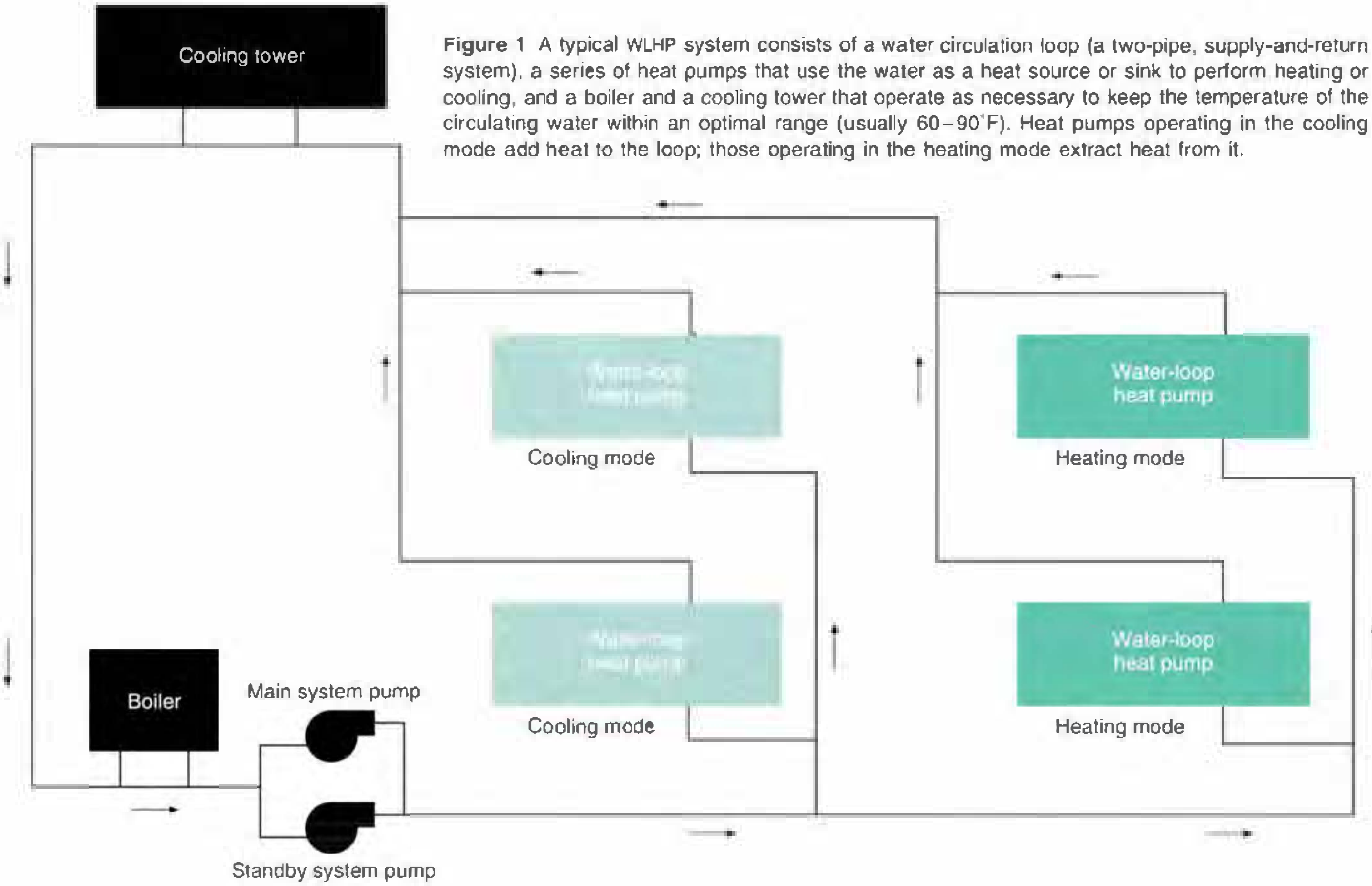


Figure 1 A typical WLHP system consists of a water circulation loop (a two-pipe, supply-and-return system), a series of heat pumps that use the water as a heat source or sink to perform heating or cooling, and a boiler and a cooling tower that operate as necessary to keep the temperature of the circulating water within an optimal range (usually 60–90°F). Heat pumps operating in the cooling mode add heat to the loop; those operating in the heating mode extract heat from it.

features that make owning and operating a WLHP system even more advantageous.

Efficiency is the key feature of this new unit, which can achieve a cooling energy efficiency ratio of up to 15.2 (at Air-Conditioning and Refrigeration Institute Standard 320 conditions) and a heating coefficient of performance of up to 4.5. But the high-efficiency WLHP offers much more. These units have been acoustically insulated to ensure quiet operation, and they come with manufacturer guidelines on techniques for further reducing noise. The guidelines also explain ways to ensure indoor air quality through the optimal introduction of outdoor air.

The new WLHP is easy to maintain and service—removable components facilitate cleaning and access to internal parts. The unit's high reliability, low operating costs, and competitive first costs make it a practical, high-quality, cost-effective choice for many buildings.

The high-efficiency WLHP is available nationwide through Trane/CommandAire, (817) 840-3244. EPRI has produced an informational brochure (CU.2047.01.92) to help member utilities make potential users aware of this product's benefits.

Guides for better installation

A WLHP system will deliver maximum efficiency benefits only if properly designed and installed. However, the generalized guidelines available from equipment manufacturers often fail to answer the more complex design questions. To fill this information void, EPRI is developing a comprehensive, two-volume water-loop heat pump engineering guide for architects, engineers, and contractors. Publication is scheduled for later this year.

The first volume is a design guide that provides technical information on selecting, designing, and specifying WLHP systems. It discusses selecting optimal design parameters and includes application guidelines for adding such features as variable-speed pumping, thermal storage, and energy management systems. It also covers the integration of WLHPs with sprinkler systems, service hot water, and ground-coupled heat pumps. Although this volume focuses on southern California, much of the information it contains is appropriate for installations in all climates. EPRI plans to revise the design guide to make it applicable to colder climates. The second volume of the WLHP engineering guide focuses on California code compliance issues.

WLHP field study

For three years, an office building in Stamford, Connecticut, has been providing EPRI with valuable real-life data on WLHP performance—as well as serving as a test case for verifying the results of performance-boosting modifications. With typical structural and occupancy characteristics and cold-weather climate conditions, the building has yielded data with a wide range of applicability.

The study has confirmed some basic assumptions, showing that proper design, installation, and operation are necessary to control boiler energy use and corresponding electricity demand in an all-electric building. The study has also demonstrated that operational changes can produce quantifiable improvements. For example, proper control strategy and careful control setting reduced the electric boiler's annual energy use by 20%. The cumulative effect of improvements involving boiler control, heat pump startup schedule, cooling-tower isolation, and the intake of outside air to the building core was to reduce electric boiler demand on the order of 30%.

In particular, one of the modifications suggested by the project team—cooling-tower isolation—can cut energy use dramatically. Previously, the building operator had left the cooling tower connected all winter in case it was needed. To protect the system from freezing, water was pumped through the cooling tower almost constantly, resulting in heat losses of as much as 400 million Btu per month. The team's solution called for putting manual valves on the cooling tower so that its use can be limited to the few days when heat rejection is needed. A 30% antifreeze solution was added to the circulating water for protection. These changes have proved invaluable: an ongoing evaluation is showing monthly energy savings of the full 400 million Btu previously lost. At this site, yearly savings could reach $8000.

Assessing enhancement options

An EPRI report published last year, *Water-Loop Heat Pump Systems: Assessment Study Update* (CU-7535), answers some of the most common questions about the systems. It also documents their cost-effectiveness, showing that WLHPs can provide an excellent combination of low heating and cooling costs and low installed costs (due to the low-cost distribution system).

In addition, the report presents concepts and guidelines for reducing energy costs and enhancing performance by improving system design and operation. In many cases, one of the best ways to reduce costs and improve performance is to keep the loop water temperature low. At low temperatures, the increased cooling efficiency of the heat pumps usually more than offsets the higher energy consumption for the cooling tower and for heat pump heating. If the loop temperature is 50°F or lower, an additional advantage is that the loop water can be used directly for cooling. Again, the higher energy use for cooling-tower operation is offset by the reduction in compressor operation. However, 50°F water coil operation requires insulated piping and an extra cooling coil, with a corresponding increase in installed costs.

Decreasing the flow rate of the loop water also can produce energy savings. Reducing the constant flow to 2.0 ± 0.5 gpm can cut energy costs by up to 25% without compromising system performance. Varying the water flow rate according to the number of heat pumps operating can provide energy cost savings of up to 35%.

Another system enhancement is the addition of thermal storage capacity. This feature seems to be most advantageous in cases when extra daytime heat can be stored and then used to help keep the building warm during unoccupied hours, displacing boiler heating. In such cases, thermal storage can reduce winter energy costs for unoccupied periods by 25–35%.

EPRI's robust portfolio of research activities is yielding WLHP improvements on several fronts. New, efficient units are available; design guides will help architects, engineers, and contractors design and install better systems; and data on actual performance and guidelines on optimal system operation should increase confidence in the cost-effectiveness and operation of these systems. (See also the favorable results on system reliability and longevity published in the April/May 1991 issue of the *Journal*, p. 50.) Together, these efforts should provide utilities a strong base for promoting this low-cost, efficient technology.

Gasification–Combined Cycles

High-Efficiency GCC Power Plants

by Nandor Hertz, Norman Stewart, and Arthur Cohn, Generation & Storage Division

The efficiency of gasification technology is influenced by several factors—some related to the gasification process itself, others to coal feedstock characteristics and the consumption of the gasification reagents. This complex relationship is best characterized by two performance indexes—cold gas efficiency and the overall thermal efficiency of the gasification process.

Cold gas efficiency is a measure of the amount of chemical energy in the clean, cold syngas and is expressed as the ratio of the syngas's chemical energy to that of the feed coal. The overall thermal efficiency of the gasification process accounts for both the syngas's chemical energy and the steam generated from the gas's sensible heat. It is expressed as the ratio of the sum of the chemical energy of the cold syngas and the heat content of the steam generated in the gasification area to the energy input of the feed streams.

Improved gasification technology

Dry-feed, entrained-flow, slagging gasification technology—developed by Shell in the United States, with cofunding from EPRI, and by Krupp-Koppers in Europe—has many of the features needed for high-efficiency gasification-combined-cycle (GCC) power plants. It offers high cold gas efficiency, efficient utilization of the sensible heat of the syngas, high carbon conversion, and good

ABSTRACT *Gasification–combined-cycle (GCC) technology gives the utility industry a coal-based power generation option that is both efficient and environmentally clean. Major ongoing EPRI-cofunded development efforts have provided new technologies to make high-efficiency GCC power plants economically attractive. Improvements in gasification technology, high-temperature combustion turbine performance, and overall plant integration now make possible high-efficiency GCC power plant designs with heat rates of about 8000 Btu/kWh (HHV basis), compared with 9500–10,500 Btu/kWh for traditional pulverized-coal plants with flue gas desulfurization. These GCC plant designs also offer environmental performance approaching that achievable with natural gas, the cleanest fossil fuel available.*

selectivity toward the fuel components of the syngas. CO, H_2, and CH_4 together make up over 90 vol% of the dry syngas.

The Shell coal gasification pilot plant, called SCGP-1, has completed four years of operation, during which a broad range of coals were tested. The results of this EPRI-cosponsored work have confirmed the expected favorable performance characteristics of this oxygen-blown, dry-feed, entrained-flow process.

Carbon conversion values in the range of 99.3–99.9% were obtained. Good single-pass carbon conversion was augmented by fly slag recycle as conditions warranted. Cold gas efficiency values ranged from 76% to 83%. The lower values were obtained with the relatively unreactive Maple Creek coal; the higher values, with the reactive Pike County coal (Figure 1). Experimentation with the moderately reactive Illinois No. 5 coal was extensive and demonstrated the beneficial effects of steam addition and fly slag recycle (Figure 2). The overall thermal efficiency of the gasification system ranged from 93% to 97%.

Construction of the first commercial-scale (260-MW) GCC power plant, which incorporates the GCC technology developed by Shell and others, is nearing completion at Buggenum, the Netherlands. Startup is scheduled for 1993. After a shakedown test and a three-year demonstration period to confirm the design thermal efficiency of 41.4% (higher-heating-value, or HHV, basis), the pioneer GCC power plant will begin commercial operation. During this phase, the Buggenum plant is expected to go through a fast learning curve, which will mature its GCC technology and ultimately lead to a commercially proven GCC power plant design with improved performance, operability, and reliability as well as lower electricity cost.

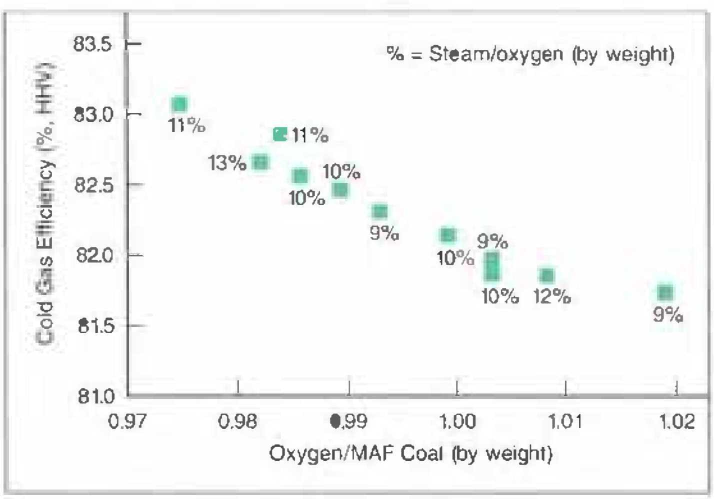


Figure 1 Gasification results for Pike County coal (with fly slag recycle). Tests at the Shell gasification pilot plant have explored how cold gas efficiency is affected by the ratio of oxygen to moisture- and ash-free coal, the ratio of steam to oxygen, and fly slag recycle. The highest cold gas efficiencies were achieved with this reactive coal.

High-temperature combustion turbine

The cornerstone of the high-efficiency GCC power block will be the new, high-firing-temperature (2300–2400°F), high-power-output (150–200 MW) combustion turbines (CTs) that have recently become available for use with either natural gas or syngas. Matching a single-train fuel plant (gasification and gas treating) to such a turbine will provide an economy of scale. These machines also operate at a high turbine exhaust temperature (1050–1150°F), which provides the steam parameters needed for an efficient steam-cycle design.

The machines are equipped with other important features, such as inlet guide vane control, air extraction capability at the CT compressor outlet, and combustors capable of firing low-Btu gas with low thermal NO_x formation.

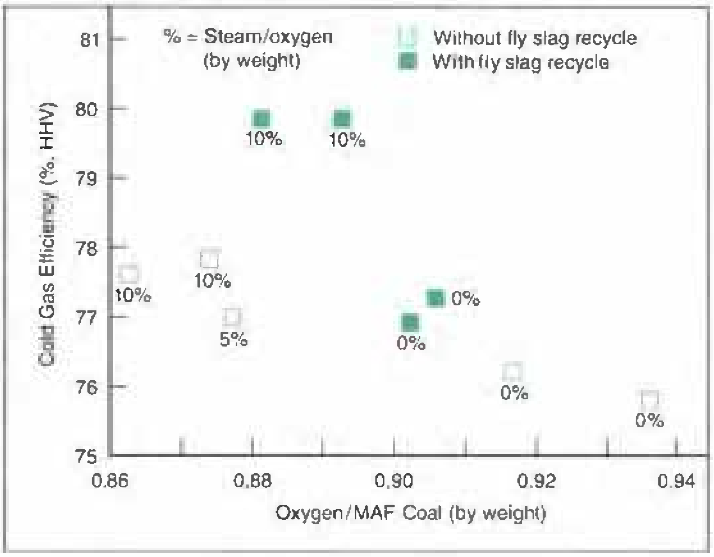
Inlet guide vane control makes it possible to reduce the CT compressor intake airflow—to as low as 75% of the design value—as necessary for efficient operation at low ambient temperature or part load.

Air extraction at the CT compressor outlet is one way to enable an off-the-shelf machine (designed for natural gas) to operate on coal gas. Specifically, by extracting air from the CT compressor outlet, the turbine inlet mass flow can be maintained at the design flow value for natural gas. The extracted air can be used in a pressurized air separation unit (ASU). In turn, nitrogen from the ASU can be added to the coal gas as a diluent for NO_x control and to provide additional motive power (mass) to the CT.

The combustion of diluted coal gas (120–130 Btu/scf, lower-heating-value basis) at high firing temperatures with low thermal NO_x formation (less than 10 ppm by volume) was confirmed at General Electric in EPRI-cofunded work using water vapor as the fuel gas diluent and at Siemens in work using nitrogen as the diluent.

Other EPRI-cofunded work at GE confirmed the feasibility of adapting the off-the-shelf GE 7F machine for low-Btu-gas operation with higher CT power output, which ultimately is limited by the torque limits of the turbine components. In this case, the machine is slightly modified in order to pass a greater-than-design flow of gas through the turbine: it is operated with a more open first turbine nozzle vane, and the pressure provided by the CT compressor is higher than is optimal for a natural gas–fired machine.

Figure 2 Shell gasification results for the moderately reactive Illinois No. 5 coal show the benefits of controlling the oxygen-to-coal ratio, of steam addition, and especially of fly slag recycle.



Overall plant integration

The conventional integration schemes applied to date have been limited to the integration of the steam and boiler feedwater systems and the use of available low-level process heat for clean fuel gas saturation. More recently, innovative integration schemes have been developed and investigated in order to improve overall system efficiency, reliability, and operability while fully utilizing the potential of the improved power plant components described earlier. The integration objective of the innovative schemes extends beyond the limits established by the more conventional schemes, addressing all three major elements of an oxygen-blown GCC power plant: the air separation unit, the fuel plant, which performs gasification, gas processing, and fuel gas saturation, and the power block, including the combustion turbine, the heat recovery steam generator, and the steam turbine.

With cofunding from EPRI, Florida Power & Light, and Virginia Power, a project team composed of specialists from Krupp-Koppers, Linde, Siemens–Kraftwerk Union (KWU), Lotepro, and Sargent & Lundy has just completed a comparative study to evaluate the merits of a conventional integration scheme and an innovative scheme. The power plant was configured with Linde's ASU; the dry-feed, entrained-flow Prenflo coal gasification technology; and the KWU V8.4 high-temperature CT. The innovative scheme provided for CT operation on low-Btu syngas by extracting 100% of the air needed for air separation from the CT compressor. The ASU for the conventional scheme was designed to operate near atmospheric pressure and to produce 95% pure oxygen; the ASU for the innovative scheme was designed to operate at elevated pressure and to produce 85% pure oxygen, found to be the optimal purity in terms of overall system efficiency.

Both schemes featured control of thermal NO_x formation to 36 ppm by volume. In the conventional scheme, this control was achieved solely by saturating the fuel gas with water vapor; in the innovative scheme, by saturating the fuel gas with water vapor and diluting it with waste nitrogen recycled from the ASU.

Pittsburgh No. 8 coal from the Blacksville

Table 1
GCC PLANT INTEGRATION SCHEMES: COMPARATIVE EVALUATION

	Conventional Integration	Innovative Integration*
Net plant heat rate (Btu/kWh, HHV)		
At 90°F full design load	8210	7970
At 60°F with natural gas augmentation	8119	7925
At 60°F without natural gas, maximum 94% load	8271	8010
Net plant efficiency at 90°F, full design load (%)	41.6	42.8
Load-following characteristics		
Inlet guide vane control of CT air mass flow (% of design value)	75–90	75–100
Minimum CT load (%)	68	60
Reduction from full CT load to minimum load (minutes)	10	8
Ramp-up from 50% CT load to 100% load (minutes)	30	23
Specific capital investment ($/kW, 1990 dollars)		
Plant facilities investment†	1303	1271
Total capital requirement‡	1742	1696
Revenue requirements (mills/kWh, constant 1990 dollars)		
At 85% capacity factor	46.2	44.9
At 75% capacity factor	50.2	48.8
At 65% capacity factor	55.3	53.8

*In this scheme, 100% of the air needed for air separation is extracted from the combustion turbine compressor.
†Excludes allowances for contingency, owner's cost, and funds used during construction.
‡Includes allowances for contingency, owner's cost, and funds used during construction.

mine was used for the study. (EPRI has conducted many gasification tests on this coal and has selected it as the reference coal for Institute studies.) It has a moisture content of 5.5 wt% and an ash content of 7.8 wt% (moisture-free basis).

The findings of the study are presented in Table 1. They confirm that the innovative scheme (with 100% of the ASU air supplied from the CT) has a 2–3% lower net plant heat rate at 90°F, full-design-load conditions; faster load-following characteristics; a 2.5% lower specific capital investment; and a 3% lower cost of electricity. The innovative scheme's performance advantage is retained at the part-load conditions investigated and at lower-than-design ambient temperature.

With EPRI cofunding, a project team composed of specialists from Shell, GE, and Air Products is investigating the merits of another innovative integration scheme for a GCC power plant—a scheme based on a pressurized ASU producing 95% pure oxygen, the Shell coal gasification technology, and the GE 7F combustion turbine. In this alternative, only part of the air needed for air separation is extracted from the CT, and the GE 7F machine is slightly modified to accommodate a higher turbine inlet flow than that for natural gas. The results of this study, which is using Pittsburgh No. 8 (Blacksville mine) coal, will be available later this year.

Results from an earlier study of a similar scheme conducted by Shell, GE, and Air Products were presented at the tenth EPRI gasification power plant conference, held in San Francisco in October 1991. They showed a heat rate of 8010 Btu/kWh (HHV basis) for Pittsburgh No. 8 coal and a capital cost of $1330/kW (U.S. Gulf Coast site, overnight construction, mid-1991 dollars).

Power Plant Corrosion Control

CHECWORKS: Integrated Corrosion Software

by Bindi Chexal, Robin Jones, James Lang, Chris Wood, and Rosa Yang, Nuclear Power Division

ABSTRACT *Corrosion is responsible for nuclear plant availability losses of nearly 5%, and its control is important in holding down O&M costs. As a result, EPRI continues to invest considerable resources in corrosion-related research. One forthcoming product—the CHECWORKS software—will provide an integrated approach to the control of corrosion in plant piping and in-line equipment. Using a series of modules that share a common database, utility personnel will be able to identify where a corrosion attack is occurring, what is causing it, and where the resulting corrosion waste is going. This predictive capability will be valuable in planning inspections to prevent failures, evaluating mitigation options, and developing new designs.*

Corrosion continues to trouble power plants, both fossil and nuclear. For example, it accounted for nuclear plant availability losses of close to 5% during the past decade. In addition, corrosion creates plant and personnel safety concerns. Many corrosion mechanisms are affected by the same factors. For example, the secondary water chemistry of pressurized water reactor (PWR) plants affects the flow-accelerated corrosion damage of piping and equipment; the steam generator sludge pile; the cracking, denting, and pitting of steam generator tubes; the corrosion of turbine generator components; and the performance of condensate polishers and demineralizers.

To reduce corrosion losses and also enhance plant safety, plant owners need an approach that addresses corrosion mechanisms in an integrated fashion. To meet this need, EPRI has dedicated considerable resources to developing a fundamental understanding of the causes of corrosion and the influence of the governing parameters. This effort involves research in materials science, water chemistry, fluid mechanics, corrosion engineering, and nondestructive evaluation technology.

This R&D, as well as related work at other industry organizations, is yielding engineering models that can predict much of the corrosion behavior of operating plant equipment. Plant owners can use such predictive technology to identify where corrosion damage is likely to occur so that they can develop proactive inspection and repair programs. They can also evaluate the potential of changes in plant design and operation to reduce corrosion damage.

Among EPRI's contributions in this area is the CHEC family of codes for use in controlling flow-accelerated corrosion damage of piping. Now researchers are extending this successful approach to cover many other types of corrosion and degradation mechanisms and are mounting the predictive technology on a software platform called CHECWORKS™ (Chexal-Horowitz Engineering Corrosion Workstation).

The first release of CHECWORKS will integrate the capabilities of the existing CHEC family of codes, simplifying the process of making predictions and reducing its cost. And since CHECWORKS is being designed to permit the addition of modules for other types of corrosion and components, plant owners will eventually be able to use it for a variety of evaluations. They will be able to assess cavitation, droplet impingement, sludge transport and deposition, fouling and corrosion in service water systems, steam generator tube cracking and intergranular attack, fuel cladding corrosion, and cracking of vessel internals, welds, and penetrations. The long-term goal is to achieve an integrated predictive capability for all pressure boundary and reactor internal components and for all relevant corrosion mechanisms.

Planning for CHECWORKS has revealed that the same mathematical subroutines can be used in making many corrosion predictions. For example, a routine to determine fluid conditions (such as flow rate, temperature, and enthalpy) in a piping component provides values that are necessary for predicting flow-accelerated corrosion, cavitation, droplet impingement, fouling, sludge generation, and sludge transport. Therefore, CHECWORKS is being developed as a modular code in which all modules share a common database (Figure 1). Users will be able to select a technology module from an interactive menu or icon panel. The results of corrosion evaluations will enter the plant database and will be available for subsequent evaluations.

Figure 1 The modular organization of CHECWORKS, in which technology software modules use a common database, is key to its efficient, integrated approach to corrosion control. Version 1.0 (color), scheduled for beta release at the end of the year, will feature seven technology modules focusing on flow-accelerated corrosion, as well as a module for generating reports. Later versions will add the other modules shown.

Initial release

The initial release of CHECWORKS (Version 1.0) will include the basic platform, the database structure, and the first group of technology modules—which will integrate the capabilities that exist today in the CHEC codes for flow-accelerated corrosion.

Since all the technology modules will access the common database, duplication of data will be eliminated. The database will consist of industry libraries, a plant library, and plant inspection data. The industry libraries, which EPRI will install, will include steam tables and information on pipe sizes, materials properties, and American Society of Mechanical Engineers (ASME) Code requirements. Users will benefit not only from the convenience of not having to install these libraries but also from the higher degree of industry standardization they will afford. Users will enter their own information into the plant library and plant data files. This can include plant drawings, inspection data and records, plant operating conditions, and acceptability evaluations.

CHECWORKS 1.0 will feature seven technology modules. These modules, which are described in the following paragraphs, will determine void fractions, fluid flow conditions, water chemistry conditions, and flow-accelerated corrosion rates, manage inspection data; determine the structural acceptance of worn fittings; and perform leak-before-break evaluations.

The void module determines the void fraction of two-phase mixtures for the full range of pressures, flows, and fluid types (steam-water and air-water) typically found in power plants. It has been qualified against several sets of steady-state, two-phase/two-component flow test data that cover a wide range of thermodynamic conditions and geometries typical of PWR and boiling water reactor (BWR) fuel assemblies and pipes up to 450 millimeters in diameter. The correlation used is based on a drift flux model. Output from this module is used in making predictions about flow-accelerated corrosion and droplet impingement.

The network flow module, which is currently operational in the CHECMATE code, determines local operating conditions for flow-accelerated corrosion predictions. It is used to determine flow rate, temperature, pressure, and steam quality in branched piping systems. The module accounts for source and sink conditions, pipe routing, elevation changes, pipe insulation, in-line equipment, valve type and position, and surface roughness.

Two major enhancements to this module are planned. One involves the capability to predict how suspended solids are transported in service water systems. This will be useful for predicting fouling and for indicating where the sediment may concentrate water impurities. The other enhancement involves the capability to determine the transport of magnetite and hematite (products of flow-accelerated corrosion) around the steam cycle. This will be useful for predicting sludge deposition in major equipment like steam generators.

The water chemistry module determines the oxygen level and operating pH on a line-by-line basis throughout the steam cycle. It takes into account system operating conditions and pH control additives (amines) and models the volatility of an amine (or mix of amines) as it partitions in wet steam lines.

Output from this module, which is currently operational in CHECMATE, is used in predicting component-by-component wear rates due to flow-accelerated corrosion. Future enhancements will model some new amines now in the experimental stage of power plant application (e.g., amino-methyl-proponal, or AMP, and diethanolamine). A similar module will model water treatment in service water systems. The goal is to determine the transport of water treatment chemicals throughout the service water systems in order to predict the microbial growth rate at each component location.

The flow-accelerated corrosion module will predict the rate of wall thinning from flow-accelerated corrosion on a component-by-component basis, enabling plant owners to focus inspections on the worst locations and identify problems long before leaks or failures can occur. The module will also be helpful in planning plant modifications. Currently, the predictive algorithms used in the CHEC and CHECMATE codes are being updated on the basis of data that have become available in the past several years. This effort will improve the technology's accuracy, ease of use, and speed.

The inspection data module will allow users to import, manage, display, store, and evaluate data from the ultrasonic inspection of piping components that have been subject to wall-thinning degradation. This capability is currently provided in the CHEC-NDE computer code. The module will also map wear areas and perform statistical analyses of the inspection data.

The structural evaluation module will assess the structural acceptance of piping components that have thinned because of flow-accelerated corrosion and similar degradation mechanisms. Such evaluations are now provided by the CHECT computer program and are compatible with proposed rules of Section XI of the ASME Code. In 1992 EPRI is sponsoring additional research to develop criteria for components and wear configurations not now covered by these rules. The extended criteria will be included in the structural evaluation module.

The seventh module, PICEP, is currently available as a stand-alone computer code for performing leak-before-break evaluations of cracked pipe. It demonstrates that leak rates are detectable before the onset of crack growth instability. PICEP is applicable to piping subject to intergranular stress corrosion cracking and fatigue. User input includes a description of the crack as well as data on piping materials, fluid conditions, and applied loads. Output includes the size of the crack opening area, the critical crack length, and the flow rate through the crack.

Future releases

Future releases of CHECWORKS will add several more modules and evaluation technologies. One of these modules will address cavitation damage. Cavitation occurs when water near the saturation pressure enters a component with a restricted flow area, such as an orifice, a flow control valve, or a level control valve. The resulting flow acceleration and large pressure drop can cause the water to flash into a two-phase mixture. If the downstream pressure is high, the vapor bubbles may colapse when they hit an orthogonal surface (such as a valve internal, an elbow, or a tee). Damage can occur anywhere between the flow constriction and the orthogonal surface. The first release of the cavitation module will indicate the likelihood of cavitation in the piping system.

A related module will address the droplet impingement that occurs when water near the saturation pressure enters a component with a restricted flow area. If the water flashes into a two-phase mixture, the entrained water droplets that strike an orthogonal surface can cause additional wear through erosion. The first release of this module will identify piping locations and operating conditions where there is potential for droplet impingement.

Service water (raw cooling water) systems in both nuclear and fossil plants have experienced a wide spectrum of corrosion, fouling, and erosion mechanisms. Another CHECWORKS module will provide a relative ranking, on a component-by-component basis, of the severity of microbial and general corrosion attacks in these systems. The module will build on the methodology currently used in EPRI's MICPro code. The goal is to help plant owners identify the causes of damage and plan inspections to prevent failures. The module output will also be useful in evaluating options for reducing the severity of the attacks.

The development of a predictive model for the generation, transport, and deposition of sludge will provide an important new tool for reducing steam generator corrosion and condensate polisher fouling. The sludge module being developed for CHECWORKS will predict sludge generation, filtering (by condensate polishers), transport, removal (by PWR steam generator blowdown systems or BWR reactor water cleanup systems), and deposition in steam generators and other plant equipment.

CHECWORKS will also feature a steam generator corrosion module that will interact with the sludge module. This module will predict and evaluate tube degradation that initiates from either the primary side or the secondary side. The degradation mechanisms covered will include stress corrosion cracking and intergranular attack. The module will address electrochemical potential, crevice chemistry, crack initiation, and crack growth. The first release will focus on helping plant owners manage the remaining life of damaged steam generators.

A BWR component cracking module will give plant owners the technology to understand the condition of piping and the reactor pressure vessel (RPV) and its internals. This capability is important because several BWR piping systems, a variety of RPV internal components, some nozzles, and some welds that attach the internals to the RPV are made from materials found to be potentially susceptible to stress corrosion cracking. The regions of greatest concern are the heat-affected zones adjacent to the welds. If cracking initiates at a nozzle or at an RPV attachment weld, there is some potential for crack propagation into the vessel. A variety of access limitations make thorough inspections of RPV internals and attachment welds very difficult. The component cracking module will identify internals or welds that require inspection and will recommend an inspection schedule. It will also help owners decide what to do if they find indications of cracking.

Another module will evaluate fuel cladding corrosion. Cladding is the first barrier preventing the release of fission product to the environment. Historically, its failure has affected BWRs more than PWRs. However, recent experience indicates that at high burnup, PWR cladding can exceed its design limits.

To avoid corrosion failures and to help in planning reload schemes, many European utilities measure and predict cladding corrosion oxide buildup rates. As U.S. utilities pursue moredemanding operating conditions—including higher discharge burnup, longer operating cycles, higher cladding temperatures, and different water chemistry environments—cladding corrosion could become a life-limiting parameter for fuels. With CHECWORKS, utilities will be able to predict fuel cladding corrosion accurately under various operating conditions.

Development plans

Initially, CHECWORKS is being designed to run on IBM PCs (and most compatibles) with a 386 or 486 microprocessor and the MS Windows operating system. It will support multiple users on local area networks and will be able to operate on all platforms that support Windows/NT. It will include guidelines for applications development, will standardize the behavior and development of applications, will enable applications to communicate with each other and with a common database, and will feature reusable software to minimize future development and maintenance costs.

Code development will continue over a seven-year period. Version 1.0, which deals primarily with flow-accelerated corrosion, is scheduled for release to utilities in a beta test version this December. Version 2.0—which will add the cavitation, droplet impingement, and service water modules—is planned for release in December 1993. Version 3.0, which will add the sludge transport and deposition module, is scheduled for December 1994. No release date has been set for Version 4.0, which will add the steam generator tube corrosion, BWR component cracking, and fuel cladding corrosion modules. Development, verification, documentation, and control of all versions will be in accordance with a quality assurance plan that meets the requirements of 10CFR50, Appendix B.

Strategic alliances are being formed to facilitate broad participation in the CHECWORKS development effort. Participating organizations will include EPRI member utilities, U.S. consultants, and utilities and consultants in other countries. Participation is likely to include information and data sharing, loaning of personnel, software development tasks, and demonstration projects at operating power plants.

CHECWORKS promises to be an effective tool for helping plant owners reduce corrosive attack on piping and in-line equipment. The existing CHEC family of codes has been very successful in reducing plant costs due to flow-accelerated corrosion. CHECWORKS will build on these codes, improving their accuracy and ease of use and extending predictive capabilities to other corrosion mechanisms and other plant components.

New Contracts

Project	Funding/ Duration	Contractor/EPRI Project Manager
Customer Systems		
Directory of Revenue and End-Use Metering and Data Communications (RP2568-21)	$107,800 22 months	Plexus Research/ *L. Carmichael*
Advanced Heat Pump Field Monitoring (RP2892-22)	$231,800 21 months	Carrier Corp./ *J. Kesselring*
Water Heater Testing and Analysis (RP2[illegible]58-18)	$297,700 4 months	ETL Testing Laboratories/ *C. Hiller*
Advances in Electric Utility Financial Information and Management Practices (RP2982-14)	$100,100 7 months	Arthur Andersen & Co./ *P. Hanser*
Field Performance of WaterFurnace ADV Heat Pumps (RP3024-8)	$77,000 18 months	Fleming Group/*C. Hiller*
Commercial HVAC Technology Assessment (RP3138-8)	$[illegible],000 12 months	Joseph A. Pietsch/ *M. Blatt*
Commercial HVAC Technology Transfer Support (RP3138-9)	$132,500 14 months	Bevilacqua Knight/ *M. Blatt*
Development and Testing of LONTalk Controller (RP3163-8)	$[illegible],600 10 months	Unity Systems/*A. Lannus*
Advanced Reverse-Osmosis Demonstration (RP3243-3)	$60,100 11 months	Water Technologies/ *P. McDonough*
Library Humidity Control (RP3280-15)	$128,700 25 months	Sud Associates/ *M. Khattar*
Wastewater Treatment of Pulp Mill Effluent (RP3328-1)	$151,300 5 months	Black & Veatch/ *A. Amarnath*
Textile Dyehouse Wastewater Color Removal (RP3329-1)	$52,500 6 months	Hydroscience/ *A. Amarnath*
Commercial Building Energy Center (RP3353-1)	$700,000 48 months	University of Wisconsin Madison/*R. Wendland*
Water-Loop Heat Pump Field Evaluation (RP[illegible]371-1)	$7[illegible],600 13 months	Climate Master/*M. Khattar*
Electrical Systems		
Conversion of Static Security Enhancement System to a UNIX Workstation Platform (RP1712-[illegible])	$259,600 14 months	Incremental Systems/ *G. Cauley*
Slow Release of Fungicides for Wood Pole Applications (RP2881-2)	$1,119,800 37 months	Southwest Research Institute/*B. Bernstein*
FACTS: Analytical Studies to Demonstrate Thyristor-Controlled Series Compensation (RP3022-15)	$158,300 17 months	New York Power Authority/*N. Balu*
Analytical Methods for Contingency Selection and Ranking for Dynamic Security Analysis (RP3103-3)	$458,600 22 months	Empros Systems International/*G. Cauley*
Investigation of S_2F_{10} Production and Mitigation in Compressed-SF_6-Insulated Power Systems (RP3178-1)	$220,000 36 months	National Institute of Standards and Technology/*G. Addis*
Fault Location Expert System and Manual for Transmission and Distribution Cables (RP7913-3)	$439,600 22 months	Power Technologies/ *D. Von Dollen*
Improved Polymer-Insulated Transmission Cable Systems (RP7917-2)	$854,100 28 months	Cablec Utility Cable Co./ *F. Garcia*
Environment		
High-Efficiency FGD Testing (RP1031-19)	$400,000 15 months	Radian Corp./*D. Owens*
Technical and Economic Impact of Chloride Removal From Wet FGD Systems (RP1031-20)	$399,900 15 months	Radian Corp./*D. Owens*
Ozone-Acid Aerosol Interactions: Animal Toxicological Studies (RP2155-4)	$430,000 2[illegible] months	University of California, Davis/*L. Goldstein*
Sidestream Fouling Monitor (RP2300-19)	$180,300 33 months	Marine Biocontrol Corp./ *B. Nott*
Full-Scale Demonstration of Urea Injection for Oil-Fired Boiler NO_x Control (RP2869-14)	$2,815,800 28 months	Radian Corp./*J. Stallings*
Field Studies of Fungal Conversion of Hydrocarbons in Soils: Excavation and Application (RP2879-16)	$426,500 8 months	Mycotech Corp./ *I. Murarka*
Full-Scale Demonstration of Low-NO_x Cell Burner Retrofit (RP2916-17)	$1,350,000 39 months	Babcock & Wilcox Co./ *D. Eskinazi*
Integrated Dry NO_x/SO_2 Environmental Control System (RP2916-18)	$1,500,000 49 months	Public Service Co. of Colorado/*J. Stallings*
Bioavailability of Ingested Trace Elements (RP2963-8)	$300,000 37 months	University of Cincinnati/ *L. Goldstein*
Cellular Responses to Low-Frequency Electric and Magnetic Fields: Electroreception in Sharks and Rays (RP[illegible]5-19)	$376,200 3[illegible] months	University of California, San Diego/*C. Rafferty*
Technical Support: Risk Methods (RP3081-4)	$55,900 29 months	Clement International Corp./*L. Levin*
Air Emissions Risk Assessment Model (RP3081-5)	$178,300 24 months	IWG Corp./*L. Levin*
Decision Framework for Air Quality Standard Cost-Benefit Analysis (RP3081-6)	$181,900 24 months	Decision Focus/*L. Levin*
Compact Hybrid Particulate Collector Demonstration (RP3083-24)	$10,400,000 30 months	Texas Utilities Electric Co./*R. Chang*
FGD Gypsum Demonstration (RP3124-1)	$100,000 25 months	New York State Electric & Gas Corp./*C. Dene*
Clean Air Technology Workstation (RP3296-1)	$363,800 17 months	Sargent & Lundy Engineers/*R. Rhudy*
Exploratory & Applied Research		
BWR Zircaloy Nodular Corrosion Investigation (RP2426-41)	$150,700 21 months	General Electric Co./ *D. Cubicciotti*
Diamond and Related Materials Consortium (RP2426-50)	$50,000 24 months	Pennsylvania State University/*R. Pathania*
Computational Modeling Study of Additive Effects on the Elastic Behavior of Alloys (RP2426-52)	$50,000 6 months	West Virginia University/ *J. Stringer*
In-service Degradation of Fossil Plant Component Materials (RP2426-53)	$165,400 27 months	Failure Analysis Associates/ *R. Viswanathan*
Bipolar, Horizontal-Orientation, Sealed Nickel-Zinc Vehicle Propulsion Battery (RP8002-33)	$196,000 12 months	Energy Research Corp./ *R. Swaroop*
Photoinhibition of Localized Corrosion (RP8002-36)	$140,000 24 months	Pennsylvania State University/*B. Syrett*
Oxidative Reactions of Sulfur Forms in Coal (RP8003-32)	$100,000 11 months	Iowa State University/ *W. Weber*
Detailed Chemical Mechanisms for Flame-Generated Deposition of Na_2SO_4 and Na_2CO_3 on Heated Metal (RP8005-15)	$170,500 30 months	University of California, Santa Barbara/*A. Mehta*
Computational Fluid Dynamics on Simplicial Meshes (RP8006-24)	$218,900 24 months	University of Pittsburgh/ *L. Agee*
Inorganic-Polymer-Derived Ceramic Membranes (RP8007-15)	$164,000 35 months	University of New Mexico/ *W. Bakker*
High-Efficiency Flame Retardants for Polyolefins Using Catalytic Modes of Action (RP8007-18)	$332,500 39 months	Polytechnic University/ *B. Bernstein*
Development of Superconductor-Based Optical Devices (RP8009-20)	$112,500 32 months	University of Texas, Austin/*T. Peterson*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Exploratory & Applied Research (cont.)		
Controller Synthesis for Critical Applications in the Nuclear and Fossil Power Industry (RP8010-19)	$112,500 28 months	University of Illinois/ *S. Bhatt*
Structural Stability in Power Systems (RP8010-21)	$125,700 23 months	University of Illinois/ *R. Adapa*
Analysis of Stressed Interconnected Power Networks (RP8010-28)	$126,100 18 months	Iowa State University/ *R. Adapa*
Cloud Chemistry With Microphysical Models (RP8011-11)	$240,400 36 months	University of Washington/ *D. Hansen*
Investigations of CO_2 Hydrate Formation (RP8011-14)	$190,500 12 months	California Institute of Technology/ *D. Spencer*
Fundamental Studies of Microwave Sintering (RP8012-3)	$113,000 38 months	University of Wisconsin, Madison/ *W. Bakker*
Optimizing Energy Use in Industrial Freezing (RP8012-11)	$50,000 3 months	University of California, Davis/ *A. Amarnath*
Weldability of Cavitation-Erosion-Resistant NOREM Alloys (RP9000-13)	$54,300 15 months	Climax Research Services/ *H. Ocken*
Generation & Storage		
Assessment of the Benefits of Distributed Fuel Cell Generators in the Service Areas of Central and South West Corp. (RP1677-25)	$114,000 7 months	Barrington-Wellesley Group/ *D. Rastler*
Boiler Tube Failure Metallurgical Guide (RP1890-9)	$229,500 9 months	Aptech Engineering Services/ *B. Dooley*
Blending of Western and Eastern Coals as SO_2 Compliance Strategy (RP1891-7)	$65,000 10 months	University of North Dakota/ *A. Mehta*
Evaluation of Advanced Fossil Power System Technologies (RP2146-9)	$52,800 12 months	Fossil Fuel Sciences/ *R. Wolk*
Applications of Molten Carbonate Fuel Cells to Electric Power Systems (RP2221-36)	$152,500 6 months	Fluor Daniel/ *J. McDaniel*
Shell Coal Gasification Process–Humid-Air-Turbine Cycle Study (RP2221-38)	$300,000 15 months	Shell Oil Co./ *N. Stewart*
TUBELIFE Code Enhancements (RP2253-14)	$56,700 6 months	Aptech Engineering Services/ *R. Viswanathan*
Thermonuclear Fatigue of Coated Superalloys for Advanced Gas Turbine Blading (RP2382-7)	$241,700 47 months	Era Technology/ *R. Viswanathan*
High-Resolution Superconducting Quantum Interface Device for Nondestructive Evaluation (RP2719-3)	$636,900 36 months	Vanderbilt University/ *J. Stein*
Application of Fossil Plant Automation Technologies at Roxboro Generating Station (RP2922-8)	$2,342,000 50 months	ABB Power Automation/ *R. Colsher*
Application of Fossil Plant Automation Technologies at Roxboro Generating Station (RP2922-12)	$1,470,000 50 months	Carolina Power & Light Co./ *R. Colsher*
Evaluation of Barium/Cerium Oxides for High-Temperature Electrochemical Hydrogen Concentration (RP3070-36)	$54,400 10 months	Institute of Gas Technology/ *R. Goldstein*
Improving Growth and Degradation Resistance of Hydrogenated Amorphous Silicon and Silicon Alloy Films (RP3120-1)	$350,000 23 months	University of Illinois/ *T. Peterson*
Compact Simulator for Repowered Station (Lauderdale) (RP3152-11)	$659,900 16 months	Trax Corp./ *M. Divakaruni*
Compact Simulator With Emulated Man-Machine Interface (RP3152-12)	$963,000 18 months	Trax Corp./ *R. Fray*
Wilson Hot Gas Cleanup Test Facility for Gasification and Pressurized Combustion Project (RP3160-2)	$43[illegible],100 14 months	Southern Company Services/ *M. Epstein*

Project	Funding/ Duration	Contractor/EPRI Project Manager
Testing of High-Temperature, High-Pressure Filters at ABB-Carbon AB Pilot Plant (RP3161-3)	$461,700 32 months	ABB Carbon AB/ *R. Brown*
Durability Testing of Ceramic Particulate Filters Under Coal-Gasifying Conditions (RP3161-6)	$104,100 11 months	Virginia Polytechnic Institute and State University/ *W. Bakker*
Fly Ash Carbon Burnout Pilot Plant (RP3162-4)	$433,000 12 months	Progress Materials/ *T. Boyd*
Integrated Energy Systems		
New York State Environmental Externalities Cost Study (RP3231-2)	$300,000 24 months	ESEERCO/ *V. Niemeyer*
Nuclear Power		
Main Coolant Pump Diagnostic Testing (RP1556-7)	$1,100,200 25 months	Ontario Hydro/ *J. O'Brien*
Design Review of the MAAP Code (RP2637-20)	$59,800 12 months	Jason Associates Corp./ *E. Fuller*
Maintenance Guide: Westinghouse DB Low-Voltage Breakers (RP2814-49)	$80,700 9 months	Grove Engineering/ *J. Sharkey*
Maintenance Guide: Westinghouse DS Low-Voltage Breakers (RP2814-61)	$75,000 10 months	Grove Engineering/ *J. Sharkey*
BWR Automated Spent-Fuel Consolidation (RP3100-2)	$450,000 16 months	ESEERCO/ *R. Lambert*
CHECWORKS Computer Program (RP3114-93)	$125,000 12 months	Altos Engineering Applications/ *B. Chexal*
Guidelines and Database on Standards and Requirements for Instrumentation and Control Upgrades (RP3114-97)	$74,700 13 months	MPR Associates/ *W. Reuland*
Instrumentation and Severe-Accident Plant Status Interpretation (RP3183-2)	$246,900 16 months	Erin Engineering and Research/ *S. Oh*
Fire and Smoke Simulation (RP3234-2)	$456,900 37 months	Numerical Applications/ *R. Oehlberg*
Probabilistic Safety Analysis Applications and Guidelines (RP3300-1)	$54,900 15 months	Science Applications International Corp./ *R. Oehlberg*
Development of Stochastic Model of Ground Motion Variability (RP3302-7)	$144,900 15 months	Norman A. Abrahamson/ *J. Schneider*
Regionalization of Ground Motion Attenuation in the Eastern United States (RP3302-8)	$275,000 15 months	Woodward-Clyde Consultants/ *J. Schneider*
Development of Guidelines for Determining Site-Specific Ground Motion Integration and Analysis Efforts (RP3302-9)	$271,800 15 months	Risk Engineering/ *J. Schneider*
Development of Ground Motion Methodology and Guidelines Using BLWN Model (RP3302-10)	$393,100 15 months	Pacific Engineering & Analysis/ *J. Schneider*
Assessment of Ground Motion From Empirical Data (RP3302-12)	$69,000 15 months	Geomatrix Consultants/ *J. Schneider*
Full-System Decontamination Enhancement Study (RP3307-3)	$257,100 3 months	Pacific Nuclear Systems/ *C. Wood*
Risk-Based Equipment Maintenance Effectiveness Evaluation (RP3323-1)	$470,100 19 months	Halliburton NUS Environmental Corp./ *B. Chu*
Browns Ferry Instrumentation and Control Upgrade Plan (RP3332-1)	$149,600 10 months	Mollerus Engineering Corp./ *R. Torok*
Human Reliability Assessment and Applications During Non-Full-Power Operations (RP3333-2)	$463,200 28 months	Science Applications International Corp./ *A. Singh*
Outage Reliability and Risk Initiative Planning (RP3333-5)	$67,600 12 months	Quadrex Energy Services Corp./ *R. Oehlberg*

New Technical Reports

Requests for copies of reports should be directed to the EPRI Distribution Center, 207 Coggins Drive, P.O. Box 23205, Pleasant Hill, California 94523; (510) 934-4212. There is no charge for reports requested by EPRI member utilities and affiliates. Reports will be provided to nonmember U.S. utilities only upon purchase of a license, the price of which will be equal to the price of EPRI membership. Others pay the listed price or, in some cases (when noted), must enter into a licensing agreement.

CUSTOMER SYSTEMS

DSM Evaluation: Six Steps for Assessing Programs
CU-6999 Final Report (RP2981-1); $200
Contractor: Barakat & Chamberlin, Inc.
EPRI Project Managers: T. Henneberger, P. Hanser

Power Quality Assessment Procedure
CU-7529 Final Report (RP2935-13); $200
Contractor: Electrotek Concepts, Inc.
EPRI Project Manager: M. Samotyj

User's Guide: HOTCALC 1.0 Commercial Water Heating Performance Simulation Tool
CM-100211 Computer Manual (RP3169-1); $295
Contractor: D. W. Abrams, P.E. & Associates, P.C.
EPRI Project Manager: K. Johnson

Evaluation of a Short-Term Residential Building Test Method
TR-100362 Final Report (RP2034-25); $200
Contractor: GEOMET Technologies, Inc.
EPRI Project Manager: J. Kesselring

Proceedings: Eighth Electric Utility Forecasting Symposium
TR-100396 Proceedings (RP3092-6); $200
Contractors: Meeting Planning Associates; Pacific Consulting Services
EPRI Project Manager: P. Hummel

Facility Management Needs in Automated Office Buildings
TR-100413 Final Report (RP3141-3); $200
Contractor: Workplace Diagnostics, Ltd.
EPRI Project Manager: K. Johnson

Electrotechnology Applications in Cereal Grain Processing: An Evaluation of Microwave Processing in Rice Parboiling
TR-100448 Final Report (RP2782-4); $200
Contractors: Louisiana State University; National Food and Energy Council
EPRI Project Managers: A. Amarnath, O. Zimmerman

DSMRank: A Model for Screening and Selecting Demand-Side Management Alternatives
TR-100468 Final Report (RP2548-12); $1000
Contractors: Polydyne, Inc.; Battelle, Columbus
EPRI Project Manager: P. Hanser

Survey of Innovative Rates, 1991, Vols. 1–3
TR-100469 Final Report (RP2343-7); $600 for set
Contractor: CSA Energy Consultants, Inc.
EPRI Project Manager: P. Hanser

Proceedings: Urban Guideway Transit Workshop
TR-100492 Proceedings; $200
Contractor: Bevilacqua Knight, Inc.
EPRI Project Manager: L. O'Connell

Field Demonstration of the Thermostone III™ Electric Thermal Storage Furnace
TR-100534 Final Report (RP2731-2); $200
Contractor: Science Applications International Corp.
EPRI Project Manager: J. Kesselring

CFCs and Electric Chillers
TR-100537 Final Report (RP2983-17); $200
Contractor: Gilbert & Associates
EPRI Project Manager: M. Blatt

ELECTRICAL SYSTEMS

Substation Voltage Upgrading
EL-6474 Final Report (RP2794-1); $5000
Contractor: GE Industrial and Power Systems
EPRI Project Manager: J. Porter

Further Experimentation on Bubble Generation During Transformer Overload
EL-7291 Final Report (RP1289-3); $5000
Contractor: ABB Transmission Technology Institute
EPRI Project Manager: G. Addis

More-Robust Solution Techniques for Nonlinear Network Analysis
TR-100244 Final Report (RP2473-38); $200
Contractor: Arizona State University
EPRI Project Manager: R. Adapa

Amorphous Steel Core Distribution Transformers, Vols. 1 and 2
TR-100295 Final Report (RP1592-1); Vol. 1, $200; Vol. 2, license required
Contractor: General Electric Co.
EPRI Project Manager: H. Ng

Development of a Lightweight Composite Trench Cover
TR-100296 Final Report (RP7910-3); license required
Contractor: Foster-Miller, Inc.
EPRI Project Manager: T. Rodenbaugh

Study of Trenching Versus Trenchless Construction Methods for Installing Underground HPFF Cable Systems
TR-100302 Final Report (RP7910-7); $200
Contractor: Foster-Miller, Inc.
EPRI Project Manager: T. Rodenbaugh

Design of a Robotic Mouse and Other Techniques for Instrumenting HPFF Pipe-Type Cable
TR-100303 Final Report (RP7910-9); $200
Contractor: Foster-Miller, Inc.
EPRI Project Manager: T. Rodenbaugh

Studies of Superhigh-Temperature Superconductivity and High Critical Current Density
TR-100326 Final Report (RP7911-18); $200
Contractor: Lockheed Missiles & Space Co., Inc.
EPRI Project Manager: M. Rabinowitz

Field Determination of Metal Oxide Varistor Characteristics
TR-100341 Final Report (RP2747-2); $5000
Contractor: Power Technologies, Inc.
EPRI Project Manager: J. Porter

Evaluation of Corrosion Control for Underground Residential Distribution Cables
TR-100379 Final Report (RP1771-4); $200
Contractor: Pacific Gas and Electric Co.
EPRI Project Manager: T. Kendrew

Waltz Mill Testing of 138-kV Factory-Molded Splice Assemblies
TR-100415 Final Report (RP7801-7); $200
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: J. Shimshock

Proceedings: FACTS Conference I—The Future in High-Voltage Transmission
TR-100504 Proceedings (RP3022); $200
EPRI Project Manager: D. Maratukulam

ENVIRONMENT

Cancer Mortality Among Nuclear Utility Workers: A Feasibility Study
EN-7373 Final Report (RP2920-2); $200
Contractor: New York University Medical Center
EPRI Project Manager: L. Kheifets

Proceedings: Ninth Particulate Control Symposium, Vols. 1 and 2
TR-100471 Proceedings (RP3083); $200 each volume
EPRI Project Managers: R. Chang, R. Altman

Fly Ash Design Manual for Road and Site Applications, Vols. 1 and 2
TR-100472 Final Report (RP2422-2); $200 each volume
Contractor: GAI Consultants, Inc.
EPRI Project Manager: D. Golden

High-Volume Fly Ash Concrete Technology
TR-100473 Final Report (RP3176-1); $200
Contractor: Center for By-product Utilization, University of Wisconsin, Milwaukee
EPRI Project Manager: D. Golden

Spray Dryer Flue Gas Desulfurization for Medium- and High-Sulfur Coal Retrofit Applications
TR-100494 Interim Report (RP2826-2); $1000
Contractor: Radian Corp.
EPRI Project Manager: R. Rhudy

Low-Cost Ash-Derived Construction Materials: State-of-the-Art Assessment
TR-100563 Interim Report (RP3176-1); $200
Contractor: Center for By-product Utilization, University of Wisconsin, Milwaukee
EPRI Project Manager: D. Golden

Mixing and Plume Penetration Depth at the Groundwater Table
TR-100576 Final Report (RP2938-1); $200
Contractor: Auburn University
EPRI Project Manager: D. McIntosh

Supplemental Proceedings: Fourth International Conference on Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete
TR-100577 Proceedings (RP3176-6); $200
Contractors: Radian Canada, Inc.; Canada Centre for Mineral and Energy Technology (CANMET)
EPRI Project Manager: D. Golden

EXPLORATORY & APPLIED RESEARCH

Microstructure and Critical Current Density in High-T_c Metal Oxide Superconductors
TR-100437 Final Report (RP8009-1); $200
Contractor: SRI
EPRI Project Manager: W. Bakker

Influence of Stress Corrosion Crack Merging on Remaining-Life Predictions
TR-100456 Final Report (RP8002-2); $200
Contractor: University of Newcastle Upon Tyne
EPRI Project Manager: B. Syrett

GENERATION & STORAGE

Feedpumps and Boiler Feedwater Systems
TR-100161 Final Report (RP1403-22); $200
Contractors: Sulzer Brothers, Ltd.; Asea Brown Boveri
EPRI Project Manager: J. Bartz

Deoxygenation in Cycling Fossil Plants
TR-100181 Final Report (RP1184-9); $200
Contractor: NWT Corp.
EPRI Project Managers: J. Scheibel, M. Blanco

Part-Load Flow and Hydraulic Stability of Centrifugal Pumps
TR-100219 Final Report (RP1884-10); $200
Contractor: Sulzer Brothers, Ltd.
EPRI Project Managers: S. Pace, T. McCloskey

FGD Retrofit Design Improvement Study
TR-100310 Final Report (RP2873-1); $1000
Contractor: Sargent & Lundy
EPRI Project Manager: C. Dene

Spray Dryer Flue Gas Desulfurization for Medium- and High-Sulfur-Coal Applications
TR-100330 Interim Report (RP2880-1); $1000
Contractor: Radian Corp.
EPRI Project Manager: R. Rhudy

Pilot-Scale Evaluation of the HYPAS SO_2 and Particulate Matter Removal Process
TR-100332 Final Report (RP2934-1); license required
Contractor: Electric Power Technologies, Inc.
EPRI Project Manager: R. Rhudy

Supercritical Power Plants in the USSR
TR-100364 Final Report (RP2819-8); $200
Contractor: Joseph Technology Corp., Inc.
EPRI Project Manager: A. Armor

A Summary of Recent Advances in the EPRI High-Concentration Photovoltaic Program
TR-100392 Interim Report (RP1415-9); $300
Contractor: Daedalus Associates, Inc.
EPRI Project Manager: F. Dostalek

Recent Advances in the EPRI High-Concentration Photovoltaic Program, Vols. 1 and 2
TR-100393 Interim Report (RP1415-9); $500 each volume
Contractor: Daedalus Associates, Inc.
EPRI Project Manager: F. Dostalek

Proceedings: Electric Utility Zebra Mussel Control Technology Conference
TR-100434 Proceedings (RP2504-10); $200
Contractor: Stone & Webster Environmental Services
EPRI Project Manager: J. Tsou

Corrosion Fatigue Boiler Tube Failures in Waterwalls and Economizers, Vols. 1–4
TR-100455 Final Report (RP1890-5); Vol. 1, $200; Vols. 2–4, forthcoming
Contractor: Ontario Hydro
EPRI Project Manager: B. Dooley

Turbine Designs for Improved Coal-Fired Power Plants
TR-100460 Final Report (RP1403-15); $200
Contractors: General Electric Co.; Toshiba Corp.
EPRI Project Manager: S. Pace

Basic Research on Advanced Silicon Materials for High-Performance Photovoltaic Devices, Vols. 1 and 2
TR-100486 Final Report (RP8001-4); $200 each volume
Contractor: Georgia Institute of Technology
EPRI Project Manager: F. Goodman

Procurement, Operation, and Maintenance Guidelines for Electrostatic Precipitators With Rigid Emitting Frames or Electrodes
TR-100511 Final Report (RP1835-25); $300
Contractor: Charles A. Gallaer
EPRI Project Manager: W. Piulle

Superconducting Magnetic Energy Storage: Technical Considerations and Relative Capital Cost Using High-Temperature Superconductors
TR-100557 Final Report (RP2988-2); $200
Contractor: Bechtel National, Inc.
EPRI Project Manager: T. Peterson

NUCLEAR POWER

MULTEQ, Equilibrium of an Electrolytic Solution With Vapor-Liquid Partitioning and Precipitation, Vol. 2: Database (Revision 3)
NP-5561-CCML, Vol. 2, Rev. 3, Computer Code Manual (RPS407-18); license required
Contractor: Maxwell Laboratories, Inc.
EPRI Project Manager: P. Paine

Determination of Thermodynamic Data for Modeling Corrosion, Vol. 3: CO_2–NaOH–H_2O System
NP-5708 Topical Report (RPS407-1); $200
Contractor: Brigham Young University
EPRI Project Managers: P. Paine, P. Millett

Roll Transition Inspection of Doel-2 Steam Generator Tubes, Vol. 3: September 1991 Inspection
NP-6716-L Final Report; license required
Contractor: Laborelec
EPRI Project Manager: L. Williams

Lotung Large-Scale Seismic Test Strong Motion Records, Vols. 1–7
NP-7496 Final Report (RP2225); Vol. 1, $200
NP-7496-L Final Report; Vols. 2–7, license required
EPRI Project Managers: Y. Tang, H. Tang

Zircaloy Corrosion Properties Under LWR Coolant Conditions (Part 2)
NP-7562-D Final Report (RPX101-1); $150,000
Contractor: Commissariat à l'Energie Atomique
EPRI Project Managers: A. Machiels, S. Yagnik

Threshold Levels for Nonstochastic Skin Effects From Low-Energy Discrete Radioactive Particles
TR-100048 Final Report (RP3099-2); $200
Contractor: Battelle, Pacific Northwest Laboratories
EPRI Project Manager: C. Hornibrook

Metal Fatigue in Operating Nuclear Power Plants
TR-100252 Final Report (RP2688-7); $200
Contractor: Structural Integrity Associates
EPRI Project Manager: T. Griesbach

Radiation-Field Control Manual, 1991 Revision
TR-100265 Final Report (RP2758); $200
EPRI Project Managers: H. Ocken, C. Wood

FATIGUEPRO™ User's Manual: On-line Fatigue Usage Transient Monitoring System for Nuclear Power Plants
TR-100272 Computer Code Manual (RP2688-3); license required
Contractor: Structural Integrity Associates, Inc.
EPRI Project Manager: T. Griesbach

Application of Fatigue Monitoring to the Evaluation of Pressurizer Surge Lines
TR-100273 Final Report (RP2688-3); $200
Contractor: Structural Integrity Associates, Inc.
EPRI Project Manager: T. Griesbach

Evaluation of PWR Radiation Fields: 1986–1990
TR-100306 Interim Report (RP2648-1); $200
Contractor: Westinghouse Electric Corp.
EPRI Project Manager: H. Ocken

Effect of Lithium Hydroxide on Zircaloy Corrosion in the Ringhals-3 PWR Plant
TR-100389 Final Report (RP2493-5); $200
Contractor: Nuclear Electric plc
EPRI Project Manager: C. Wood

Stress Corrosion Monitoring and Component Life Prediction in BWRs, Vol. 2: Data and Predictive Models for Environmental Cracking of Nickel Alloys
TR-100399 Final Report (RP2006-17); license required
Contractor: General Electric Co.
EPRI Project Manager: R. Pathania

EPRI Events

SEPTEMBER

21–23
5th Predictive Maintenance Conference
Knoxville, Tennessee
Contact: Lori Adams, (415) 855-8763

23–25
Application of Fluidized-Bed Combustion Technology for Power Generation
Cambridge, Massachusetts
Contact: Linda Nelson, (415) 855-2127

23–25
Battery Storage Applications Workshop
San Francisco, California
Contact: John Berning, (415) 855-5461

28–30
Power Quality Conference: End-Use Applications and Perspectives
Atlanta, Georgia
Contact: Marek Samotyj, (415) 855-2980

28–October 7
NDE In-service Inspection Training Course: IGSCC Detection
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

29–30
Distributed Generation: Assessing High-Value Utility Applications
New Orleans, Louisiana
Contact: Dan Rastler, (415) 855-2521

29–October 1
EMF Basics: A Short Course for EMF Newcomers
Lenox, Massachusetts
Contact: Leonard Sagan, (415) 855-2585

29–October 2
Basic Vibration Testing and Analysis Course
Eddystone, Pennsylvania
Contact: Robert Frank, (215) 595-8872

30–October 1
1992 Gas Turbine Procurement Seminar
Danvers, Massachusetts
Contact: Henry Schreiber, (415) 855-2505

OCTOBER

5–9
Computer-Aided Control System Analysis
Eddystone, Pennsylvania
Contact: Joe Weiss, (415) 855-2751

5–9
NDE Technical Skills Training Course: Ultrasonic Examination (Instructors)
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

8–9
Gas Turbine Controls Upgrade Workshop
Dearborn, Michigan
Contact: Dave Dobbins, (704) 547-6100

8–9
GE Low-Voltage Circuit Breaker Maintenance Workshop
Newport News, Virginia
Contact: Jim Sharkey, (704) 547-6057

12–14
NDE In-service Inspection Training Course: Detection Requalification
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

12–16
Feedwater Heater Technology Seminar and Symposium
Birmingham, Alabama
Contact: Lori Adams, (415) 855-8763

12–16
NDE Technical Skills Training Course: Visual Examination (Level 2)
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

13–14
Compressed-Air Energy Storage Working Group
Mobile, Alabama
Contact: Thea Goossens, (415) 855-7922

13–14
ESPRE (EPRI Simplified Program for Residential Energy) Training Workshop
Irving, Texas
Contact: Paul Grimsrud, (415) 855-8902

13–16
1992 EMF Science and Communication Seminar
San Francisco, California
Contact: Amy Birney, (612) 623-4600

14–15
1992 Fuel Oil Utilization Workshop
Atlanta, Georgia
Contact: William Rovesti, (415) 855-2519

14–15
T&D Cable Fault Location Workshop
Marlborough, Massachusetts
Contact: Don Von Dollen, (415) 855-2679

14–16
Coatings and Applications Workshop
Eddystone, Pennsylvania
Contact: Robert Frank, (215) 595-8872

14–16
Planning Your First Transmission Cable Project
Orlando, Florida
Contact: John Shimshock, (412) 722-5181

19–23
American Wind Energy Association Annual Meeting
Seattle, Washington
Contact: Earl Davis, (415) 855-2256

19–23
Workshop on Demand-Side Management Program Evaluation
Palm Beach, Florida
Contact: Jean Ciallella or Lorna Smith, (510) 987-8141

19–30
NDE Technical Skills Training Course: Ultrasonic Examination (Level 2)
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

20
Utility Coal Gasification Association Meeting
San Francisco, California
Contact: Barbara Evatt, (415) 855-2174

21–22
Fuel Supply Seminar
Cambridge, Massachusetts
Contact: Susan Bisetti, (415) 855-7919

21–22
Multifactor Aging Mechanisms and Models for Electrical Installations
Victoria, British Columbia
Contact: Bruce Bernstein, (202) 293-7511

21–23
Coal Gasification Power Plants
San Francisco, California
Contact: Linda Nelson, (415) 855-2127

21–23
National Electric Vehicle Infrastructure Conference
San Francisco, California
Contact: Pam Turner, (415) 855-2010

26–27
EPRINET Users Group Conference
Irving, Texas
Contact: Carrie Koeturius, (510) 525-1205

26–28
Workshop on Air-Operated Valves
Alexandria, Virginia
Contact: Ken Barry, (704) 547-6040

27–28
Compact Simulator Host Utility Group Meeting
Charlotte, North Carolina
Contact: Roy Fray, (415) 855-2441

27–28
Defining User Requirements for On-line Dynamic Security Assessment
San Francisco, California
Contact: Gerry Cauley, (415) 855-2832

27–28
Generator and Large-Motor Winding Assessment Using MICAA
Palo Alto, California
Contact: Jan Stein, (415) 855-2390

29–30
FGDPRISM Training Workshop
Dallas, Texas
Contact: Rob Moser, (415) 855-2277

29–30
System Voltage Stability/Security Analysis
San Francisco, California
Contact: Dominic Maratukulam, (415) 855-7974

NOVEMBER

2–5
NDE Training Course: Maintenance Proficiency Evaluation
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

2–6
NDE In-service Inspection Training Course: IGSCC Sizing
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

4–5
Short Course on Power Plant Pumps
Eddystone, Pennsylvania
Contact: Tom McCloskey, (415) 855-2655

4–5
Utility Strategic Asset Management Conference
Cambridge, Massachusetts
Contact: Lori Adams, (415) 855-8763

8–11
Wood Pole Conference
Starkville, Mississippi
Contact: Harry Ng, (415) 855-2973

9–11
Substation Diagnostics
Palo Alto, California
Contact: Joe Porter, (202) 293-7510

9–12
International Conference on Low-Level Waste
Baltimore, Maryland
Contact: Carol Hornibrook, (415) 855-2022

9–13
American Society for Nondestructive Testing Thermography Course (Level 1)
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

9–13
NDE Training Course: Nuclear Utility Procurement
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

10–12
PEAC Training Course on Power Quality
Knoxville, Tennessee
Contact: Marek Samotyj, (415) 855-2980

11–12
NSAC–Operational Reactor Safety Engineering and Review Group Workshop
New Orleans, Louisiana
Contact: Linda Nelson, (415) 855-2127

12–13
Underground T&D Construction Workshop
St. Petersburg, Florida
Contact: Tom Rodenbaugh, (415) 855-2306

16–19
Decision Analysis for Utility Planning
Miami, Florida
Contact: Charles Clark, (415) 855-2994

16–19
NDE In-service Inspection Training Course: Weld Overlays
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

17–19
AIRPOL '92 International Seminar: Solving Corrosion Problems in Air Pollution Control Equipment
Orlando, Florida
Contact: Paul Radcliffe, (415) 855-2720

17–19
Heat Rate Improvement Conference
Birmingham, Alabama
Contact: Pam Turner, (415) 855-2010

17–19
ROBAL Computer Code for Rotating-Machinery Balancing
Eddystone, Pennsylvania
Contact: Tom McCloskey, (415) 855-2655

17–20
NDE Training Course: Microbiologically Influenced Corrosion
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

18–20
EPRI-EUMRC Market Research Symposium
Dallas, Texas
Contact: Susan Bisetti, (415) 855-7919

18–20
1992 PWR Plant Chemists' Meeting
San Diego, California
Contact: Peter Paine, (415) 855-2076

30–December 4
NDE Technical Skills Training Course: Ultrasonic Examination (Level 3)
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

DECEMBER

2–4
Noncombustion Waste Seminar
Orlando, Florida
Contact: Susan Bisetti, (415) 855-7919

7–11
NDE Technical Skills Training Course: Basic/Specific (Level 3)
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

7–16
NDE In-service Inspection Training Course: IGSCC Detection
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

8–9
Space Charge in Extruded Cables
Scottsdale, Arizona
Contact: Bruce Bernstein, (202) 293-7511

8–11
Machinery Alignment Course
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

9–11
1992 Advanced Computer Technology Conference
Scottsdale, Arizona
Contact: Pam Turner, (415) 855-2010

14–18
NDE Technical SkillsTraining Course: Visual Examination (Level 3)
Charlotte, North Carolina
Contact: Annette Medlin, (704) 547-6110

15–18
Motor Monitoring and Diagnostics Course
Eddystone, Pennsylvania
Contact: John Niemkiewicz, (215) 595-8871

FEBRUARY 1993

3–5
Coal-Handling Systems: State of the Future (call for papers)
Pensacola, Florida
Contact: Barbara Arnold, (412) 479-6012

9–10
Conference on Energy-Efficient Electric Motor Systems
Baltimore, Maryland
Contact: Les Harry, (415) 855-2558

9–11
Conference on Cable Condition Monitoring
San Francisco, California
Contact: Linda Nelson, (415) 855-2127

Contributors

Kopelman

Spencer

Wendland

Blatt

Joyner

Krill

Tapping the International R&D Resource (page 4) was written by Leslie Lamarre, *Journal* senior feature writer, with information provided by two members of EPRI's Office of Commercialization & Business Development.

Jay Kopelman, manager of international activities for OCBD, joined EPRI in 1978 as manager of special studies for the Strategic Planning Division. Before that, he spent five years with the Stanford Research Institute as manager of the Energy Modeling Program and project leader for the SRI world energy study. Earlier Kopelman was director of the Office of Research Services at the University of Colorado, where he also served as an assistant professor of physics and an assistant dean of the graduate school. He has a BS in physics from Rensselaer Polytechnic Institute and a PhD in physics from Northwestern University.

Dwain Spencer, vice president for OCBD, has headed the office since it was established in 1988. Before that, he was vice president for the Advanced Power Systems Division. He joined EPRI in 1974 as program manager for solar and geothermal energy. Previously he worked at the California Institute of Technology's Jet Propulsion Laboratory for 16 years, the final 2 of which he was on loan to the National Science Foundation, designing a program of solar energy research. Spencer has a BS degree in chemical engineering from the University of Notre Dame and an MS in engineering from Purdue University. ■

Cool Storage: Saving Money and Energy (page 14) was written by Leslie Lamarre, *Journal* senior feature writer, with information provided by two members of EPRI's Customer Systems Division.

Ron Wendland, manager of thermal storage technology, joined EPRI in 1985. Before that, he was vice president for business and technical development at Aqua-Chem, Inc. Earlier he held various positions involving the development and marketing of technical products. Wendland has two BS degrees from the Massachusetts Institute of Technology, one in aeronautics and astronautics and one in industrial management.

Morton Blatt, manager of the Commercial Program, joined the Institute in 1985. Previously he was manager of end-use efficiency programs in the Energy Systems and Conservation Division of Science Applications International Corporation. Before that, he was a senior thermodynamics engineer with General Dynamics. Blatt received a bachelor's degree in mechanical engineering from Cooper Union, an MS in industrial engineering from New York University, and an MS in business administration from San Diego State University. ■

Refrigerants for an Ozone-Safe World (page 22) was written by Taylor Moore, *Journal* senior feature writer, with assistance from two members of EPRI's Customer Systems Division.

Powell Joyner is the technical manager for advanced projects in the Residential Program. He came to EPRI in 1985 after 17 years with Trane Company, where he was vice president for research on HVAC systems and industrial fume incineration. From 1963 to 1968 he worked for Allis-Chalmers, and still earlier he held scientific and management posts at Honeywell and at Callery Chemical Company. Joyner graduated in physics from Centenary College and earned a PhD in physical chemistry at the University of Iowa.

Wayne Krill is a senior project manager in the Commercial Program, responsible for projects to develop advanced heating and cooling equipment and appliances for commercial buildings. He joined EPRI in 1991 after 11 years at Alzeta Corporation, which he helped found and which designs and develops low-emission, radiant burner combustion systems. A registered professional engineer in California, Krill earned BS and MS degrees in mechanical engineering at the University of California at Berkeley. ■

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